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Analysis of The Thermal Energy Consumption Measurements of The Energy Center

Relatori: Prof. Davide Papurello

Candidati: Ahmed Omer Abdelrahman Mohamed

ABSTRACT

Building's energy consumption and especially for large buildings is an important component of the total energy consumption. Therefore, improving energy efficiency in buildings has become a global issue today in the fight against climate change. Accordingly, there have been numerous directives and bonuses promoted by the EU in recent years, which set the goal of decarbonisation by 2050. and to locate the status of energy consumption for these buildings different energy monitoring systems have been developed as a result of the fact that an excellent data-based energy management analysis can only be performed through energy monitoring "You can't manage what you can't measure". Therefore, monitoring is the first and fundamental step in being able to optimize the building as it allows to understand the internal situation through the measurements recorded in the building by the sensors which send data that are not always optimal.

In this regard, this thesis work focuses on the analysis of the energy consumption, and in particular on thermal energy consumption (heating and domestic hot water) of the energy center which is a building mainly used for offices use and located in the city of Turin (Piedmont region, Italy). The main goal is to investigate the instrumental checks of a monitoring system for thermal energy that is consumed by the building. the state-of-the-art monitoring system allows to quantify the consumption spent by the machines for the production of energy vectors useful for providing the heating and DHW services essential to ensure comfort conditions inside the building by measuring the temperatures and flowrate through sensors and flow meters from siemens and Micronics with a consumption management software developed by Eurix srl that provide the data of consumption measurements.

This data of consumption measurements which are measured with a very high frequencies, approximately every 15 minutes, has been rearranged to develop a graphical analysis for the measured data of thermal energy consumption of heating and hot water supply inside the building that is met through the district heating system, solar thermal collectors, and geothermal polyvalent group during the heating season. The analysis of the recorded data obtained from the readings of the thermal energy meter installed in the building revealed

that energy consumption profile of district heating had some anomalies and not very reliable compared to power consumption profile which is consistent and more reliable. While the energy consumption profiles of polyvalent group and solar thermal system are correspondent with power consumption profiles.

Accordingly, the energy consumption profiles have been reconstructed based on the power consumption data. Then, comparisons between the reconstructed data and the measured data of energy consumption have been made in order to have clearer view on the consumption measurements from energy meters.

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The conclusion of this thesis work coincides with the conclusion of a university experience that is not going only to allow me of acquiring a degree but did much more. it allowed me above all to grow, train, take note of my abilities and goals that I want to reach. Also, allowed me to meet new people who were best company throughout this experience, and they will always be present in my life.

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ACRONYMS

ACER	Agency for the Cooperation of Energy Regulators
ACS	Acqua Calda Sanitaria
AHU	Air Handling Unit
ANN	Artificial Neural Network
APE	Attestato di Prestazione Energetica
AR	Assessment Reports
ARERA	Autorità di regolazione per Energia Reti e Ambiente (Italian NRA)
BACS	Building Automation and Control System
BEM	Building Energy Modelling
BMS	Building Management System
CAD	Computer Aided Design
CFD	Computational Fluid-Dynamics
COP	Coefficient of Performance
DER	Distributed Energy Resources (or Distributed Generation, DG)
DHW	Domestic Hot Water
DR	Demand Response
DSM	Demand-side Management
DTA	Differential Thermal Analysis
ECES	Energy Conservation and Energy Storage
ECI	Energy Center Initiative
EED	Energy Efficiency Directive
EER	Energy Efficiency Ratio
EHC	Effective Heat Capacity
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Company
FDD	Fault Detection and Diagnosis
FEM	Finite Element Method
GHG	Green House Gases
GTA	Global Temperature Adjustment

HVAC	Heating Ventilation and Air Conditioning
IAQ	Indoor Air Quality
ICT	Information and Communications Technology
IEA	International Energy Agency
IGV	Inlet Guide Vain
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Center
KPI	Key Performance Indicators
LCC	Life Cycle Cost
NOAA	National Oceanic and Atmospheric Administration
NOCT	Normal Operating Cell Temperature
NRA	National Regulatory Authorities
NZEB	nearly Zero Energy Building
OECD	Organization for Economic Cooperation and Development
PAA	Piecewise Aggregate Approximation
PCM	Phase Change Material
POET	Performance, Operation, Equipment and Technology efficiency
PPD	Predicted Percentage Dissatisfied
RES	Renewable Energy Sources
SDS	Scenario di Sviluppo Sostenibile
STC	Standard Test Conditions
TCP	Technology Collaboration Program
TER	Total Efficiency Ratio
TSO	Transmission System Operator
UNEP	United Nations Environment Program
UPS	Uninterruptible Power Supply
WEO	World Energy Outlook
WMO	World Meteorological Organization

1. INTRODUCTION

The construction and operation of buildings are responsible for over a third of the world's energy consumption [1]. Data shows that energy consumption and GHG emissions in building sector are growing at an advanced rate than in other sectors [2]. As a result, reducing energy consumption has become essential to planning, construction, and use of buildings from the environmental point of view [3]. This also entails that the building sector has considerable potential for energy and energy related CO2 emissions savings [4]. According to the International Energy Agency, the building sector can reduce energy consumption with an estimated energy savings of 1509 Mtoe (million tonnes of oil equivalent) by 2050. Furthermore, through energy-efficient building design, carbon dioxide (CO2) emissions can be reduced which can possibly mitigate 12.6 Gt (gigatonnes) of CO2 emissions by 2050 [5].

Energy consumption by built environments can be reduced through new designs, technologies, and materials; proper control; and the use of effective energy management systems by considering factors such as building orientation, shape, wall–window ratio, insulation, use of high-efficiency windows, and natural ventilation [6]. However, electrical loads, especially miscellaneous electrical loads (involving a range of products, devices, and electrical equipment in some combination, common in every household) consume a significant portion of total building energy [7]. A substantial share of total energy consumption is due to improper use of appliances and eliminating this wastage can reduce the overall energy consumption by approximately 30% in buildings [8]. Today it is important to focus on greater energy efficiency to reduce our impact on the environment by reducing fossil fuel consumption [9], [10]. Built environments also have a significant impact on human health. The extent of a building's impact on human health and the environment depends on the building design, materials, and the methods used for construction and operation [11]. According to the Science Advisory Board of the United States Environmental Protection Agency (EPA), indoor environment stands among the top five environmental risks to public health. Considering the fact that human health is affected by poor indoor air quality (IAQ), it is important to maintain a healthy IAQ in the interest of occupant health. Continuous monitoring of indoor environmental quality (IEQ) can thus play a significant role in maintaining healthy indoor environments. A significant aspect of assessing the sustainability of a building is the monitoring of energy performance [12].

Recent innovations in sensing, data logging, and computing technologies have improved monitoring of indoor environment and energy performance of buildings. “Real-time” energy performance and IEQ monitoring are significant from the perspective of real-time feed-back to promote energy-saving behaviour, and for maintaining healthy IAQ. Proper targeting and monitoring of energy consumption and continuous energy management can be effective strategies for improved energy performance of buildings and can result in reductions in operating costs of facilities [13], [14].

1.1 LITERATURE REVIEWS

Research studies examining the effect of energy feedback information on occupant behaviour have shown that real-time feedback can be a powerful impetus for behavioural change. McClelland and Cook (1980) first tested the impact of continuous energy feedback on electricity usage. The results showed that on average electricity usage was lowered by 12% in the homes with continuous electricity usage feedback compared to the homes with no usage feedback system (as cited in Allen & Janda, 2006).

In another study, a technical research university has monitored energy usage to reduce energy costs through an energy awareness program that offered departments a chance to receive payments of up to 30% of the savings achieved. The departments had accomplished energy savings (saving about $300,000 per year) after one and half years of monitoring through improved operations and maintenance procedures and reduced their usage from about 44million kWh to 40 million kWh (Energy Star, 2002). Hutton, Mauser, Filiatrault, and Antola (1986) have shown how the feedback provided by monitoring helped to conserve energy for over 75% of the subjects in 25 households in three cities.

In a case regarding water usage, the city of Boston, MA, USA was unable to account for the use of 50% of the water used in its municipal water system and, after installing meters, water that was unaccounted for had dropped to 36% (Grisham & Fleming, 1989). Another study has shown that an effective energy management system can identify problems in an operating system which might not otherwise have been identified (Mills & Mathew, 2009).

Yang and Wang (2013) has shown that energy management systems can also provide comfortable building environments with high energy efficiency.

Literature reviews from the last ten years show that usage of energy can be reduced from 0% to 20% by using a variety of feed-back mechanisms (Abrahamse, Steg, Vlek, & Rothengatter, 2005). However, despite the fact that providing appropriate feedback can significantly reduce the overall energy consumption, relying only on occupants' awareness and behavioural change might not be an effective approach.

In a recent study, wireless AC plug-load meter sand light sensors were deployed in a computer science laboratory as a case study in energy monitoring. The study reported that more than 30% energy savings were achieved immediately after installing a monitoring system, but that the savings were subsequently reduced to less than 4% of the week one level by the fourth week of the study. In light of this case, it might be considered that an effective solution for reducing energy consumption could be an automated energy management system, in addition to user cooperation (Jiang, Van Ly, Taneja, Dutta, & Culler, 2009). Major progress has been made in recent years in accomplishing greater awareness (Jiang et al., 2009), showing that advanced measurement of energy usage enables reduction of energy consumption. While the approach of monitoring energy usage is useful to achieve financial benefits, a holistic monitoring of the performance of the building system can also be used to identify the factors influencing irregular energy usage or non-standard IEQ. Any information pertaining to irregularity of building system performance can contribute to building management systems intended to support operational improvement and can also provide the information needed to encourage behavioural and operational changes by building occupants and operators.

Monitoring is essential to achieving an energy-efficient building management system, but sensor-based monitoring is sometimes costly. In recent years more cost-effective high performance sensor technologies have been introduced, such that the benefits of utilizing this technology outweigh the associated costs. Continuous collection of the individualized energy use information would translate into increased energy use awareness, identification of problems in the building management system, and notification of irregular energy usage and non-standard indoor environmental parameters, all of which can lead to more sustainable building operations. [15]

1.2 ENERGY CONSUMPTION MONITORING TECHNOLOGY

Energy consumption monitoring technology (ECMT) is a new information technology for energy saving that records energy consumption and periodically sends the data back to a central server for monitoring, analysis, and control.

ECMT has six main parts: metering devices for collection and management of energy consumption data, a field bus, a communication network for transmitting energy data, the server's data centre and an energy consumption platform. ECMT has features beneficial to energy-consuming units: it helps the energy-consuming units understand energy consumption and find the energy consumption problems in time, optimises, and controls the problems and increases the energy efficiency to the highest extent during the operation phase of planned behaviour (PB).

Researchers have demonstrated that the practical implementation of ECMT can lead to energy savings of 5–15% in power consumption of the building sector compared with conventional approaches. ECMT may also support the services market in contract energy management and energy efficiency retrofits of buildings because it provides better methods for measuring and verifying energy savings and offers the means to repay the initial investment. Additionally, researchers have argued that revealing energy consumption data provides necessary information that helps national and local governments make scientific and standard policies for energy-saving management on PB and guides related work and activities.[16]

1.3 ENERGY CONSUMPTION MONITORING SYSTEMS

The contradiction between the rapidly growing energy use and energy shortage has become more and more serious throughout the world with the rapid economic development. Buildings account for a large part in all kinds of energy consumption. Buildings contribute to 42% of energy consumption in Western countries and to 1/3 in China. However, energy demand is still growing. Furthermore, building energy consumption is a major release source of CO_2, which is one major gas that causes greenhouse and other environmental pressures, such as acid rain and climate change the decrease of quantity of building energy consumption and the improvement of energy use efficiency are the ultimate goals of building energy conservation. Hence, the only criterion for evaluating relevant work is that the energy consumption data should be obtained from actual operations. However, millions of users are still not clear about the quantity of energy that they consume, which is a prime cause of wastage. The real problem is how to get all kinds of energy consumption data we need, including quantity of water, electricity, gas and heat. Furthermore, it is helpful to make a better decision about how to decrease energy consumption rates in buildings if we can locate when and where energy consumption happens exactly. The traditional artificial reading is evidently impracticable. Therefore, the building energy consumption monitoring system which can collect energy data from target buildings periodically offers a new way to solve this problem.[17]

Moreover, environmental conservation has become a very important issue. The use of renewable energies has experienced a significant growth from the crisis of the oil in the 70's, in which renewable forms of energy started to be considered as a potentially alternative to the oil producing finite resources of the Earth. Recent European Community Directives point to an energy consumption reduction, leading to an annual improvement in energy efficiency of around 6% in 2012. Strict regulations, regarding power consumption and energy efficiency, have been set to preserve the environment. To fulfil energy conservation goals, it will be helpful if consumers could assess their energy load diagram so that they can plan/re-plan their energy consumption profile. Unstable global energy supplies, increasing load demands and increasing environment concerns are forcing energy producers and consumers to re-evaluate the energy usage paradigm. An energy monitoring system is an essential tool to help consumers understanding their energy usage profile and the associated environment impact and providing an instrument to re-shape their energy load diagram and, consequently, reduce its inherent costs.

The developed system helps and instructs people to use their energy in a better way. The efficient use of energy has direct consequences for the users, such as consumption and inherent costs reduction. Several strategies can be taken to fulfill these objectives: load shifting, automatic load control, energy storage, autonomous generation, and renewable energy usage. Nevertheless, in order to implement any of those strategies it is fundamental to accurately know the load diagram and load profile of each user. There are some commercial tools that can be used to monitor energy consumption and perform power management analysis, however when large complexes, with hundreds of metering points, are considered they become extremely expensive.[18]

2. DESCRIPTION FOR THE CASE STUDY

2.1 GENERAL OVERVIEW

The Energy Center is an office building of Politecnico di Torino built at the address of V. Paolo Borsellino 38/16 - 10138 Torino (TO) - ITALY. [19]

Figure 1: Satellite Map of Energy Center site location

The idea of the construction of an Energy Center go back to 2008. It has been conceived as an environment whose aim is to collect places, actors and knowledge which pursue the innovation in energy and environmental field. The conceived role was to represent a reference at European and national level for innovative programs and plans in relation to the energy sector. Therefore, it should collect the different needed knowledge in a single place coordinating public and private entities, promoting study and technologies evaluation and providing support to both public and private institutions. [20] As a matter of fact, Politecnico di Torino has launched since 2016 **the Energy Center Initiative (ECI)** to support and stimulate series of actions and projects that will provide support and advice to local, national and transnational authorities on energy policy and technology. The two pillars of the ECI are:

- **The Energy Center House (EC-H)**, a new building in the Politecnico di Torino campus, that will host companies, start-ups and public administrations who are active in the field of energy technology, R&D, management, and policy.

- **The Energy Center Lab (EC-L):** the Interdepartmental Center for Energy, that gathers a multi-disciplinary group of Politecnico faculty members who are devoted to discovering the best technical, economic, social, and environmental solutions for a transition toward a more sustainable society. [19]

2.2 DESCRIPTION OF THE BUILDING

Figure 2: Energy Center Building

The building is constituted of a single block, of about 30000 m^3 of gross volume and 5441 m^2 of net surface. It is developed on four floors and a basement whose main areas partitioning is reported in the **Table.1** below. The **Basement** presents an underground parking area of about 50 parking spaces, equipped with two charging stations for electric vehicles, and an internal space that will hosts the Energy Center Lab, an office area for researchers. Moreover, the basement presents the technical rooms that host heating and cooling plants, fluid distribution system (pumps), two of five Air Handling Units (AHU) installed, the Uninterruptible Power Supply (UPS) group and the emergency diesel generator. The **Ground Floor** hosts an exposition Hall, that develops for all the other three floors, with a reception station, an Auditorium with approximately 150 seats, and a Laboratory. The **Mezzanine level** present the control room where it is installed the PC Room through which it is possible to manage the Supervision system of the building. Finally, the first, second and third floors present the Offices spaces that accommodate private enterprises and researchers of the Politecnico di Torino.

Intended Use		Surface [m2]
Basement Office (EC Lab)		327
Hall		270
Control Room (Mezzanine level)		80
Laboratory		460
Auditorium		160
Offices and relative services	Floor 1	985
	Floor 2	986
	Floor 3	997

Table 1: Summary of main areas subdivision.

In the following paragraphs main energy systems installed at the Energy Center will be presented. Generally, the energy services of the building are satisfied through two main energy vectors:

- Electricity, through the connection to the medium-voltage electricity grid;
- Heat, through the connection to the District Heating network of the city of Turin.

Moreover, the Energy Center presents other two on-field Renewable energy sources:

- A Photovoltaic system with a total installed Power of 47 kW for the production of electricity.
- A Solar thermal plant of 30 m^2 for hot water production, mainly destinated to DHW use. [20]

2.3 CENTRAL PLANT ROOM

This technical room is situated in the basement and hosts different systems, whose main energy characteristics are summarized in the **Table**.2 below, dedicated to the satisfaction of building energy services as heating, cooling and DHW.

Firstly, the Geothermal Polyvalent Group, showed in the **figure**.3 below installed in the technical room of the building is a direct expansion machine that uses the refrigerant gas, in particular the R134A fluid, which by passing through the various components characterizing the cycle, allows the production of both hot and chilled water. at the same time. In particular, the chilled water, which passes through the cold circuit, is used to cool and condition the rooms during the summer season while the hot water is used to power the post-heating coils of the AHUs for humidity control during the mid-season or in summer. In winter, the system is generally shut down as the demand for thermal energy is satisfied by the district heating network.

The multipurpose unit installed inside the technical rooms of the basement is the "Climaveneta ERACS2-WQ / S 1702" unit, consisting of two distinct refrigeration circuits characterized by two screw type compressors and three bundle exchangers common tube such as the evaporator, the condenser, and an auxiliary exchanger.

The group has three different operating modes depending on the thermal demands of the system such as: production of hot water, production of chilled water and simultaneous production of hot and cold water. The transition from one mode to the other is managed by an automatic microprocessor, installed on the machine, capable of optimizing the energy spent according to the heat load requests by the users.

The operating modes are described individually below:

- Production of hot water: The multipurpose unit works in this case as a heat pump in which the auxiliary exchanger is used as an evaporator, releasing thermal energy, taken from the groundwater to the user-side condenser.
- Chilled water production: The group works as a refrigeration machine (chiller) in which the auxiliary exchanger is used as a condenser by removing thermal energy, transferred to the groundwater, from the evaporator on the cold user side
- Simultaneous production of hot and cold water: The unit works as a chiller with recovery and does not use the auxiliary exchanger. In this configuration, the evaporator is used to remove thermal energy from the primary cold circuit, while the condenser is used to transfer thermal energy to the primary hot circuit to produce hot water.

The polyvalent Group has type of regulation that is described in the documentation provided by "Climaveneta", takes place through a slide valve which, depending on the position, determines a step reduction of the compression chamber, thus allowing the compressor to deliver the 100%, 75% and 50% of its capacity. In particular, the thermoregulation takes place on the two hydraulic circuits depending on the water return temperature.

A further characteristic of the multipurpose unit lies in the presence of thermal accumulations in the hot and cold circuits, used to stabilize the flow of hot or chilled water depending on the accumulation, and to avoid having the compressor switched on and off continuously, thus increasing the global inertia of the system. Starting from these thermal storage tanks, the chilled or hot water is sent to the delivery manifold, respectively cold or hot, from which, thanks to the thrust of the variable flow pumps installed on the delivery, the water is sent to power the various utilities.

In addition, the multipurpose machine consists not only of hot or chilled water outlet pipes, but also of a pipe that reaches inside the geothermal wells containing groundwater that allows the excess heat to be disposed of. In particular, the circuit with groundwater reaches the plant through a pipe, visible in figure 4.6, containing a filter that retains the sand and impurities present in the groundwater so as to circulate only clean water inside the system.

The groundwater circuit also features both flow and temperature meters as there is an obligation to communicate annually to the city of Turin the flow rates supplied from the water with the withdrawal and return temperatures. Particular attention is paid to the return temperature, which has the constraint of not being able to reach values below 22 [$° C$], in agreement with the city of Turin.

Figure 3: Geothermal Polyvalent Group Installed in Energy Center.

Then it is possible to find the heat exchangers for the connection to the District Heating network. In particular there are three heat exchangers for three different intended uses: one for heating purposes, one for DHW production and one for feeding of the absorption chiller.

Equipment		Parameter	Value
Geothermal Polyvalent Group (water-water)	Heating Mode	COP	4,44
		Heating Capacity	473,7 kW
		Power Absorbed	104,7 kW

	Cooling Mode (without Recovery)	EER	5,65
		Cooling Capacity	442,7 kW
		Power Absorbed	73,7 kW
	Cooling Mode (with Recovery)	TER	7,94
		Cooling Capacity	362 kW
		Power Absorbed	103,4 kW
Absorption Chiller		EER	0,7
		Heat Absorbed	~ 200 kW
		Power Absorbed	2,5 kW
District Heating (Heat Exchangers)	Heating	Nominal Power	350 kW
	DHW	Nominal Power	50 kW
	Absorption Chiller	Nominal Power	255 kW
Thermal Energy Storages	Hot Water	Capacity	4000 l
	Cold Water	Capacity	4000 l
	Solar Thermal Plant	Capacity	1000 l
DHW Boiler	DHW	Capacity	1500 l

Table 2: Main Energy Characteristic of equipment installed in Heating/Cooling Plant Central Room.

The latter is represented by an indirect-fired LiBr absorption chiller. Its main characteristic is that it requires heat to operate but a small amount of electricity. In this case, as anticipated previously, feeding heat is provided by the district heating network. Actually, it has been just tested after the construction of the building, but never used in normal operation for three main reasons:

- It represents a very sophisticated system that require a high and frequent maintenance, in particular to guarantee the vacuum necessary for its operation.
- It presents strict requirements regarding the temperature of the feeding fluid (90-110 °C) that the supplier of the DH is not always able to guarantee.
- Its refrigeration capacity could not be sufficient to cover the entire cooling demand in Summer period.

Figure 4: Absorption Chiller

As it is possible to see in the **figure**.5 below, it has been even installed two Thermal Energy Storages in order to accumulate respectively hot and cold water and so provide thermal inertia to the Polyvalent Group.

Figure 5: Thermal Energy Storage

Then, in the Central Plant Room it is possible to find even the inertial TES of the solar thermal plant and the DHW boiler fed by the District Heating. The solar thermal main purpose is the production of DHW, but in case of excess heat at a certain temperature, it is delivered to the 4000 l TES.

Besides all the systems presented, used to produce, store heat and cool, the Central Plant Room hosts even the pumps that belongs to the primary fluids distribution system, apart the ones of the aquifer which are submerged in the wells. The intended use of the different pumps and the nominal power absorbed has been summarized in the **table**.3 below. [20]

Pump ID	Purpose	Installed Power [kW]
EP1	Aquifer – Well A	30
EP2	Aquifer – Well B	30
EP3	Polyvalent Group – Cooling	4

EP4	Polyvalent Group – Heating	5,5
EP5	Absorption Chiller	2,2
EP6	AHU – Cooling	2,2
EP7	Radiant ceiling panels	3
EP8	Radiant floor panels	0,43
EP9	Radiators	0,75
EP10	AHU – Heating	4
EP11	Fan Heaters	0,13
EP12	District Heating – Heating	2,2
EP13	District Heating – DHW	0,39
EP14	Recirculation Pump	0,03
EP15	Solar thermal circuit	0,35
EP16	Cooling Water – CED/UPS	0,12
EP17	AHU - Antifreeze	0,75
EP18	Absorption Chiller - Dissipation	/

Table 3: HVAC fluid distribution systems installed pumps.

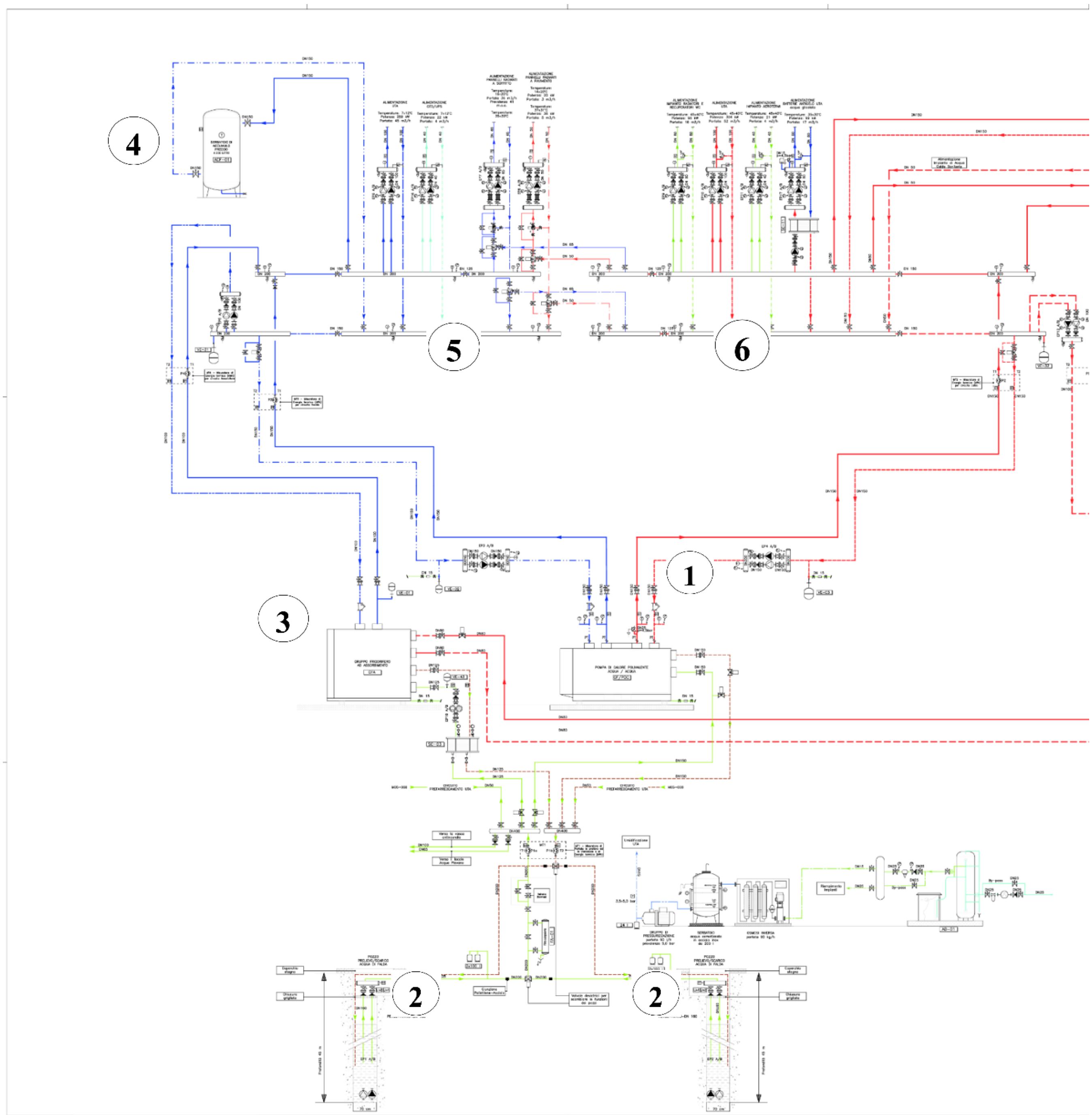

Figure 6: Central Plant Room Technical Scheme. Part 1

1. Geothermal Polyvalent Group
2. Aquifer Wells
3. Absorption Chiller
4. Cool Storage
5. Cooling System Manifold
6. Heating System Manifold

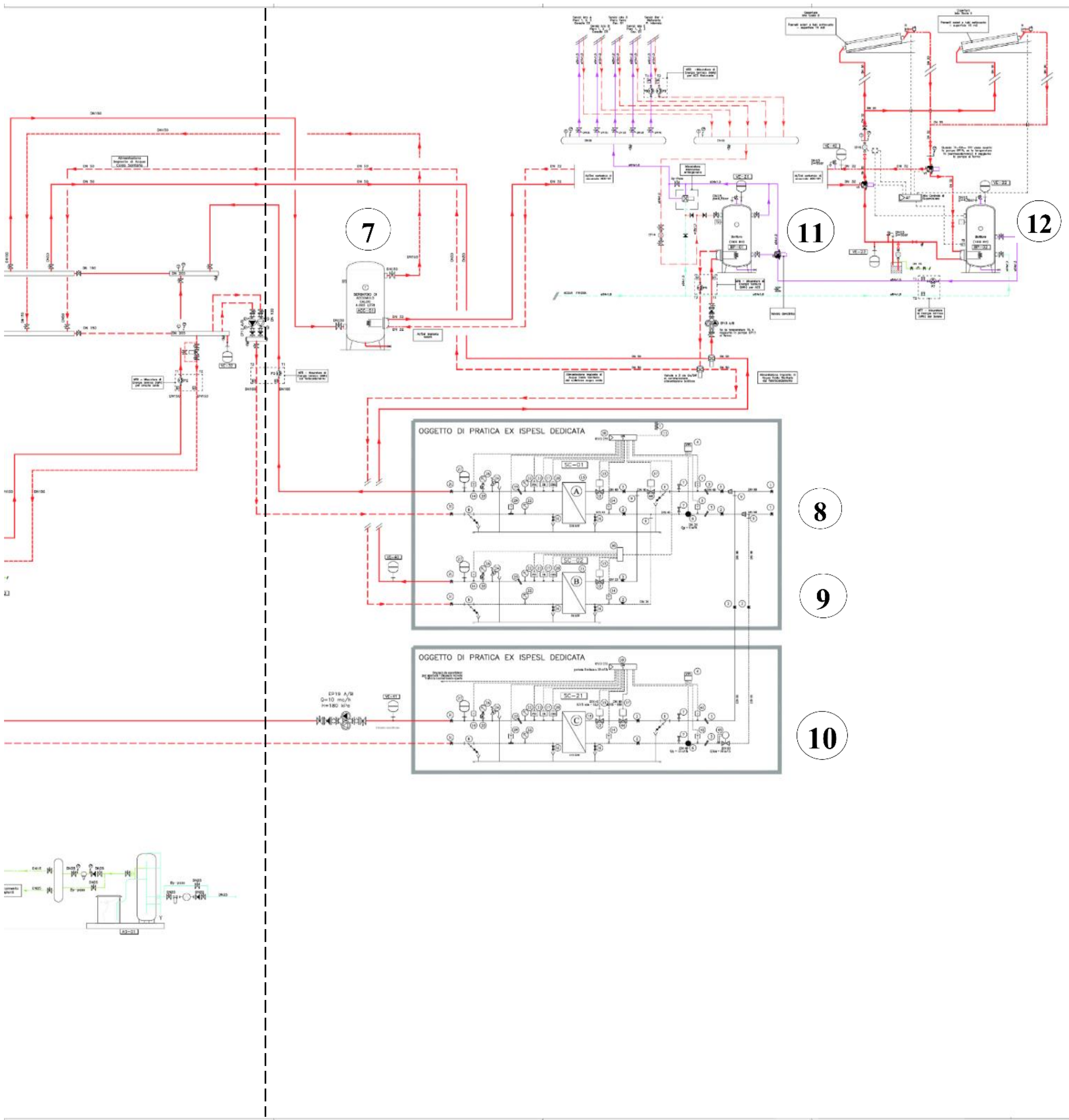

Figure 7: Central Plant Room Technical Scheme. Part 2.

7. Heat Storage
8. DH heat exchanger – Heating
9. DH heat exchanger – DHW
10. DH heat exchanger – Absorption Chiller
11. DHW boiler
12. Solar Thermal Storage

3. MAIN THERMAL ENERGY SYSTEMS AND SUPERVISION

3.1 HVAC SYSTEM

Heat and cool produced by the equipment present in the Central Plant Room, described in the previous chapter, is then distributed to the different Utilities. Considering the areas distribution and the related intended use, Energy Center HVAC system has been differentiated and presents specific characteristics depending on the area served. Therefore, it is possible to distinguish:

- The basement: characterized by an all-air system[1] with a dedicated AHU located in one of the technical rooms in the basement.
- The Hall: served by a primary air system[2] with a dedicated AHU located in the basement. The sensible heating or cooling load is satisfied through floor radiant panels located at the ground floor and in the exposition parts of Floors 1,2 and 3.
- The Auditorium: served by an independent all-air system with a dedicated AHU.
- Laboratory: served by fan coils only for heating purposes.
- North-west Offices: characterized by a primary air system with a dedicated AHU (for all the three floors) and radiant ceiling panels.
- North-east Offices: characterized by a primary air system with a dedicated AHU (for all the three floors) and radiant ceiling panels.
- Sanitary Facilities: served by Radiators and a dedicated ventilation system for IAQ purposes **Table**.5
- Technical Rooms (1-2-3 floors), Control Room and UPS Room: all served by dedicated direct expansion split systems that operates independently to guarantee the correct internal conditions, generally to balance the heat load produced by the electronic components **Table**.6

About the Hydronic systems constituted by radiant floors and ceilings, that serve the Offices and the Hall, it represents a two-tube system. It means that, when necessary,

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[1] A type of HVAC system, that use only the supply air, with a certain value of temperature and humidity, to satisfy both IAQ and thermal comfort requirements.

[2] A type of HVAC system in which the supplied air is used only for the hygrometric control and for air quality purposes. The sensible load, and so the temperature desired, is satisfied through hydronic diffusion systems (radiators, radiant panels, fan coils, etc).

facility managers operate the commutation from heating to cooling mode because the supply and return conduits are univocal. The commutation is operated remotely through the management system, respecting the authority prescription about the heating season that for Turin goes from the October 15th to April 15th. It is done operating on the BACS system that consequently acts on the commutation valves.

The Supervision system control all the equipment related to the HVAC system following a timer mode of a single clock. Therefore, all the equipment turns on and off at the same time. Approximately, the scheduling applied by facility managers has been:

- Turning-on 7:00.
- Turning-off 19:00.

Beside the timer, the system is even designed in order to regulated itself depending on the load. For example, considering the spaces equipped with radiant panels (floor or ceiling), each room presents its own valve. Following the set-point of the room and considering the actual temperature, the ambient control regulates the opening of the valve following a proportional logic. [20]

AHU served area		Power Absorbed [kW]	Nominal Flowrate [m^3/h]
Offices North-West	Supply	6,03	12000
	Return	3,61	11000
	Humidifier	41,46*	/
Offices North-East	Supply	2,2	4000
	Return	1,15	3500
	Humidifier	9,27*	/

Hall	Supply	3,04	6000
	Return	1,7	5000
Auditorium	Supply	1,99	7200
	Return	3,23	6900
Basement	Supply	2,29	5000
	Return	1,43	4700

Table 4: Summary of AHU main characteristics.

*Estimated in design phase. No technical sheet at disposal.

Location	Number of Units	Unit Power [kW]
WCs – Basement	4	0,35
WCs - Ground Floor	2	0,35
WCs – Floor 1	3	0,35
WCs – Floor 2	3	0,35
WCs – Floor 3	3	0,35
MT/BT cabin room	1	0,35

Table 5: Summary of air extractors installed power.

Location	Number of Units	Unit Nominal Power absorbed [kW]
Control Room	3	1,875
UPS Room	1	2,18
Floors Technical Rooms	2	2,79

Table 6: Summary of technical rooms independent split systems installed power.

3.2 HOT WATER SYSTEMS

The hot water required to meet the energy needs by the users for the heating is entirely supplied by the district heating network of the city of Turin. With regard to the DHW request, the building has several methods of production which will be described later. In the description of hot water production, it is therefore appropriate to distinguish between the hot water needed for heating and DHW. In fact, the Energy Center presents different operating logics of the systems, in particular for the DHW production.

3.2.1 HOT WATER FROM DISTRICT HEATING

District heating makes it possible to supply thermal energy to buildings for heating and ACS. The required thermal energy is provided through production and distribution of hot water coming from the production plants present in the belt of the city of Turin, in particular these are plants in cycle cogeneration combined for the production of thermal energy and electricity, with powers overall of approximately 1100 electrical MW and 740 thermal MW[21]. The hot water produced, through the distribution network it reaches the connected buildings, where it is present a substation which substantially corresponds to one or more heat exchangers in which the thermal energy from district heating is transferred to the building system. The Energy Center has three exchangers connected to the district heating network, located in the technical room in the basement. Each of them is connected to different areas of the system, such as to power different users. with the corresponding heat exchangers SC-01, SC-02, SC-03, which correspond respectively to the production of hot water for DHW, heating and absorption refrigeration unit.[22]

The hot water of the secondary circuit, at the exit from the exchanger, reaches a temperature of 90 [$° C$] and subsequently returns inside the exchanger with a temperature difference of about 30 [$° C$] unlike the temperature difference of the primary circuit of about 60 [$° C$].

The hot water produced in passing through the heat exchanger is sent to the hot manifold which distributes it by means of the pumps to the various circuits of the various utilities installed on the different floors of the building. The pumps installed on the delivery manifold are in particular variable displacement pumps equipped with an inverter that modulates the speed in order to maintain constant pressure and circulate only the necessary water flows, saving both electrical energy in terms of pumping and water in terms of dispersion of the pipes.

The regulation of the district heating substation takes place by modulating the flow of water in the primary circuit through a valve capable of opening or interrupting the flow of overheated water to the exchanger using temperature probes installed on the secondary circuit delivery.

3.2.2 HOT WATER FROM SOLAR THERMAL

The solar thermal system consists of vacuum glazed tube collectors, with an inclination angle of 15 ° and with a peak power of around 10 kW, it certifies an annual producibility of approximately 12,500 kWh. The panels are arranged on the roof, where the collector system is present, they collect the hot water produced and then send it to the plant through a special circulation electric pump such as to power the thermal coil has inside the 1000 litres solar tank, the water present in which is then heated. The production of the solar thermal system is governed by the control logic of the recirculation pump, where it comes from represented the connection of the solar system with the thermal power plant, they are described the possible operating modes of the pump and the three-way valves. The hot water produced by the collectors is sent to the tank indicated with BP-02 following a logic managed by the supervision system that checks the difference of temperature between the outlet temperature of the T1 collectors and the read temperature from the TS tank. If this difference is greater than 5 C the electric pump is activated and allows the passage of "solar" hot water to heat the BP-02 tank, when the system detects a higher TS tank temperature or equal to the set-point value, the pump is deactivated and controlled valves V1 so that way B is closed, and way C opens. In doing so, the hot water produced and therefore the thermal energy, which cannot be used to heat the solar tank, is sent to the accumulation of 4000 litres, which respectively constitute the reintegration with cold water from the water supply and delivery to the distribution system of the DHW to the users. A period of maintenance of the solar system, this did not allow the detailed study of its functioning. Furthermore, in the absence of historicized and monitored data also for previous periods, it was not possible to carry out a monitoring analysis accurate to determine the real contribution of the solar thermal to meet the need for domestic hot water.[22]

3.2.3 HOT WATER FROM POLYVALENT GROUP

The plant layout envisaged for the production of domestic hot water deserves a detailed description. The key component of the system is the tank of 1500 litres, the water content of which is heated to reach a temperature expected set-point of 60 C. The domestic hot water required by the users comes then taken from the tank and reintroduced into it. The thermal energy required by the tank to reach the temperature value desired happens through an exchanger in which hot water circulates, sized for a maximum heat exchange power of 50 kW. The hot water that circulates in the exchanger inside the tank it can be supplied by district heating or by polyvalent group. The two power modes never happen at the same time but, thanks to the presence of a three-way valve system, a control logic is set hourly and seasonal to establish when the thermal energy to be supplied to the tank must be produced by the multipurpose group or by district heating. As for the multi-purpose group, it should be remembered that its function priority is the production of refrigeration energy for cooling, hence the contribution of hot water relates to the period of operation of the unit in summer regime.

Over the course of a full year, the thermal energy supplied to the tank for the production of domestic hot water by the polyvalent group is evidently reduced, despite the unit present a period of activity also in periods like April / May and October / November. That is matched by the setting of the multipurpose group in cooling priority.[22]

3.3 SUPERVISION SYSTEM

The Energy Center is equipped with a sophisticated Building Automation and Control System (BACS), designed to perform three principal functions:

- Safety
- Security
- Automation

Its network is organized with a tree structure that goes from the central control to the so-called level 0, which includes the field devices. In particular, the Energy Center is equipped with Siemens hardware components that, through the network, are then interfaced to the software management system, Desigo CC, that allow the control, regulation and monitoring of all the equipment associated, even remotely. Considering the Automation part, which is the most interesting one for Demand-side Management, it is divided in three main sub-systems:

- **HVAC control, production and distribution of primary fluids.** It regards the control and regulation of all the systems that are involved in the production and distribution of the primary fluids of the HVAC systems. For the systems that already present a dedicated regulation system, the Supervision system must be able to communicate with them in order to coordinate completely the operation of the entire system.
- **Ambient Regulation.** That regards the control and regulation of the comfort parameters of the single ambient (rooms) of the buildings. Therefore, each room is equipped with a system that is able to interact with sensors and actuators installed in the same room. As a matter of fact, it is the room system that register the room temperature that comes from the sensor and regulate the opening of the room valve in order to follow the desired temperature setpoint.

- **Electrical System.** Finally, it represents the control of the lighting system and the plug-in load. Great part of the lamps installed in the building are interfaced with the DALI technology protocol. It allows to operate a different control, programming the supervision system.

Therefore, the Supervision system is conceived and designed in order to allow an easier control of all the equipment installed in the building, even pursuing the energy saving. It is able to coordinate all the operations making all the sensors and actuators able to communicate in a closed loop system.

Moreover, in addition to automation, regulation and control, the Supervision System has been even conceived for the energy monitoring of the building. As a matter of fact, the building has been equipped with multimeters and heat meters whose purpose is to acquire measurements about both electricity and heat production and consumption. In **Figure.**8 the integration of the heat meter device with the system is observed in a simplified plant engineering diagram for heating users.

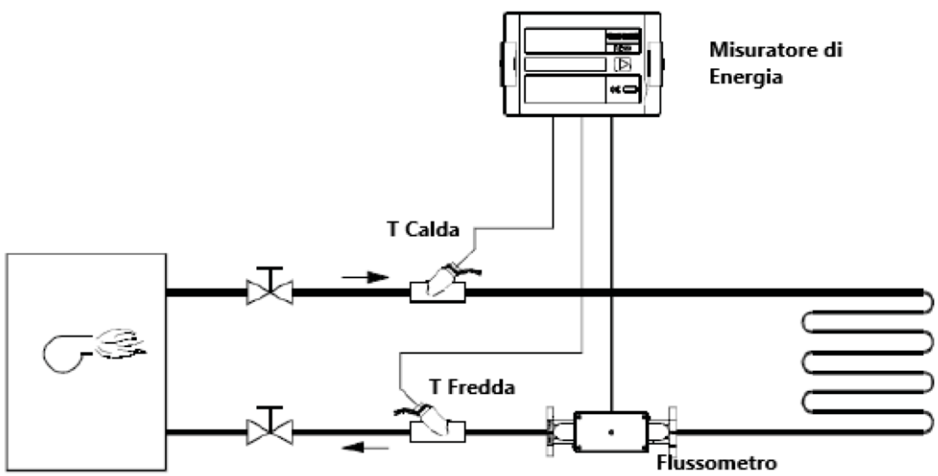

Figure 8: Thermal Energy Meter

The recorded measurements are historicized, and the values refer to a discretization time of 15 minutes. The devices used have certain encodings to know and verify, so as to be able to locate the correct measured energy vector in a specific section of the plant. This allows to associate each energy stream to the corresponding device. **Table.**7 lists the thermal energy meters present and their position within the system as a whole. In addition, each meter detects flow, flow and return temperatures, power and energy, the latter is in terms of cumulative energy.

Meter ID	Intended Use	Energy Service
MT1	Aquifer Circuit	Heating/Cooling
MT2	Polyvalent Group - Hot Circuit	Heating/DHW
MT3	Polyvalent Group - Cold Circuit	Cooling
MT4	Absorption Chiller – Cold Production	Cooling
MT5	District Heating	Heating
MT6	District Heating	DHW
MT7	Solar Thermal Plant Circuit	DHW
MT8	DHW for Basement	DHW

Table 7: Heat Meters installed in Energy Center.

The historicization of these heat meters could allow the assessment of several evaluations. For example, it could be possible to evaluate the real contribution of Solar Thermal to the DHW. Moreover, it could be possible to close the energy balance of the Polyvalent Group and evaluate the real evolution of its performances (COP/EER). [20]

4. THERMAL ENERGY CONSUMPTION MEASURING DEVICES

4.1 THERMAL ENERGY CALCULATOR

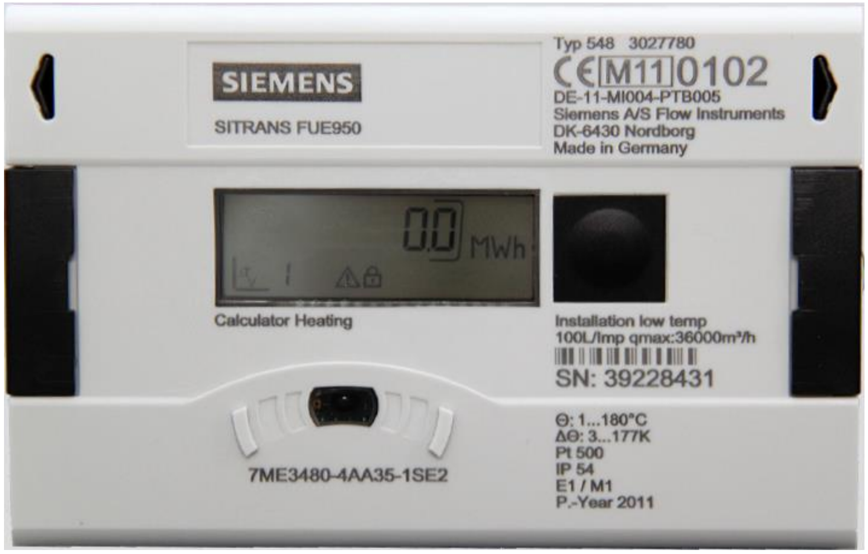

Figure 9: SITRANS FUE950 Energy Calculator

4.1.1 GENERAL DESCRIPTION

SITRANS FUE950 is a universal thermal energy calculator that meets the requirements of EN 1434 and has the MID approval for heat metering. For cooling the SITRANS FUE950 has the national German approval according to the PTB K7.2 standard. The SITRANS FUE950 energy calculator has been developed for Siemens Flow Instruments and is applicable with the following flowmeter types:

- SITRANS FUS380/FUE380
- SITRANS F M MAG 5000/6000
- SITRANS F M MAG 8000

Typically, the device is used with the SITRANS F US flowmeter program for energy custody transfer in district and central heating systems, in which the medium is water with temperatures up to 190 C, or with the SITRANS F M flowmeter program in cooling systems using water as coolant. The energy calculator is modular in construction and can be fitted with optional modules depending on the application.

4.1.2 MEASURING PRINCIPLE (ENERGY CALCULATION)

The calculation of energy is based on the following formula:

Energy = Volume x (TH - TC) x K-factor(Ti)

- Volume: Volume of a given number of volume pulses from the flow meter
- T_H: Measured temperature in the hot pipe
- T_C: Measured temperature in the cold pipe
- K-factor $_{(Ti)}$: Thermal coefficient of media enthalpy and heat content

The energy calculation is made by a counter and depends on temperature difference, pulse input frequency and local legal requirements. The calculator always carries out at least one energy calculation every 2 sec. (mainspowered version; battery-powered version: 4 sec.). If the connected flowmeter has not sent enough pulses, the energy calculation and the flow indication is also based on the 2 sec. (4 sec.) value.

4.1.3 APPLICATIONS

The SITRANS FUE950 is able to perform energy calculation in three kinds of applications (Heating and cooling applications):

- District heating applications
- Chilled water applications
- Combined cooling/heating applications

The separate flowmeter for the input of volume pulse can be installed in the hot or the cold pipe. The hot pipe is the pipe with the higher media temperature. In heating systems called forward line and in cooling systems the return line. The cold pipe is the pipe with the lower media temperature. In heating systems called return line and in cooling systems the forward line.[23]

4.2 TEMPERATURE SENSORS

Temperature sensors are one of the integral components of every thermal energy meter in heating or cooling applications. They are used for determining temperature changes in fluids due to energy released from or supplied to the loop. The temperature is measured by mounting temperature sensors upstream and downstream from the point where the exchange in the thermal energy of the system occurs. The temperature sensors can be used in applications with pipe diameters from approximately DN 50 and upwards. They have good thermal properties with low heat radiation and must always be used with related sensor pockets (typically ordered together with the temperature sensor pair).

4.2.1 TEMPERATURE MEASUREMENT

In heat transport systems, the release of energy (heat loss) is determined by measuring the supply (hot side) and return (cold side) temperatures as well as the volume of the measuring medium. In heating loops the supply side is defined as the hot side and the return side as the cold side. Cooling systems are opposite to heating systems in the sense that the supply side is defined as the cold side and the return side as the hot side. The effective difference between the supply and return temperatures is always of critical importance for determining the thermal energy exchanged. The absolute value of the temperature is required but is only of secondary importance for purposes of accuracy. The measuring error in the differential temperature is directly included in the total error when calculating the energy involved.

4.2.2 THERMAL CONSIDERATION

Heat flows from a warm to a cold region. If a sensor head at a measurement point becomes warmer, then the heat has most probably come from the liquid, i.e. heat flows from the measurement point to the sensor head located on the outside of the pipe. This dissipation inevitably produces varying temperatures along the flow path where the measuring resistor may be situated. For exact measurements, it is important that this heat dissipation is kept as low as possible.[23]

4.3 FLOW METERS

Figure 10: SITRANS Flow Meter FUE380

The SITRANS FUE380 2-way flowmeter, available in version powered by battery or mains, it is designed for measurement high flow rates on fluid transport installations temperature such as district heating systems, distribution networks premises, heating stations, secondary plant stations of cooling water and all applications with water in general.

The main field of application for the SITRANS FUE380 is the flow rate measurement of liquids in metered systems energy for custody transfer, in district heating plants or cooling water systems. The SITRANS FUE380 can be integrated into an energy metering system in association with an energy flow calculator and a pair of temperature sensors.[24]

Figure 11: SITRANS Flow Meter MAG 5100 W

The SITRANS F M MAG 5100 W is an electromagnetic flow sensor designed to meet ground water, drinking water, wastewater, sewage or sludge applications.

The flow measuring principle is based on Faradays law of electromagnetic induction according to which the sensor converts the flow into an electrical voltage proportional to the velocity of the flow.

The complete flowmeter consists of a flow sensor and an associated transmitter SITRANS F M MAG 5000, MAG 6000 or MAG 6000 I. The flexible communication concept USM II simplifies integration and update to a variety of fieldbus systems, e.g. HART, Device Net, PROFIBUS DP and PA, FOUNDATION Fieldbus H1 or Modbus RTU/RS 485. [25]

Figure 12: SITRANS Flow Meter transmitters MAG 5000/6000

MAG 5000/6000 compact version (Left) and recessed 19” version (Right), the high performance MAG5000 and 6000 transmitters are characterized by ease of assembly, commissioning, and maintenance. They are able to evaluate the signals transmitted by SITRANS FM sensors such as MAG 1100, MAG 1100F, MAG 3100, MAG 3100P and MAG 5100W.

Types of transmitters:

- MAG 5000: Maximum measurement error ±0.4% ± 1 mm/s (incl. Sensor)
- MAG 6000: Maximum measurement error ±0.2% ± 1 mm/s (incl. Sensor)

SITRANS FM flowmeters are suitable for measuring almost all electrically conductive liquids. Pasty substances and sludges. Its use is mainly applied in the following fields:

- water and wastewater
- Chemical and pharmaceutical industries
- Food and beverage industry
- Production and distribution of energy.

The MAG 5000/6000 models are transmitters with integrated alphanumeric display in different languages. This transmitter evaluates the signals from its electromagnetic sensors and also provides a power lock function that supplies a constant current to the magnetic coils. [26]

5. ANALYSIS OF THERMAL ENERGY CONSUMPTION DATA

In the following paragraphs and in its corresponding sections we proceed with the study of the real monitored operations of the plants. The results we want to achieve from the monitoring analyses are, first of all, a general view of consumption over the course of the heating season, and ultimately the determination of a load profile representative for the chosen valuation period.

The first step to be able to perform an excellent data-based energy analysis, can only be energy monitoring. Famous and appropriate to the context is the phrase of Robert Kaplan, creator of the Balanced Scorecard “You can't manage what you can't measure”.

Monitoring with the help of the temperature sensors, flow meters and energy calculator that are previously illustrated in the previous chapter is the first and fundamental step in being able to optimize the building as it allows to understand the internal situation through the measurements recorded in the field by the sensors, then send data, which are not always optimal. In fact, the main phase of monitoring is the Data pre-processing divided into Data preparation and Data characterization.

This phase takes about 80% of the time it takes to develop the entire analysis, which, to be of quality, must necessarily be based on reliable data. Famous, in this regard, is the saying "Garbage in = Garbage out" which expresses how everything that comes out of a process depends mainly on what is input.

The measured variables, which influence the energy consumption inside the building under study, are mainly the parameters concerning the temperature of water and the flow of water that leads finally to energy calculations which is essential for energy analysis

The next phase of the Data preparation is the Data transformation which allows to report all the data on the same scale in order to organize the dataset, which are all merged in a single cell and not distributed on the different cells. Generally, the most common task in this process is the distribution of the merged data into separate cells. In particular, in order to organize the data, various Microsoft excel functions were used including:

• Mid function: extracts a given number of characters from the middle of a supplied text string

• Left function: used to give the number of characters from the start from the string which is from left to right

• Right function: extracts a given number of characters from the right side of a supplied text string

The last phase of the Data preparation is the Data reduction which allows to reduce a certain number of data available for a good analysis depending on the case. In particular, the data are generally monitored with very high frequencies, approximately every 15 minutes, but if a smaller amount of data is required, it is useful to resort to Data reduction which uses reduction strategies allows to approximate the dataset by replacing the values of the original time series, with their average value, thus reducing the amount of data that have to be processed.

At the end of the Data preparation step, we move on to the second step of the Data pre-processing or the Data characterization.

Data characterization is mainly characterized by the visualization phase of the dataset which plays an essential role in the Data pre-processing step. This phase allows to have a first overall view of the data that will later be used to carry out the analysis. Among the different views, the most common are, for example, column chart, bar chart, line chart and area charts

The Energy Center has a state-of-the-art monitoring system that allows to quantify the consumption spent by the machines for the production of energy vectors useful for providing the heating, cooling and DHW services essential to ensure comfort conditions inside the building.

The reference heating period considered in the analysis is imposed by the Law which requires for the buildings located in the city of Turin (climatic zone E) that the switching on of heating systems from 15 October until 15 April.

5.1 CONSUMPTION OF DISTRICT HEATING

5.1.1 ENERGY CONSUMPTION

The monitoring system records the energy consumption of district heating system to meet the needs inside the building. The data are shown graphically in **Figure**.13

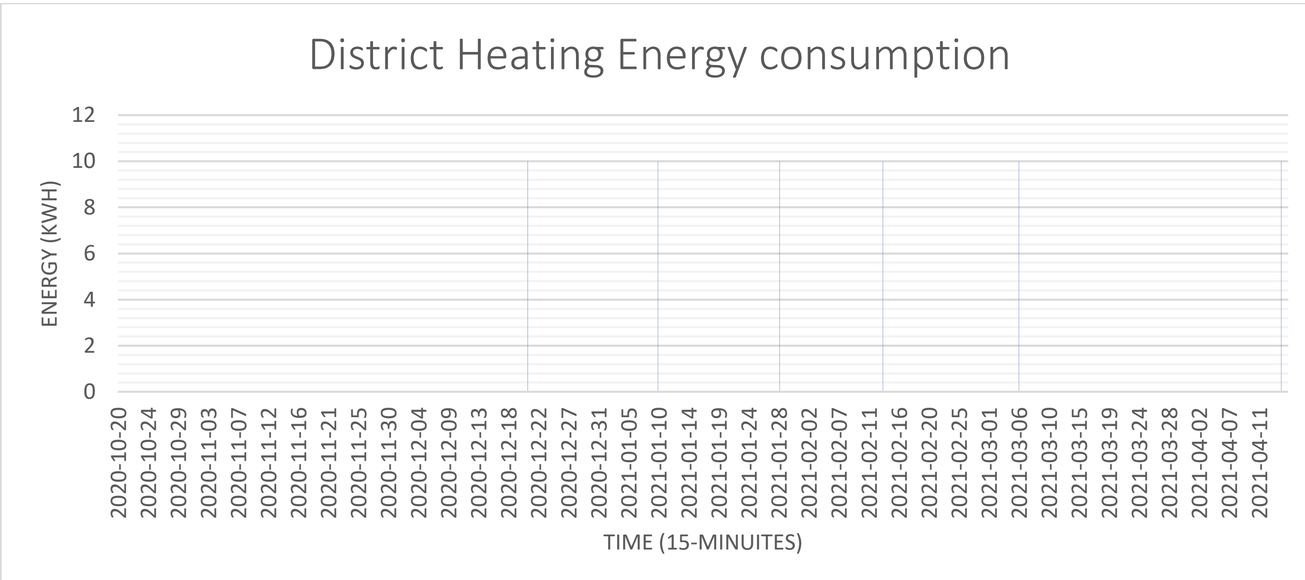

Figure 13: District heating energy Consumption (every 15-minuites)

The graphical analysis shows the trend of the district heating energy consumption in a measurements frequency of 15 minutes. The greatest consumption, in fact, occurs during the central months of the winter season such as December, January and February where consumption peaks of about 10 $[kWh]$ are reached.

The trend in monthly consumption is represented in more detail by the following graph in **Figure.**14

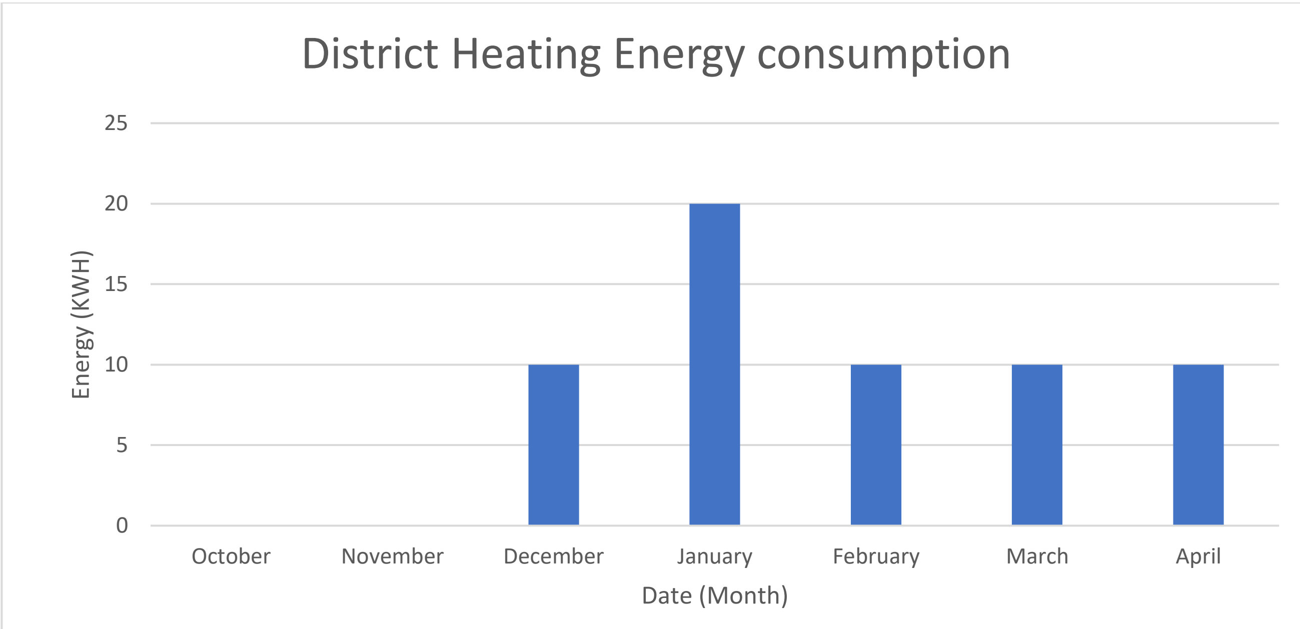

Figure 14: District heating energy Consumption (Monthly)

The greater consumption of thermal energy from district heating is during the month of January, when consumption of approximately 20 [kWhmonth] is recorded, compared to approximately 10 [kWhmonth] consumed during each of the months December, February, March and April.

In summary, the recorded measurements for energy consumption from district heating is not very reliable as there are no measurements recorded for the first two months.

5.1.2 POWER CONSUMPTION

From **figure**.15 it is possible to observe the trend of the thermal power consumption every 15-miniuites in which a power peak is almost present daily when the system is switched on.

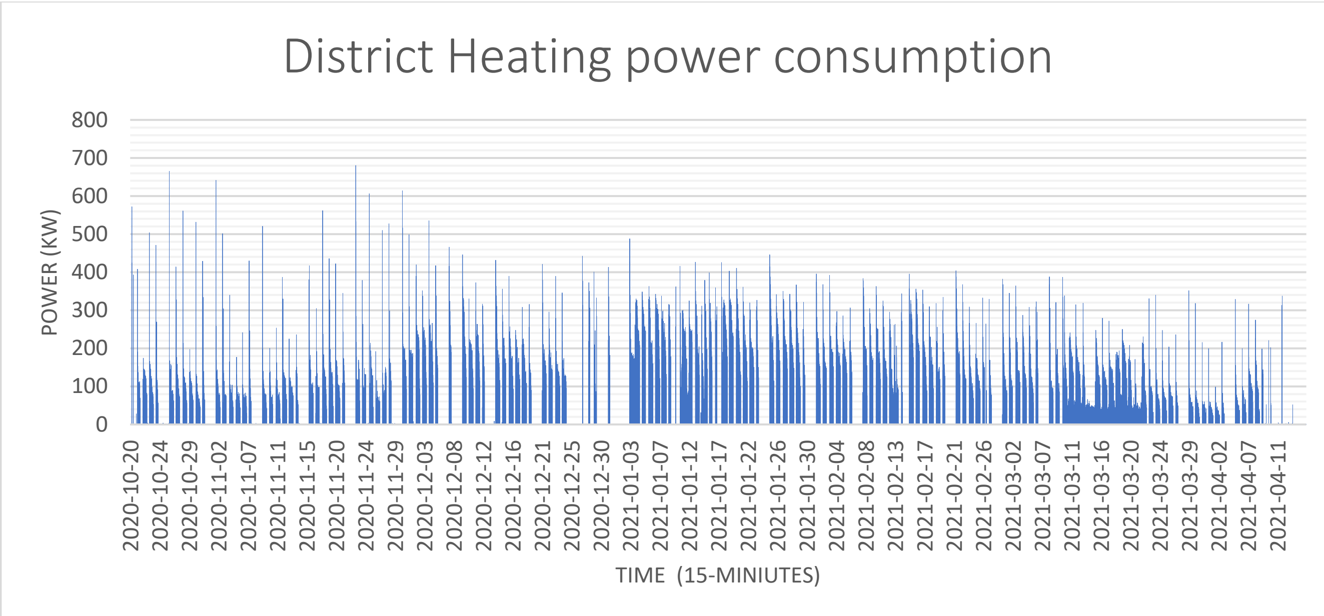

Figure 15: District heating Power Consumption (every 15-minuites)

This consumption is due to the low temperatures of the water reached during the night inside the pipes, which, to reach the temperatures required by the users, is heated with a greater thermal power exchanged with the primary district heating circuit, thus increasing the consumption. To solve this problem, it could be useful to install a latent thermal storage with phase absorption materials in order to reduce the load taken from the district heating network during peak hours.

The graphical analysis also shows the trend of the district heating power consumption in months which is represented in more detail by the following graph in **Figure**.16

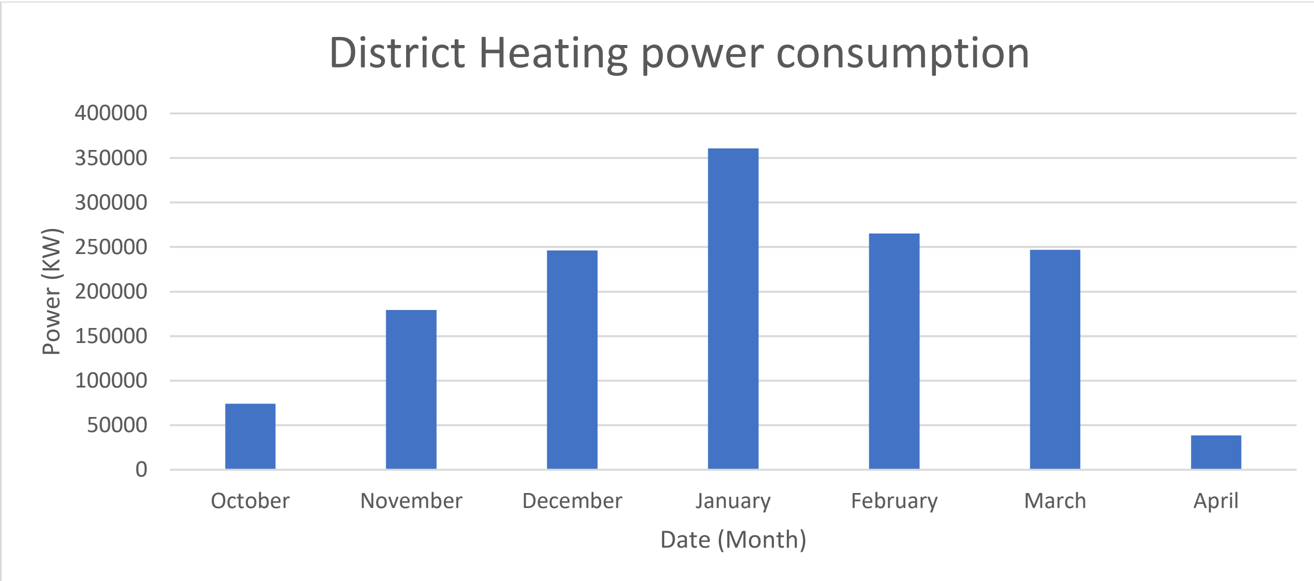

Figure 16: District heating Power Consumption (Monthly)

The greatest consumption, in fact, occurs during the central months of the winter season such as December, January and February where consumption peak of about 360000 [kWmonth] is reached in January.

In summary, the recorded measurements data of district heating power consumption are not correspondent to energy consumption recorded data. but, they are reliable and consistent.

5.2 CONSUMPTION OF DOMESTIC HOT WATER (DHW)

5.2.1 ENERGY CONSUMPTION

The monitoring system provides the data of energy consumption for domestic hot water that is measured on a 15-minute scale, which rearranged to made it possible to develop the graph visible in **figure**.17 which shows the energy consumption during the winter of 2020-2021.

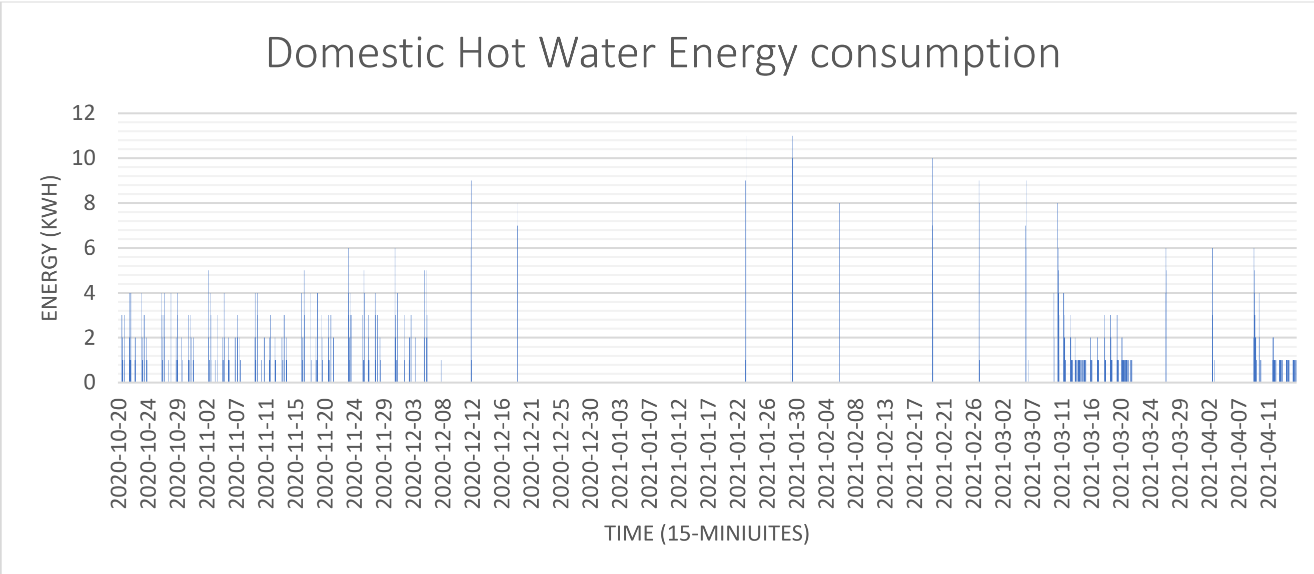

Figure 17: Domestic Hot Water Energy Consumption (every 15-minutes)

The period illustrated in the figure tends to highlight the Peak energy consumption encountered during the central months of the winter season such as December, January and February where peaks of about 11 $[kWh]$ are reached.

In order to better understand the amount of energy used by the building for the domestic hot water during the winter season, the following graph has been shown, in **figure**.18, which shows the energy consumption for hot water on a monthly basis.

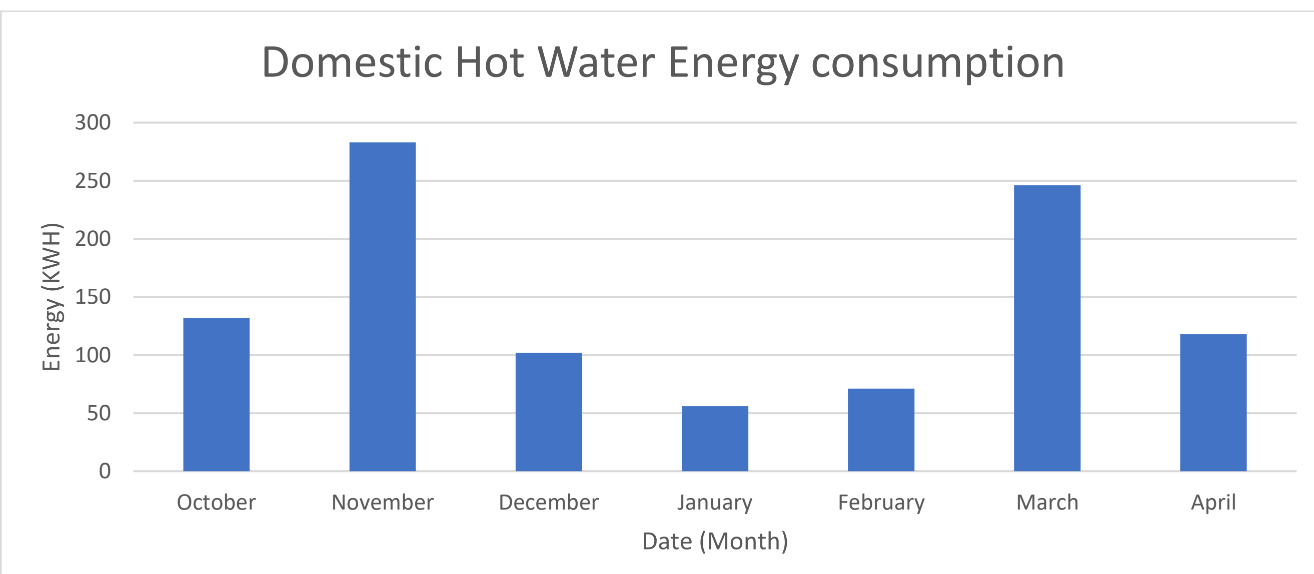

Figure 18: Domestic Hot Water Energy Consumption (Monthly)

from the graph in **figure**.18, it is possible to observe the greater use of the energy during the months at the starting and the ending of the winter season considered in which energy values of almost 280 [kWhmonth] are reached, in the month of November, unlike about 55 [$kWhmese$] registered in January. This value is not very far from the consumption recorded during the months of December and February.

In summary, the recorded measurements of domestic hot water energy consumption from solar thermal is consistent and showing that during the peak months of winter such as December, January and February where the external temperatures are very low, accordingly the energy produced and consumed from solar thermal is very low as well.

5.2.2 POWER CONSUMPTION

From **figure**.19 it is possible to observe the trend of the thermal power consumption every 15-miniuites.

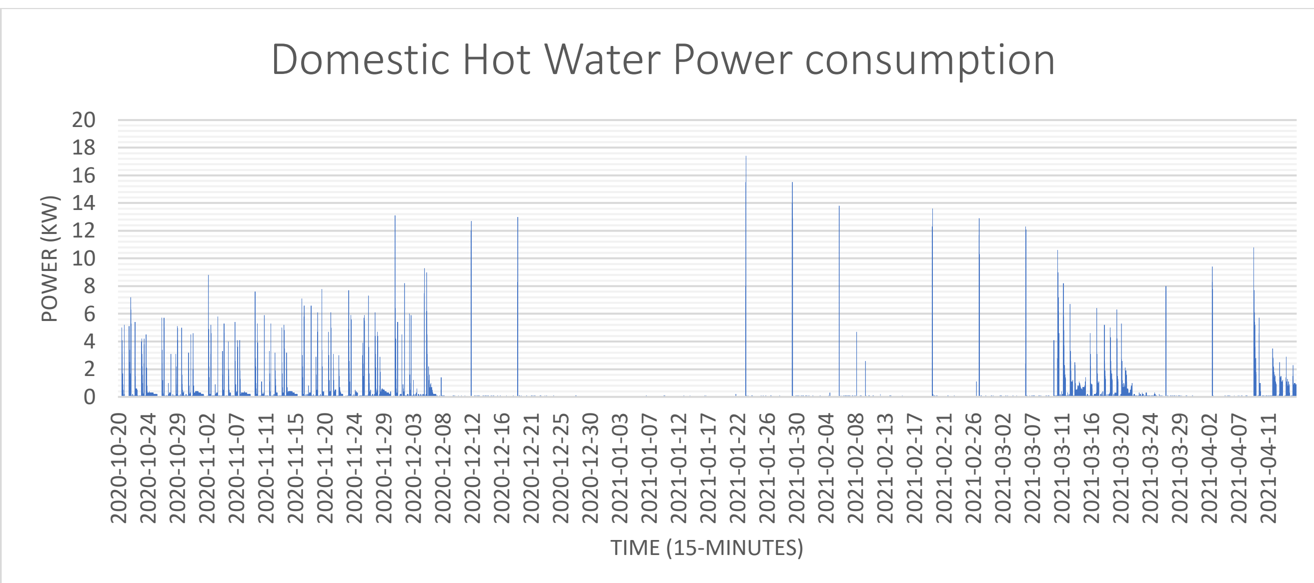

Figure 19: Domestic Hot Water Power Consumption (every 15-minutes)

The period illustrated in the **figure**.19 tends to highlight the peaks of power consumption encountered during the winter season where the maximum peak of about 17 [kW] is recorded in january.

The graphical analysis also shows the trend of the domestic hot water power consumption in months. which is represented in more detail by the following graph in **Figure**.20

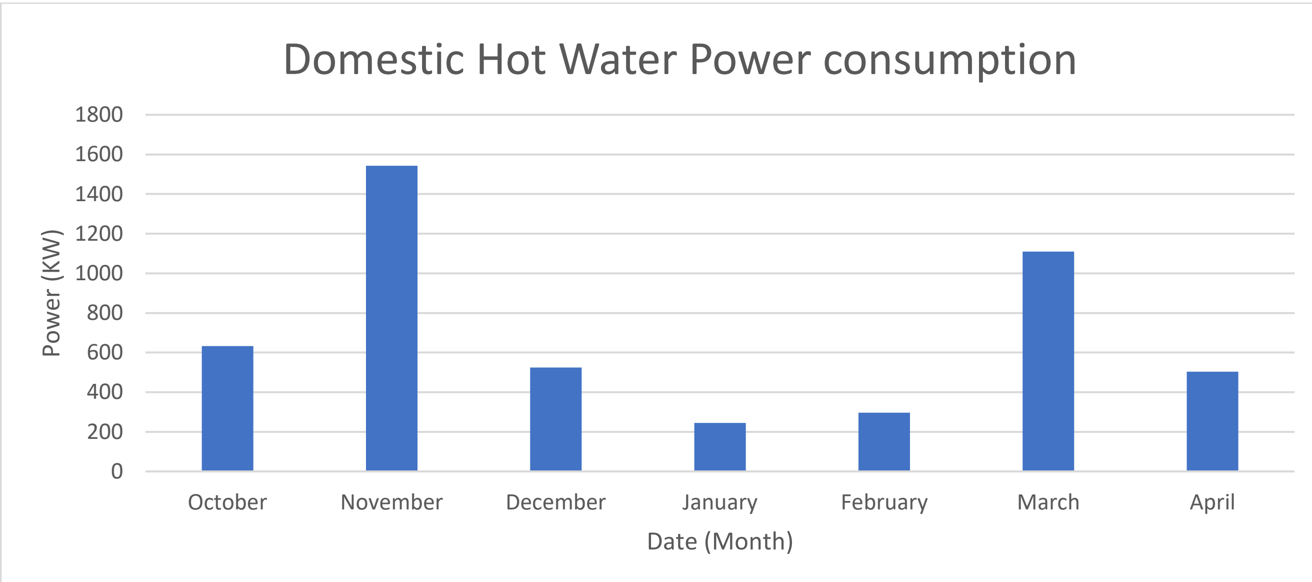

Figure 20: Domestic Hot Water Power Consumption (Monthly)

The greatest consumption, in fact, occurs during the months at the starting and ending of the winter season such as November and March where maximum consumption of about 1550 [kWmonth] is reached in November while a minimum of about 220 [kWmonth] is recorded in January.

In summary, the recorded measurements data of domestic hot water power consumption from solar thermal is correspondent to energy consumption and showing that during the peak months of winter such as December, January and February where the external temperatures are very low, accordingly the power produced and consumed from solar thermal is very low as well.

5.3 CONSUMPTION OF POLYVALENT GROUP

5.3.1 ENERGY CONSUMPTION

The monitoring system records every 15-miniuites the energy consumption of PDC to meet the needs inside the building. The data are shown graphically in **Figure**.21

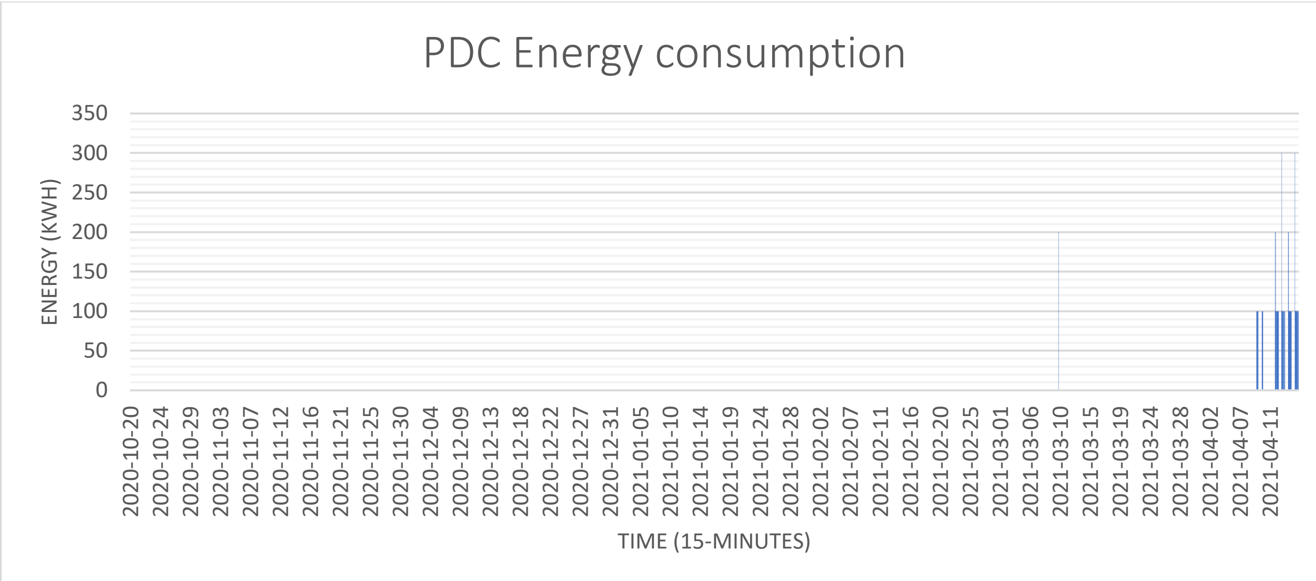

Figure 21: PDC Energy Consumption (every 15-minutes)

The period illustrated in the figure tends to highlight the Peaks of energy consumption which are encountered during the final months of the winter season March and April where the maximum peak of about 300 $[kWh]$ is reached in April.

The graphical analysis also shows the trend of the PDC energy consumption in months. The greatest consumption and the trend in monthly consumption is represented in more detail by the following graph in **Figure**.22

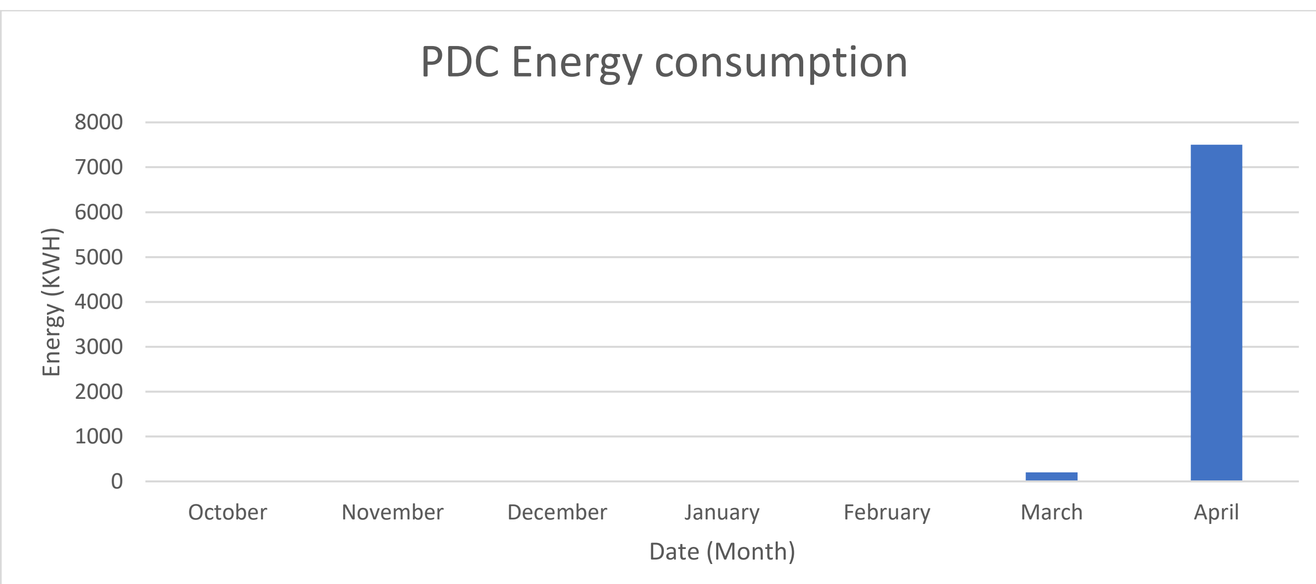

Figure 22: PDC Energy Consumption (Monthly)

The greater consumption of thermal energy from PDC in fact occurs during the final months of the winter season where the greatest consumption is recorded during the month of April of approximately 7,500 [kWhmonth], compared to approximately only 100 [kWhmonth] consumed during the month of March.

In summary, the recorded measurements data for Energy consumption from PDC shows that the system is utilized for only the last two months of winter season as there are no records during the first months

5.3.2 POWER CONSUMPTION

From **figure**.23 it is possible to observe the trend of the thermal power consumption every 15-miniuites.

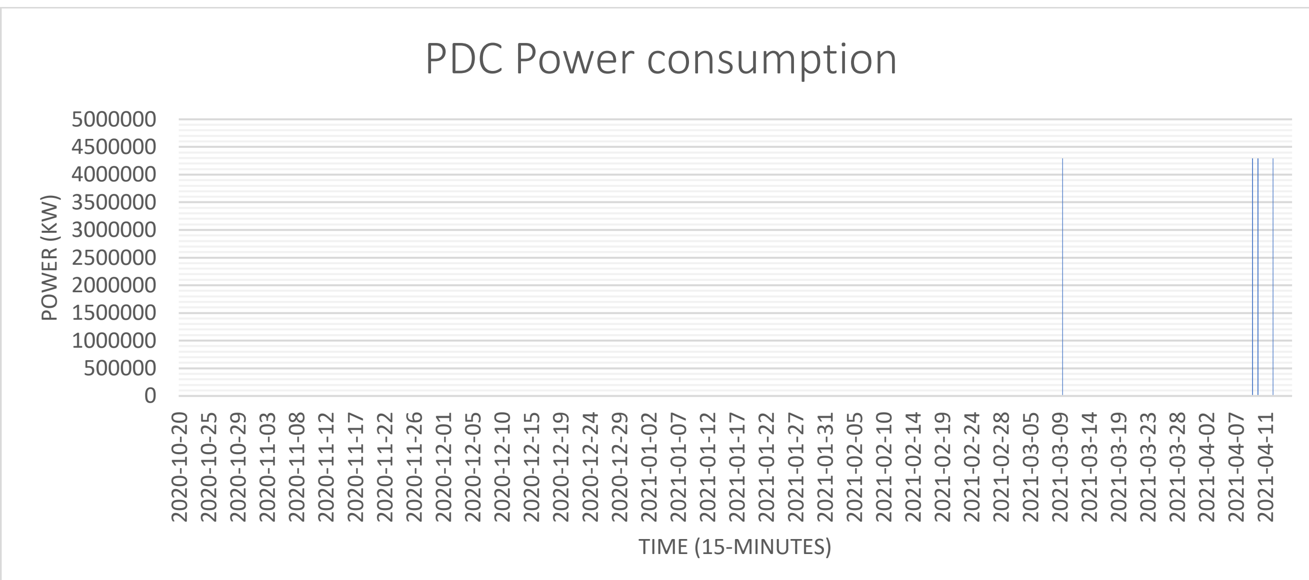

Figure 23: PDC Power Consumption (every 15-minutes)

The period illustrated in the figure tends to highlight the peaks of power consumption encountered during the winter season where the maximum peak of about 4,250,000 [kWh] is reached in April.

The graphical analysis also shows the trend of the PDC power consumption in months. The trend is represented in more detail by the following graph in **Figure**.24

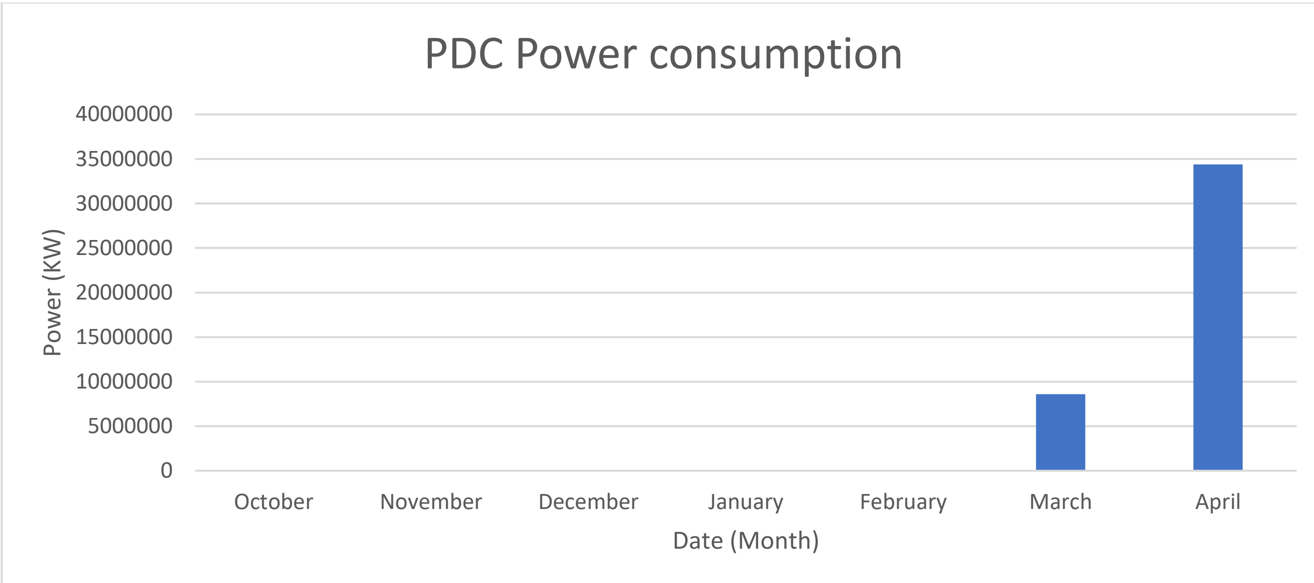

Figure 24: PDC Power Consumption (Monthly)

The greatest consumption, in fact, occurs during the final months of the winter season which are March and April where consumption peaks of about 35,000,000 [kWhmonth] is reached in April, compared to approximately 9,000,000 [kWhmonth] consumed during the month of March.

In summary, the recorded measurements data for power consumption from PDC are correspondent to energy consumption measurements and shows that the system is utilized for only the last two months of winter season as there are no records during the first months

5.4 CONSUMPTION OF SOLAR ENEGY

5.4.1 ENERGY CONSUMPTION

The monitoring system records every 15-miniuites the energy consumption of Solar energy during the winter of 2020-2021. to meet the needs inside the building. The data are shown graphically in **Figure**.25

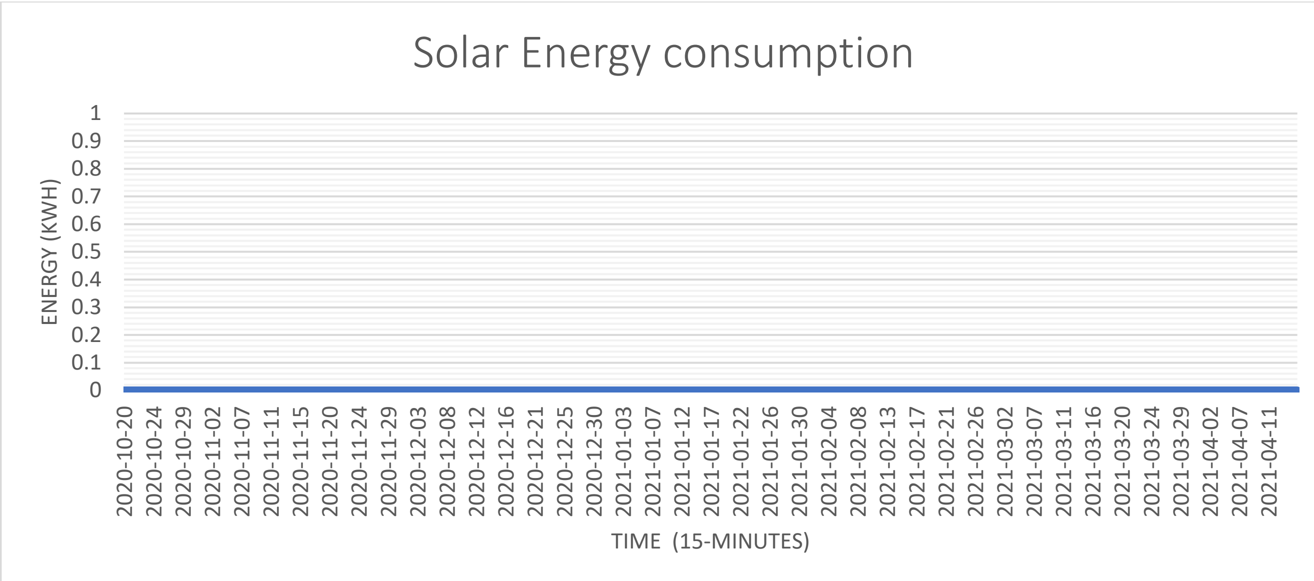

Figure 25: Solar Energy Consumption (every 15-minutes)

The period illustrated in the figure tends to highlight that no energy consumption recorded during the months of the winter season. The reason is probably that there is no fluid flow to be measured for the solar energy, so the energy calculator is not able to provide measurements for solar energy consumption.

5.4.2 POWER CONSUMPTION

From **figure**.26 it is possible to observe the trend of the solar power consumption every 15-miniuites.

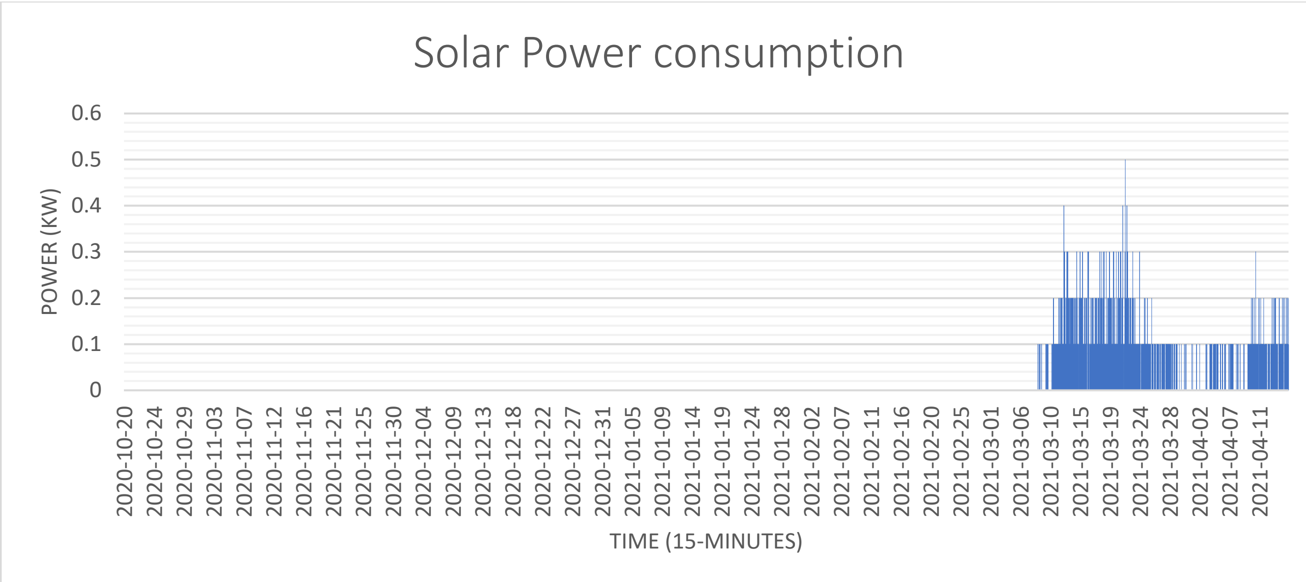

Figure 26: Solar Power Consumption (every 15-minutes)

The period illustrated in the figure tends to highlight the peaks of Solar power consumption encountered during the winter season where the peak of about 0,5 $[kWh]$ is reached in March.

In summary, the recorded measurements data for solar power consumption are not correspondent to energy consumption data which were not possible to be calculated with the energy calculator as there is no flow rates that can be measured by flow meters.

5.5 VERIFICATION FOR ENERGY CONSUMPTION DATA

Depending on the previous representation of recorded consumption data from different systems during the winter season and considering that it has been found the measured data of power consumption are more reliable than energy consumption, therefore it has been decided to reconstruct energy consumption profiles using the power consumption data in order to have more clear view about the energy meter measuring problems.

The following was considered to rebuild the energy consumption profiles:

- Power to energy formula (Energy = Power*Time)
- Duration of time equal to15 minutes.

5.5.1 DISTRICT HEATING ENERGY CONSUMPTION

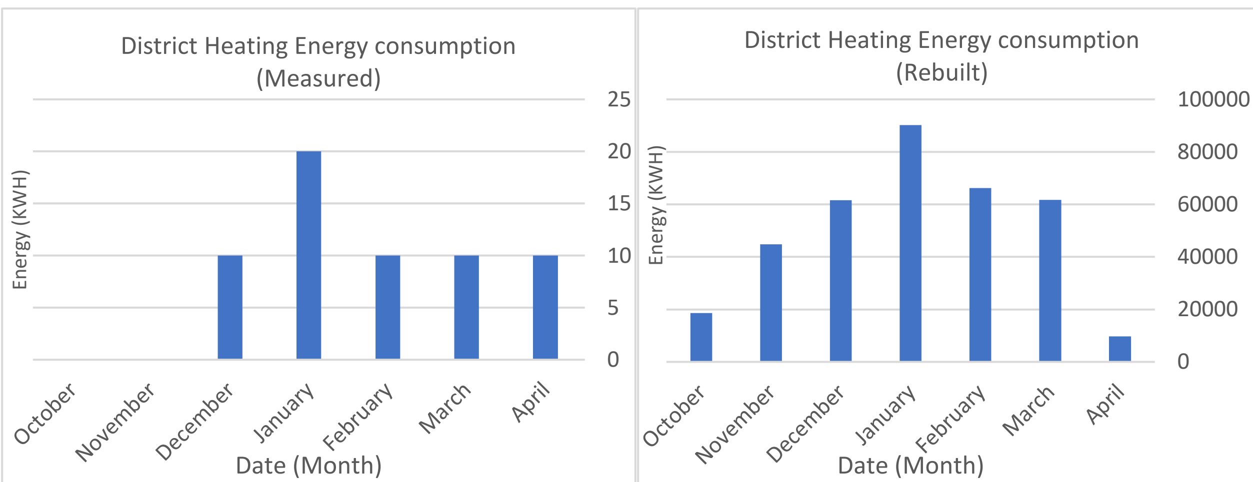

Figure 27: Comparison for Measured and Rebuilt Energy Consumption of district heating

Concerning the district heating energy meter, From the **figure**.27 above its clearer that the energy meter was not working completely during both October and November and accordingly did not record any data on these two months.

Moreover, the measured data for other months have an obvious deviation from the rebuilt data which show an inaccuracy on the energy meter measurements.

5.5.2 DOMESTIC HOT WATER ENERGY CONSUMPTION

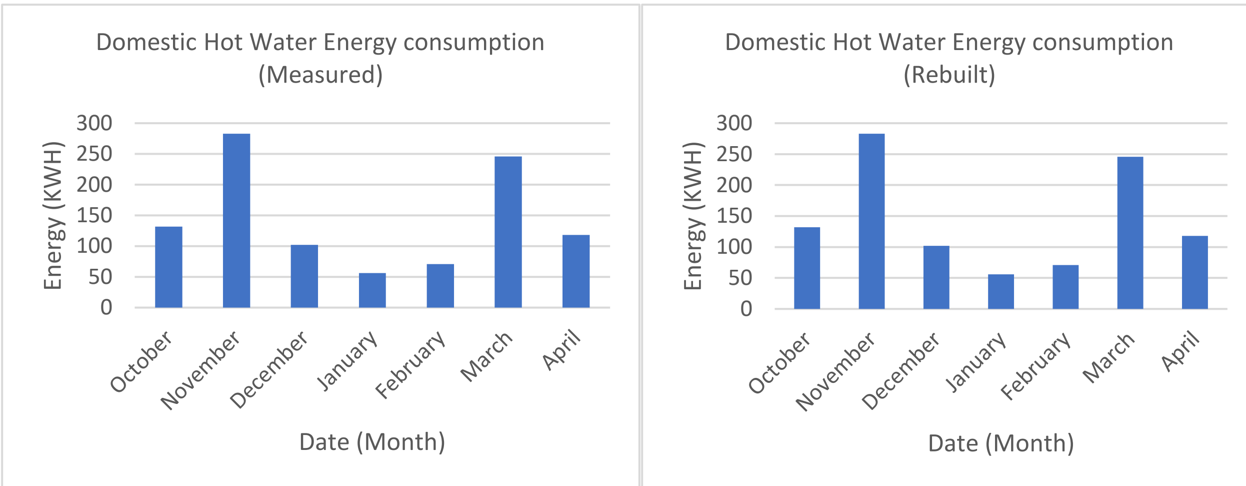

Figure 28: Comparison for Measured and Rebuilt Energy Consumption of domestic hot water

Concerning the domestic hot water energy meter, From **figure**.28 above its clearer that measured and rebuilt energy consumption data are almost similar which indicates that the energy meter was working during the complete period of winter season also provides a good and consistent measurements for the domestic hot water energy consumption.

5.5.3 POLYVALENT GROUP ENERGY CONSUMPTION

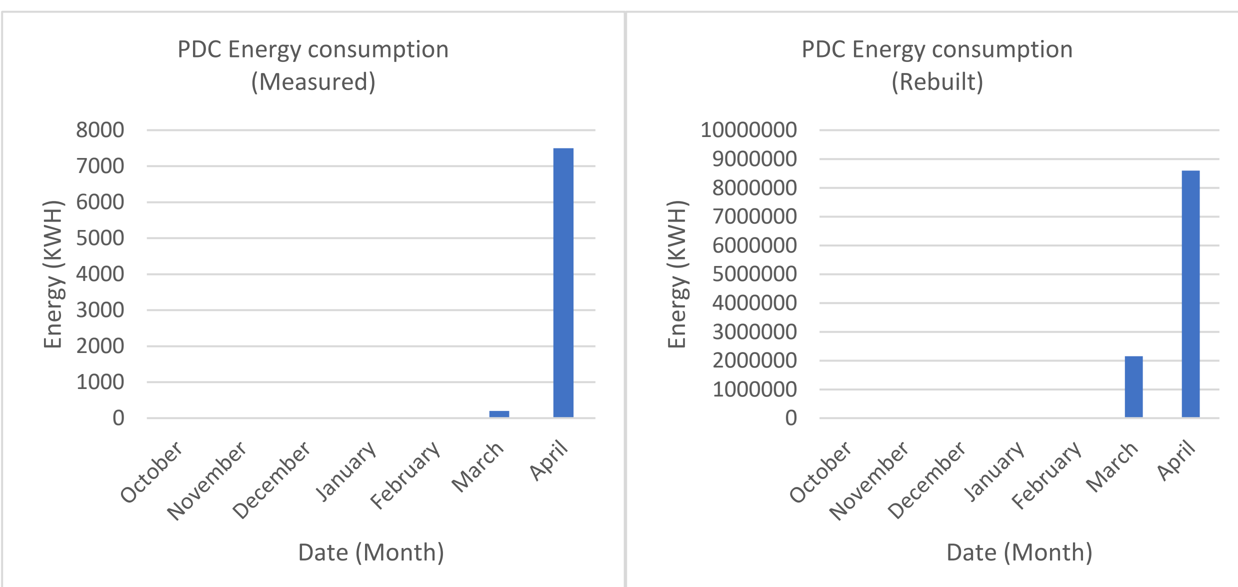

Figure 29: Comparison for Measured and Rebuilt Energy Consumption of domestic hot water

Concerning the Polyvalent group energy meter, from **figure**.29 above its clearer that the system of polyvalent group was working only for the last two months of winter season as a result of the fact that it is mainly utilized for cooling on the summer season.

However, the recorded data on the two months of march and April are showing a great deviation between the measured and rebuilt data because of an obvious existence for a sequences of data outliers (quite high values) within the rebuilt data that is based on the power consumption data which in this case indicates for inaccuracy on power consumption data and accordingly lead to a difficulty of deciding the accuracy status of the measured energy data.

5.5.4 SOLAR ENERGY CONSUMPTION

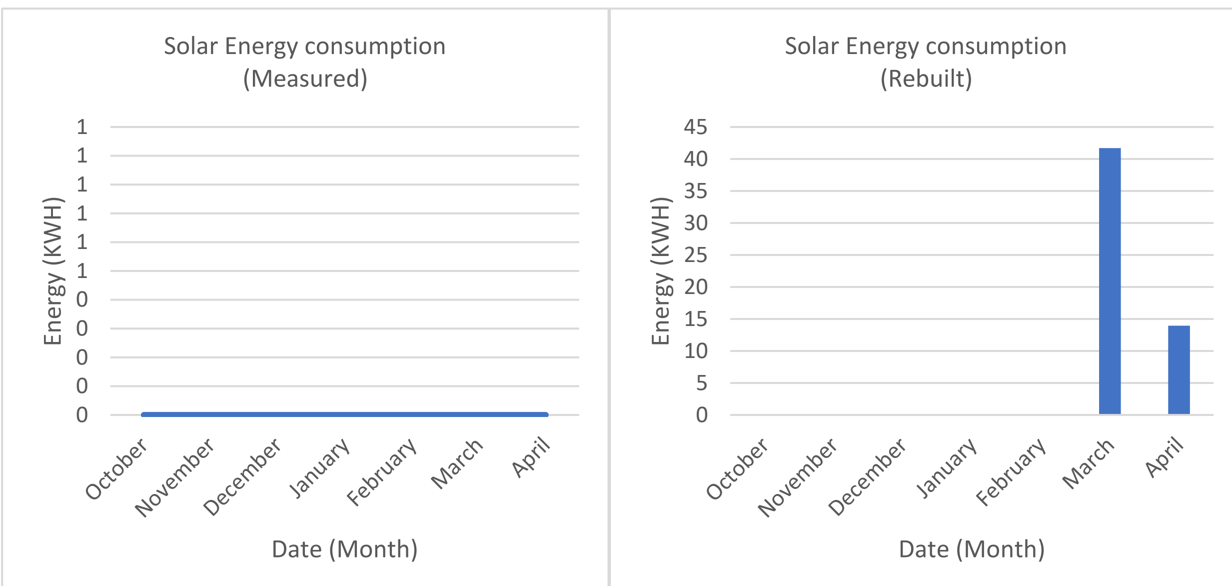

Figure 30: Comparison for Measured and Rebuilt Energy Consumption of domestic hot water

Concerning the Solar energy meter, from **figure**.30 above its clearer that energy meter did not record any data during the complete period of winter season, even for the last two months which is shown only on the rebuilt data.

6. DISCUSSION AND CONCLUSION

In this thesis work it has been analysed the thermal energy consumption measurement data for an office building, considering the Energy Center of Politecnico di Torino as a case study. The work was carried out with the aim of investigate the instrumental checks of the monitoring system for thermal energy which provides the consumption data of thermal energy to meet the needs inside the energy center building. This data which is measured on a 15-minute time scale, has been rearranged to made it possible to develop an energy consumption profiles. Furthermore, to better understand the amount of thermal energy used by the building during the heating season which requires by the Law for the buildings located in the city of Turin (climatic zone E) that the switching on of heating systems from 15 October until 15 April. Therefore, an energy consumption profiles have been developed which shows the monthly energy consumption.

Concerning the district heating energy meter, according to the graphical representation of energy and power consumption measurements data, also the comparison between the measured and reconstructed energy consumption profiles, it shows that the energy meter was not working completely during both months of October and November and accordingly did not record any data on these two months. Moreover, the measured data for other months have an obvious deviation from the rebuilt data which shows inaccuracy on the energy meter measurements.

In regard to the domestic hot water energy meter, according to the graphical representation of energy and power consumption measurements data, also the comparison between the measured and reconstructed energy consumption profiles, it shows that measured and rebuilt energy consumption data are almost similar which indicates that the energy meter was working during the complete period of winter season also provides a good and consistent measurements for the domestic hot water energy consumption.

About the geothermal polyvalent group, according to the graphical representation of energy and power consumption measurements data, also the comparison between the measured and reconstructed energy consumption profiles show that the system is utilized for only the last two months of winter season as the system is mainly used for covering the consumption of cooling energy. However, the measured data on the two months of march and April are showing an obvious deviation from the rebuilt data because of an obvious existence for a sequences of data outliers (quite high values) within the rebuilt data that is based on the power consumption data which in this case indicates for inaccuracy on power consumption data and accordingly lead to a difficulty of deciding the accuracy status of the measured energy data.

For solar energy consumption measurements, the comparison between the measured and reconstructed energy consumption profiles show that the energy meter did not record any data during the complete period of winter season, even for the last two months which is shown only on the rebuilt data.

The presence of anomalies and inconsistencies within the recorded energy measurement dataset is due to various causes, including data outliers which are inconsistencies that are easily identifiable graphically as they are points, or entire sequences of data such as that existed within power consumption data of polyvalent group, which significantly deviate the trend represented.

In particular, the anomalies and inconsistencies that lead to low quality of the recorded energy measurement data is resulted from various sources of faults of different nature, including:

- Incorrect communication of sensors with energy meter
- improper installation for associated instrumentation. For example: improper cabling causes electromagnetic compatibility problems.
- improper configuration for meters, sensors and control system
- Malfunctions of the sensors
- leakage on the heat exchangers or piping.
- Malfunctions of the flow meters
- Faults happened during maintenance or Systems shutdowns. or sudden reset of energy meters because of a drained batteries or blackout or other problems related to energy meters electrical components.

The main problem of the occurrence of these issues could be due to the lack of checks for the measuring equipment or could be lack of systems that through logic are able to detect these issues and subsequently solve them. The measuring equipment, in fact, should be checked daily so as not to carry out incorrect analyses that would lead the building into discomfort conditions.

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