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Festo's Building Automation

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Thank you   **Grazie mille**   **Gracias por siempre**

Abstract

Smart Building Project
Automation and energy saving at Festo building

The main objective of this thesis project is to design and implement a system which will be able to manage the complete company building. That means, to control the compressed air, electric and thermic energy sources and store the energy consumption of the company building. In order to achieve this objective, has been necessary to obtain a great knowledge about the building system and also about PLC programming.

Furthermore, the project includes the aim of control of the energetic, productive and functional sources by HMI (human machine interface). That is the most comfortable way to obtain a domotic control of a huge system as could be the Festos building.

Finally, it will be studied a new fashion concept into the automatic and control engineering fields as Industry 4.0 which will allow to share the collected information to the Festo World and make this project visual to workers and also clients.

This project represents every single part of the studies of Mechatronic Master at Politecnico di Torino since it is a combination of mechanic, electronic and of course automatic field. Also, it has been included extra leraning about general industrial topics as Thermodynamics, Fluid Dynamics, Power Electronics and Electricity which complete the engineering studies.

It is important to highlight that Festo is an experienced company at mechatronics, which means it will be the ideal atmosphere to develop this master thesis.

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Chapter 1

Introduction

1.1   Thesis Objective

The aim of this thesis project is to manage and control every system whose behavior has an important influence on the building lifetime.

These systems previously described will be:

- **Network system**

- **Electric system**

- **Compressed Air system**

- **Thermic system**

Each system characteristic and behavior is totally different and furthermore, it is composed by many different devices. Each one gives essential information to manage and also a different impact on the building.

The main objective is to control all of them singularly to obtain a complete management of the building. This objective will be true thanks to the use of Codesys as main control programming and Designer Studio to build the human machine interfaces.

Furthermore, the energy and consumption data acquisition has permitted to build an energy saving program, making some logics and changes inside the building in order to save energy and also to save money.

The result of this project has also been building a straightforward application that, a person without any programming knowledge could manage it from inside the building but also from his home.

The final objective of the project is to expand its limits so the collected data could been seen from the Festo workers until Festo clients.

1.2 Previous situation

Each device is individual and it has its own control. In order to collect the information, alarms included, or to command the devices it is necessary to go physically where the device is installed and control it manually. The different devices are placed of course in different rooms so, if a problem appears, the maintenance man was bound to go and check the all the possible sources of the problem.

That is why more than one technicians were always inside the building controlling that everything was working properly.

Thanks to the Smart Building Project, all these problems will try to be simplified. This project will become a huge advantage in terms of comfortability security and fast response.

1.3 Motivation

It will be a project focus on building a system that could be shown to clients in order to astonish them thanks to the advanced technology used in the company.

Also, although this project will be developed for a specific environment with known devices, the idea of this company is using it in such a flexible way that the system could be adapted to different buildings. It will be sell as a new innovative product so it will be really useful for the company Festo.

So finally, it will be a project with prosperous future which became of course a motivation to the writer.

1.4 Content organization

The Smart Building Project Thesis has been structured:

- **Introduction**

- **State of Art**

- **Smart Building Project**

  – Network system

  – Electric system

  – Compressed Air system

  – Thermic system

  – Industry 4.0, OPC UA

- **Conclusions**

Chapter 2

State of Art

The State of art chapter will be divided into three different fields:

- Festo Italy
- Festo Products
- Programs and Standards
- Comunication Protocols

2.1   Festo Italy

Festo is a German multinational industrial control and automation company whose sales subsidiaries, distribution centers and factories are located in 61 countries worldwide.

Festo is an engineering-driven company, producing and selling pneumatic and electrical control and drive technology for factory or process automation.

There are four phrases that define the company soul:

- Noi siamo sicurezza
- Noi siamo efficienza
- Noi siamo semplicit
- Noi siamo competenza

That means

- We are security

- We are efficiency

- We are simplicity

- We are competitivity

- We are Festo

What does it mean? That values could only be assigned to an experienced and competitive world-wide company that is always searching innovative ways to continue being the leader.

Festo is a leading world-wide supplier of automation technology and the performance leader in industrial training and education programs. The Festo main objective is maximize productivity and competitiveness for our customers.
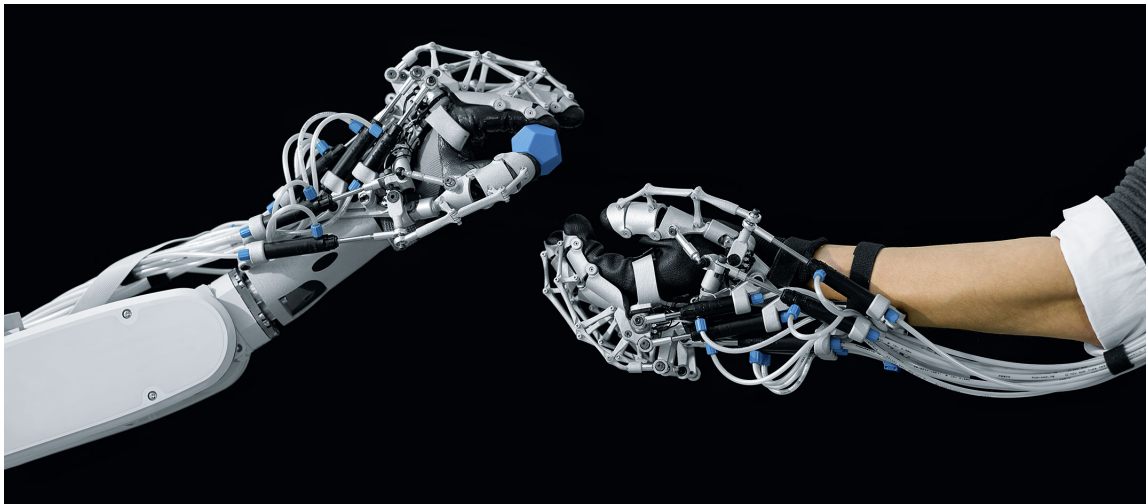
Figure 2.1: Festohands

Industry 4.0 is the current trend of automation where this project will be developed. It will be introduced in the followig subsection.

2.1.1 Industry 4.0

Figure 2.2: Industry 4.0

Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies.

Industry 4.0 creates what has been called a "smart factory". Within the modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time, and via the Internet of Services, both internal and cross-organizational services are offered and used by participants of the value chain.

Many of the aspects of Industry 4.0 are already a reality in Festo, that is a general feeling inside the company.

The next comment, taken from the Festo website shows how important is for a leader have the future trends in mind:

"An ability to adapt, maximum added value, the best possible quality, speed, delivery reliability and short routes to the customer are the key ingredients for creating production environments that are fit for the future."

Festo is always trying to anticipate the future and, as it is possible to observe, Industry 4.0 is the right way to do it.

2.2 Festo products

As it has been said in the previous section, Festo is a leader on the automation field. That assumption has been posible thanks to his wide product range:

Festo Porducts	
	Pneumatic drives
	Servo-pneumatic positioning systems
	Electromechanical drives
	Motors and controllers
	Grippers
	Handling systems
	Vacuum technology
	Valves
	Valve terminals
	Sensors
	Vision systems
	Compressed air preparation
	Pneumatic connection technology
	Electrical connection technology
	Control technology and software
	Other pneumatic devices
	Process automation

Table 2.1: Festo Products

2.2.1   Festo main used products

The main Festo products used on the development of the thesis are the following:

- CPX

- CDPX

(a) CPX   (b) CDPX
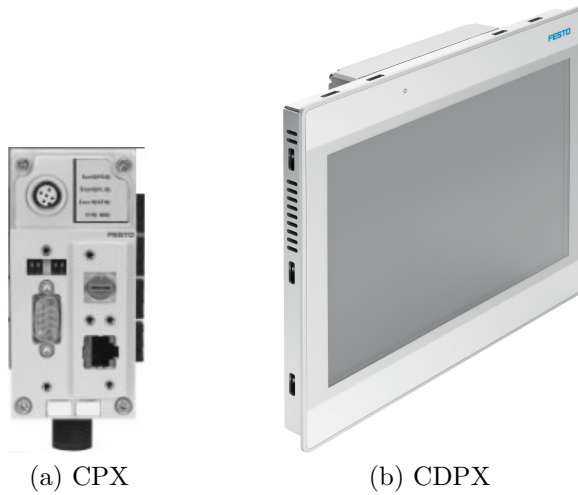
Figure 2.3: CPX and CDPX

They will be explanied in the next subsections.

2.2.2 CPX
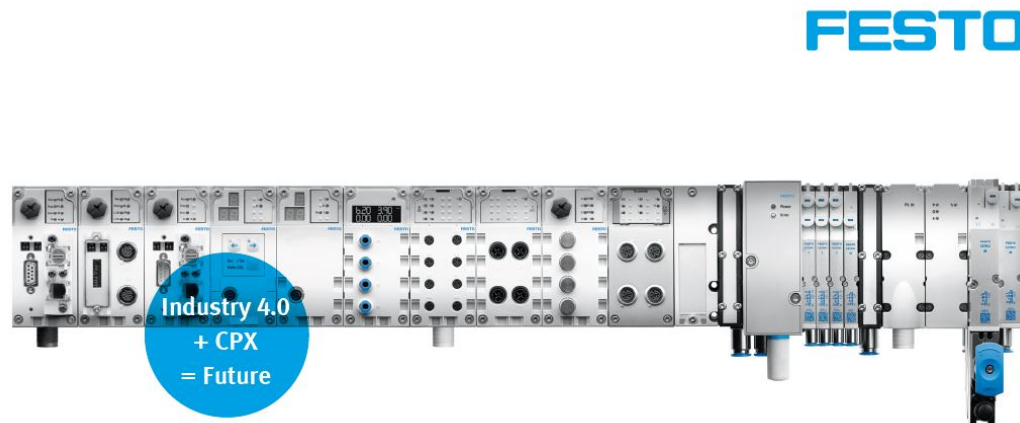
Figure 2.4: CPX Industry4.0

The Festo CPX is the first real PLC platform for integrated automation, highly competent in all standard functions. It is the perfect platform to combine any kind of input or output terminal, whether they are electrical or pneumatic peripherals. With CPX, it is possible to integrate control chains easily, quickly, flexibly and seamlessly into all automation concepts and company-specific standards.

Every point commented before is why it is the perfect product to introduce the company into Industry 4.0.

It is a Modular electrical terminal, as it could be seen on the figure 2.5 it could be integrated in many modules as could be imagined in an excellent flexible and modularity make way. As it is said on the guide document Maximum productivity: terminal CPX, the slogan of this product could be: *"One platform for many applications"*.

There are tow kind of CPX used, eveyone controls via fieldbus/Ethernet:

- CPX-CEC-S1-V3

- CPX-CEC-C1-V3

The CANopen could be master (-C1) or serial interface (-S1). The used program is always CODESYS V3.
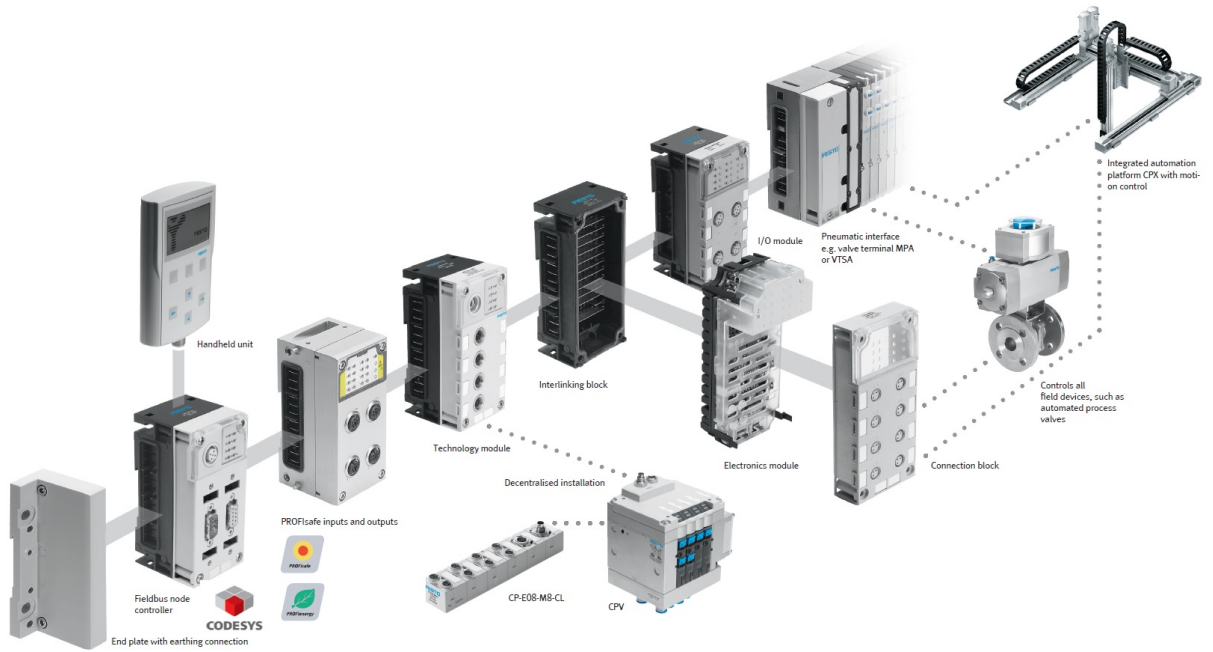
Figure 2.5: CPXmodule

On this thesis project will be used sixeen CPX around the building that will be seen on the following chapters.

If the reader is interested in more information about the product, it could be consult the next CPX file on the webpage Maximum productivity: terminal CPX [6].

2.2.3   CDPX

Festo CDPX panels are high-performance processors combined with widescreen technology. They provide functions at a higher resolution for the interfaces between man and machine.

The new generation of CDPX has integrated a controller which, combined with powerfull processors and widescreen technology give it higher resolution and versatile access options.

For full information the reader could consut the CDPX guide[7] on the festo website https://www.festo.com.

2.3 Programs and Standards

2.3.1 Programs

CODESYS

CODESYS (controller development system) is a development environment for programming controller applications according to the international industrial standard IEC 61131-3. Standard that will be develop in the next subsection 2.3.2. CODESYS has been chosen on Festo because it is a successful program to create simple or sophisticated automation applications for industrial controllers.

Different field busses can be used directly in the programming system CODESYS. For this purpose, the tool integrates configurators for the most common system such as PROFIBUS, CANopen, EtherCAT, PROFINET and EtherNet/IP, MODBUS TCP. In our case will be used the MODBUS protocol, explained on the subsection 2.4.1.

Designer Studio

Designer studio is the program used by the company Festo to design and create his graphic interfaces. It is particularly focus on the HMI Festo products as the previous explained CDPX device. It is very simple to use thanks to his graphic management.

2.3.2 Standard IEC 61131-3

IEC 61131-3 is the third part (of 10) of the open international standard IEC 61131 for programmable logic controllers [1].

Part 3 of IEC 61131 deals with basic software architecture and programming languages of the control program within PLC. It defines two graphical and two textual programming language standards:

- **IL** (instruction list) is an assembler like programming language

- **ST** (structured text) is similar to programming in Pascal or C

- **LD** (ladder diagram) enables the programmer to virtually combine relay contacts and coils

- **FBD** (function block diagram) enables the user to rapidly program both Boolean and analogue expressions

- **SFC** (sequential function chart) is convenient for programming sequential processes and flows

All five programming languages for application programming are available in the CODESYS development environment. In this thesis project, the used program language will be ST and FBD (CFC on Codesys), as an easier way to block programming.

2.4   Communication Protocols

A Communication Protocol is a system of rules that allows two or more entities of a communications system to transmit information. The protocol defines the rules syntax, semantics and synchronization of communication and possible error recovery methods. Protocols may be implemented by hardware, software, or a combination of both.

Communications protocols have to be agreed upon by the parties involved. To reach agreement, a protocol may be developed into a technical standard

Whatever communication concept and bus architecture it could be chosen, Festo's terminals range and electrical peripherals can be adapted to virtually all networking tasks.

Festo's terminals are open to all fieldbus protocols and also provide comprehensive diagnostic and energy management functions. In the image 2.4, it is possible to see the main Fieldbus communication supported by Festos products:

Each device companies choose his communication protocol but, Festo devices could be adapted to everyone. In this project has been used some of this communication protocols, the most used are explained in the next sections.

2.4.1   Modbus

The objective of this fieldbus is the transmission of information between different electronic equipment connected to the same bus. There are only one Master device

Figure 2.6: Communication Protocols

and several Slaves connected.

In its origin it was oriented to a connectivity through serial lines such as RS-232 or RS-485, but with the passage of time have appeared variants like the Modbus TCP, that allows the encapsulation of the Modbus series in TCP / IP in a simple way.

From a technical point of view, its implementation is very simple and consequently the development time is considerably shorter with respect to other protocols in which the structure of the frames is complicated and consequently the access to the data that are not stored in structures complex.

The transmission of information is not committed to any type of data. This implies some flexibility in the exchange of information.

Modbus RTU

Modbus RTU is an open, serial (RS-232 or RS-485) protocol, which is derived from the Master/Slave architecture. Modbus RTU is widely used within Building Management Systems and Industrial Automation Systems.

MODBUS RTU messages are a simple 16-bit CRC (Cyclic-Redundant Checksum). The simplicity of these messages is to ensure reliability.

Modbus Message

Address	Function	Data	CRC Check
8 bits	8 bits	N x 8 bits	16 bits
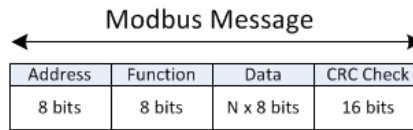
Figure 2.7: Modbus RTU

Modbus TCP/IP

Modbus is a serial communications protocol for use with its programmable logic controllers (PLCs). Simple and robust.

It is basically the Modbus RTU protocol using the TCP interface in the Ethernet network. Different application layers used in TCP/IP protocol are used to define the Modbus data structure. While the transport protocol, TCP is used to ensure that the data is received and sent correctly and the IP is the address and routing information. Thus Modbus TCP/IP is nothing but a Modbus RTU command included in an Ethernet TCP/IP wrapper.

2.4.2 CANopen

A **Controller Area Network (CAN bus)** is a robust vehicle bus standard designed to allow microcontrollers and devices to communicate with each other in applications without a host computer. It is a message-based protocol.

The CANopen communication protocol, based on CAN (Controller Area Network), is used to network complex equipment/systems. It comprises higher-layer protocols and profile specifications. CANopen has been developed as a standardized embedded network with highly flexible configuration capabilities.

As it is said on the CiA webpage, *"It was designed originally for motion-oriented machine control systems, such as handling systems. Today it is used in various application fields, such as medical equipment, off-road vehicles, maritime electronics, railway applications, or building automation."*

CANopen unburdens the developer from dealing with CAN hardware-specific details such as bit timing and acceptance filtering. It provides standardized communication objects (COB) for time-critical processes, configuration as well as network management data.

Chapter 3

Smart Building Project

This chapter will explain the **Smart Building Project**, how has been structured and which are the particularities of each part.

The main objective of the Smart Building project is control every either electric, electronic, thermal or mechanical part of the Festo building from a simple HMI (human machine interface) and the Codesys program.

The Smart Building Project has been divided in 4 smaller projects. Each one of them represents different systems, with completely different control peculiarities. Every project is composed by one or more PLCs adjusted to the complexity involved.

The singular projects whose is composed the Smart Building Project will be separately explained in the following sections. They are shown in the next list:

- **Network Plant**
- **Electric Plant**
- **Thermic Plant**
- **Compressed Air Plant**

Inside each section it is descripted:

- Involved components, working mode and communication protocols.
- Codesys programming control and alarm management.
- HMI design, visualization and control.

- Measures and results.

In this chapter it will be explained, step by step, page by page, how has been thought and how has been managed every single room and every single element. In order to undestand the behavior of the different elements it will be explained the logic programming process and the design one.

In order to have a guide on the pages layout and access, it is shown in the next scheme how is the distribution of the **Design Project**.
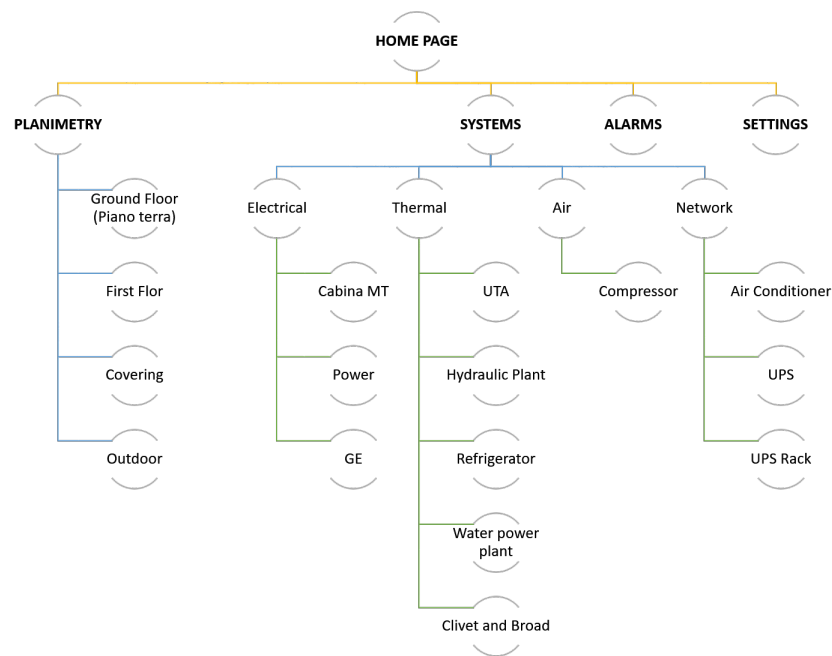
Figure 3.1: General CDPX Diagram

The homepage is the main window of the design project. It must be the symbol of the system, the representation of what belongs internally, the fast access of each building control.

In the picture 3.2, it is shown how the main interface looks like.
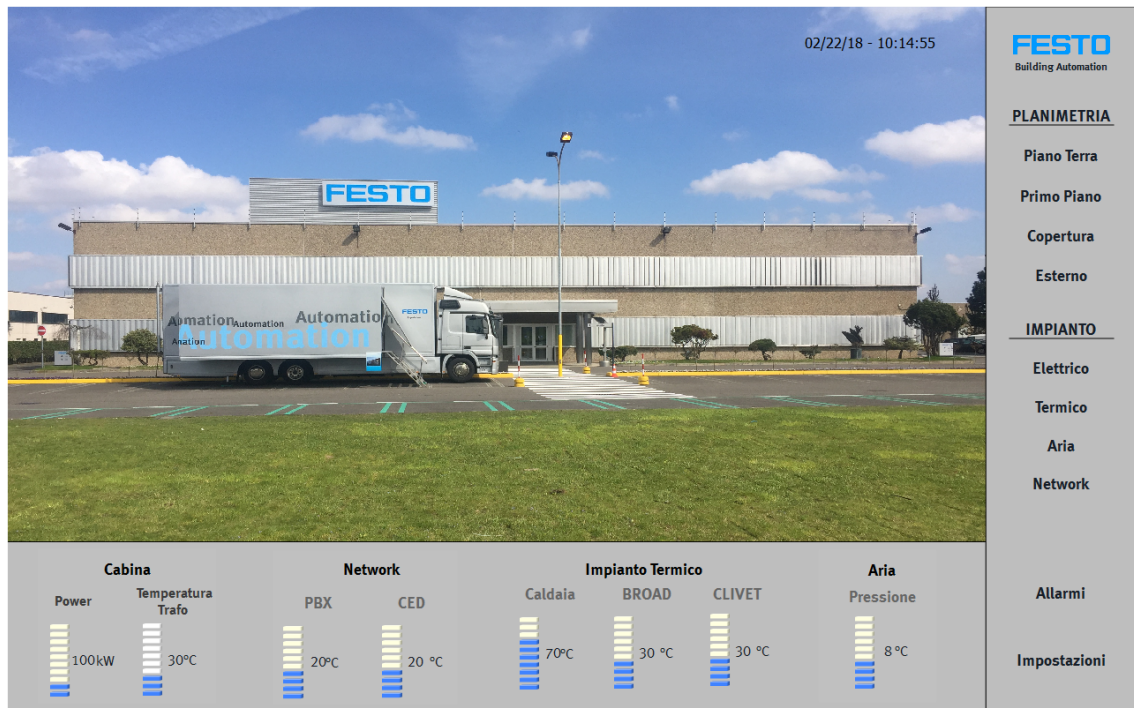
Figure 3.2: Main CDPX Interface

The Smart Building Project homepage is divided in two sections. The vertical section shows the general navigation into the Smart Building Project and the bottom one shows the essential information. As it could be seen in the interface 3.2, the

navigation column of the homepage is schematized in two types of navigation, by Planimetry or directly by System selection. In this chapter it will be explained the different systems one by one, Network, Compressed Air, Electric and Thermic. In order to have an idea of how the rooms are distributed and of course to navigate inside them in a easy way, it has been created the mapping pages. The picture 3.3 shows that distribution.
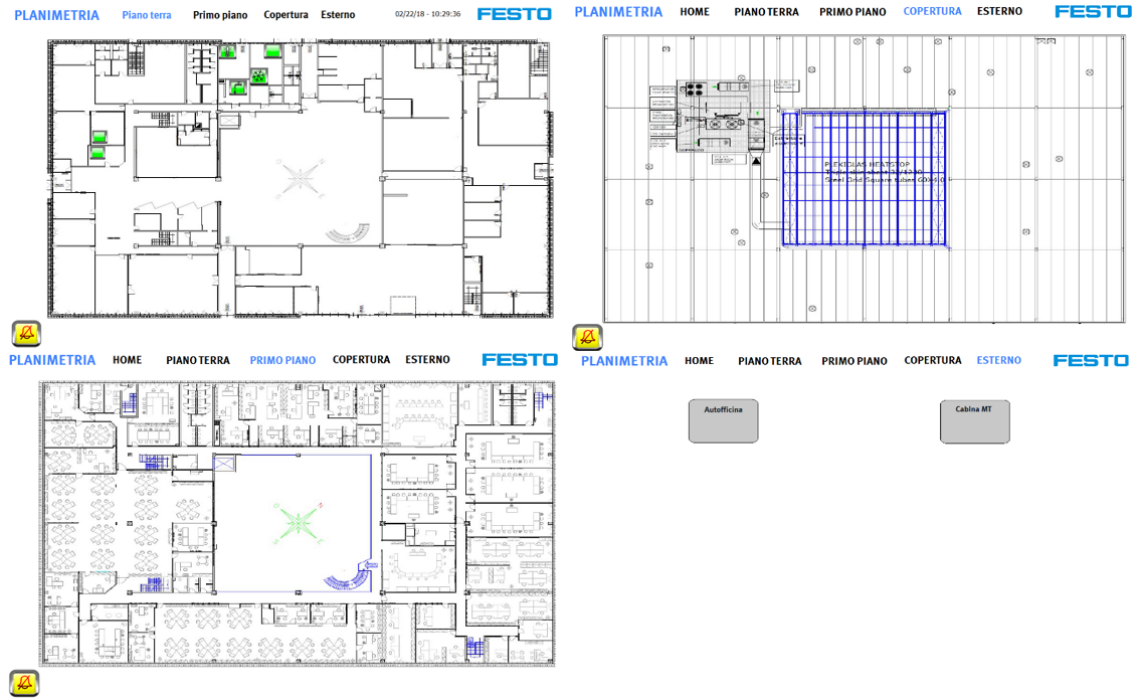
Figure 3.3: CDPX Mapping

In the following chapters it will be explained system by system, room by room the characteristics, the internal logic and the results of the project.

The final section called Industry 4.0 as OPC UA connectivity, explains how the mos important information of the Smart Building Project has been collected and shown via OPC UA to the customers inside the building.

3.1   Network Project

The Network plant has huge importance on the building. It is where all the Festo Italia informatic data is collected, organized, managed and distributed.

The network plant is composed by two rooms, PBX room called Centralino Room and CED room or also called Server Room.

In order to obtain an efficient and long life of the Network plant, it is compulsory to assure constant and standard working conditions. Therefore, it is crucial to control the temperature and the power supply so, the Network Plan Project will be focused on the good working state of its thermal and electrical supply elements.

The crucial elements to control in these rooms are the **Air Conditioner** , the **Electric Boards** and the **Uninterruptible Power Sources (UPS)**. These elements will be particularly explained on the next subsections.

The Contact center and the Server room are controlled by a single **PLC (CPX-CEC-S1-V3)** connected as a MODBUS TCP Master and five MODBUS TCP Slave, corresponding to each conditioner, three by server room and one by contact center, and the last one will be used to the UPS information. The electric boards information will be directly connected to the CPX.

So, in order to understand it in an easy way, the reader will find the chapter divided in the next subsections:

- Air Conditioners

- UPS

- Electric Board

- PLC

- General Alarms

3.1.1 Air Conditioners

There are four **Datatech** air conditioners working for the building, three of them are inside the server room and the other in the contact center room.

The main objective of the air conditioners is to stablish a set point temperature and follow it as a thermostat device. Also, it sends alarms about its state and can receive instructions to change its behavior.

Thanks to the MODBUS TCP connection with the Master PLC CPX-CEC-S1-V3, connected directly with the Slaves MODBUS TCP of each Air conditioners, is possible to receive all the information corresponding to the device.

Figure 3.4: Air conditioner

The main information received from each air conditioner to work with has been the next one:

- Air conditioner State (On/Off)

- Stablished Set Point

- Room Temperature

- Motor Power

- Air conditioner Fan Speed

- Air conditioner Mode

- Air conditioner Alarm

- Air conditioner Fault Code

- Filter Alarm

All the data is sent together by block by the ModBus TCP IP connection. The next step is select the interesting elements of the block.

On the next paragraphs will be explained how is the process of obtaining the ModBus TCP data by Codesys.

As it is shown on the next table, the data information has been obtained from the DATATECH Air conditioners ModBus TCP documentation [3]. It is possible to realized that the data has been taken thanks to its included the address from the block. It has been highlighted two data from the main device information.

Figure 3.5: Datatech Air Conditioner

Codesys allows to filter this information thanks to the offset and the size determination.

Figure 3.6: Codesys Air Conditioner Programming 1

When the data is collected, a specific address is determined for each data. This given address is how the variable will be called by the Codesys definition page as could be seen on the next image.

Figure 3.7: Codesys Air Conditioner Programming 2

Figure 3.8: Codesys Air Conditioner Programming 3

Being received this information, it is very simple to create an alarm screen of the air conditioner where you can realize if there would be problems on the system.

Also, it is also possible to send instructions to the air conditioners:

- Turn On/Off

- Reset

- New Set Point

- New Air Conditioner Mode

Thanks to these instructions, it is possible to manage from the screen the main functions of the air conditioner, it easies the Air Conditioner control, avoiding the necessity to go in situ.

Finally, it has been created some functions that will give to the system a faster and useful control. The functions added to the system are:

- **Set Point Change**: It has been developed a double check system where, first of all, it is written the new set point value and then it is compulsory to push a button to confirm it. The temperature written value must be between two threshold values, a maximum and a minimum temperature, stablished to assure the integrity of the system. That values have been set as 25 and 18 °C.

- **Turn On/Off**: The turn on instruction will be a simple button that will stablish that function. In the other hand, the turn off button must be maintained pushed two seconds in order to complete its function. It has been possible thanks to the use of TP timers.

- **Default instruction**: Thanks to this function, it is possible to put, with only a button pulse, the default values of the Air Conditioner: Set Point temperature and Air Conditioner Cooling Mode.

- **Alarms logic**:

    - Too high set point: it will appear if the set point stablished is too high.
    - Air conditioner off: it will appear if every air conditioner is off more than ten minutes, one air conditioner in case of contact center and three in case of server room.
    - General alarms: these signals will be studied on the last subsection 3.1.5, called General Alarms.

In order to clarify the utility of the data collection and the logic programming that has been done, the picture 3.9, shows the full information of the air conditioners.

It could be seen that every single element is depicted and described in a fast visual way. If there would be any problem on any Air conditioner, the generic alarm would go off and from this page could be seen where is the problem.

Furthermore, the writing commands are included on this page:

- **Buttons**: ON, OFF, Reset, and Default.

- **Writing analog data**: In order to set a new set point, the number must be simply clicked, selected the new set point and pressed finally the check button.
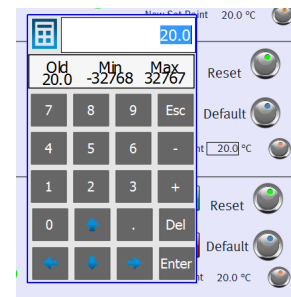
Figure 3.10: NumberPad
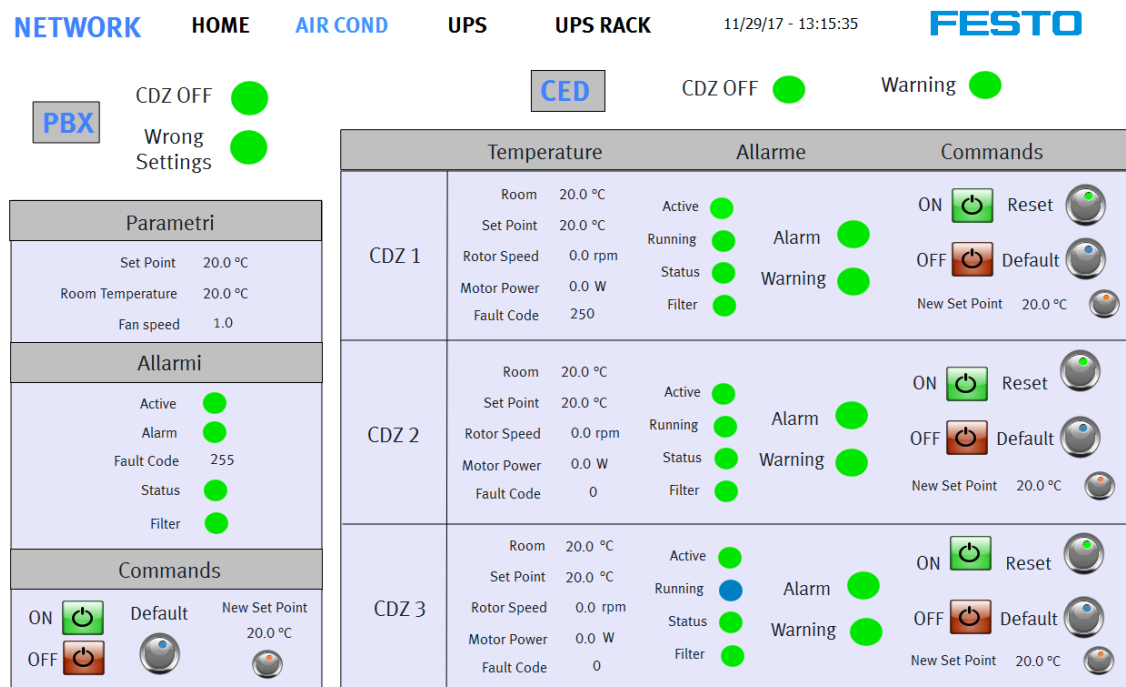
Figure 3.9: Air Conditoner Interface

3.1.2 UPS

An UPS is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails. It will provide instantaneous protection from input power interruptions, by supplying energy stored in batteries. The on-battery runtime of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment.

Figure 3.11: UPS

The UPS is a security element so it will send states or alarm information but it will be not possible to send or modify the inside parameters.

Our rooms are composed by three UPS, two for the Contact center and the other one for the Server room. The essential information that we will receive from the UPS will be the state of the main elements whose is composed the UPS:

- **Battery**
- **Inverter**
- **Bypass**
- **Input line**
- **Exit line**

Furthermore, on the rack UPS it is possible to obtain extra useful information from:

- **Battery** (percentage, low, charging, charged)
- **Input and output** (Voltage, frequency, power)
- **UPS temperature**

The UPS information is obtained by two different ways, the one Server Room UPS gives a ModBus TCP IP connection while Centralino one gives the data directly by the PLC input output electronic connection.

The ModBus TCP IP connection is similar to the Air Conditioner one, searching the information from the following table 3.12, taken from the ACS manual [2]:

UPS: *TABLES OF STATES, MEASUREMENTS, NOMINAL DATA AND COMMANDS*

REGISTER[1]		UPS - STATES		BIT[2]	
NUMBER	ADDRESS			NUMBER	ADDRESS
				1	0
		Test in progress	[0=No / 1=YES]	2	1
				3	2
		Shutdown active	[0=No / 1= YES]	4	3
				5	4
		Battery charged	[0=No / 1= YES]	6	5
		Battery charging	[0=No / 1= YES]	7	6
1	0	Bypass bad	[0=No / 1= YES]	8	7
				9	8
		Normal operation	[0=No / 1= YES]	10	9
				11	10
		On bypass	[0=No / 1= YES]	12	11
		Battery low	[0=No / 1= YES]	13	12
		Battery working	[0=No / 1= YES]	14	13
		UPS locked	[0=No / 1= YES]	15	14
		Output powered	[0=No / 1= YES]	16	15
				17÷28	16÷27
		Input Mains present	[0=No / 1= YES]	29	28
2	1	Alarm temperature	[0=No / 1= YES]	30	29
		Alarm overload	[0=No / 1= YES]	31	30
		UPS failure	[0=No / 1= YES]	32	31
3	2			33÷48	32÷47
				49÷63	48÷62
4	3	Communication lost with UPS [0=No / 1= YES]		64	63
5÷8	4÷7			65÷128	64÷127

Figure 3.12: UPS Table

On the other hand, the physical connection is easier to find. You have only to obtain what pin was stablished for each connection and search the address of the pin as it has been done on the ModBus TCP connection.

The left part of the picture 3.13 shows how is an 8 pin inputs and 8 pin outputs module on the CPX while the right one shows how a 4-analog input module is.

Finally, the received information will be logically treated and sent to the HMI device. The result of the pages design is shown in the picture 3.14 where it could be find every collected data from the UPSs.

Each UPS has a general information about its own state. Looking at the warning and alarm lights the main problems are detected. Furtheremore it is depicted on its particular elements: **Line, Battery, Inverter, Bypass, Exit**

Each one of these elements includes an alarm light that shows the working condition of each moment. Also an error could be highlighted by the pipes colour. If the electricity does not arrive to a point, the pipe becames grey.

Finally, the different sections will change colour if a problem appears, particular elements or individual UPS as a block.
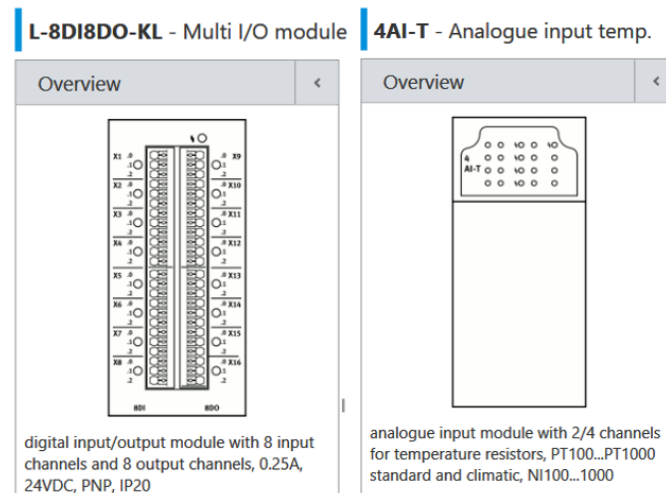
Figure 3.13: CPX Module UPS
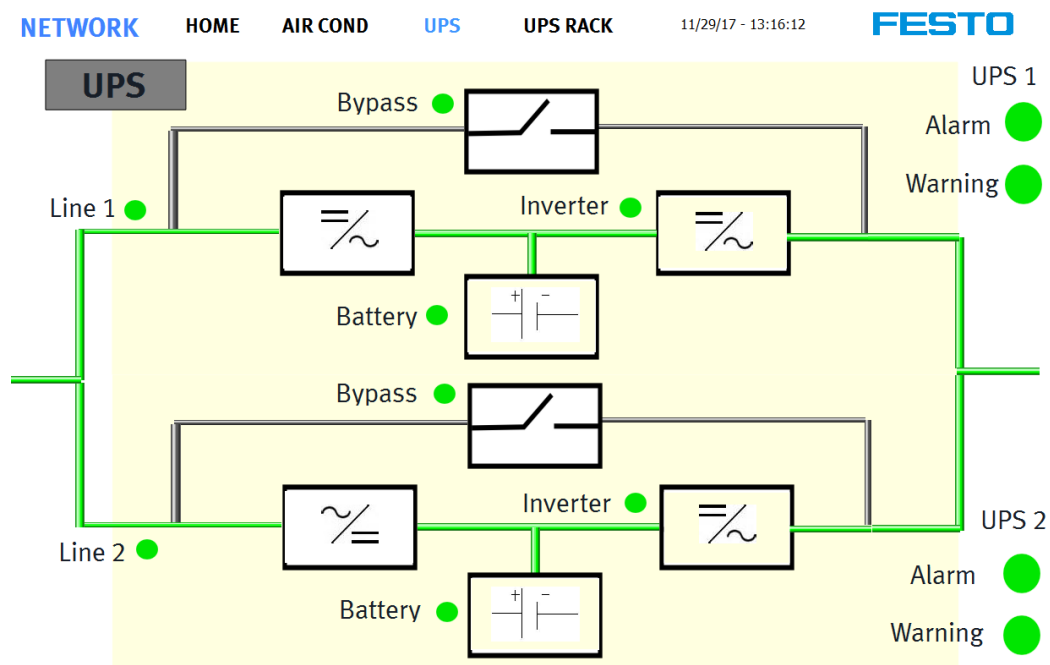
Figure 3.14: UPS Interface

The Server Room UPS, thanks to its ModBus TCP connection obtains also analog information about UPS state than the Centralino one as temperature, tension or frequency. Its representation will be the next one 3.15:
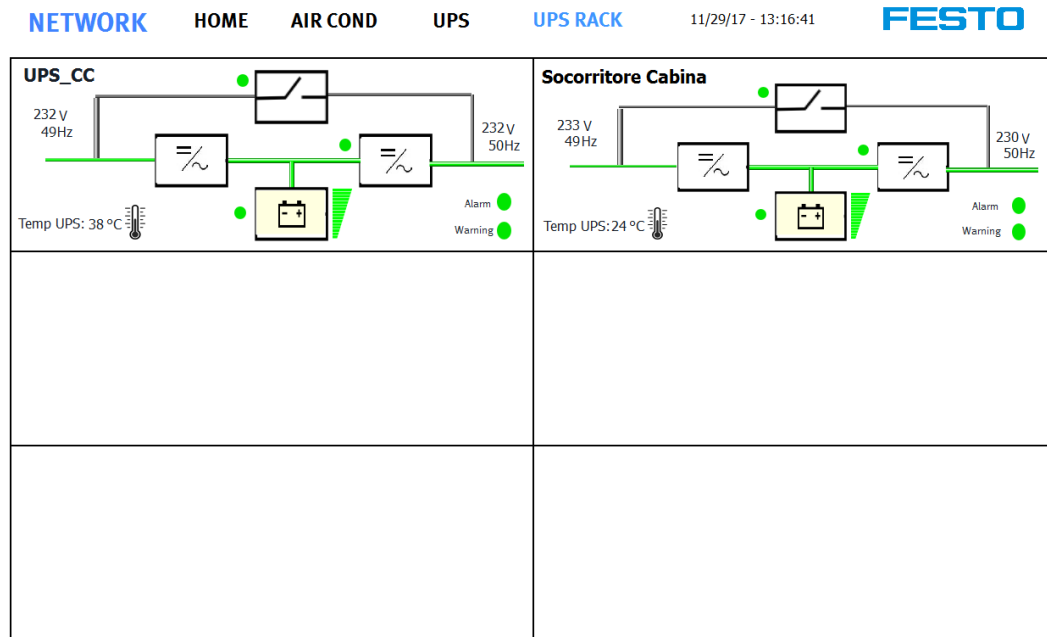
Figure 3.15: UPS RackInterface

On each UPS, every single element error will be treated as a particular error and then, depending on the gravity will be sum up as the general alarm or warning error. For example, if the inverter is not working there are two possibilities. If the bypass works, the warning led will be activated and if the bypass is not working it will be understood as an alarm situation

That general alarms will be sent to the subsection 3.1.5, General Alarms that will be later explained.

3.1.3   Electric Board

The electric board is composed by temperature and electric net sensors.

There are four thermometers distributed into the two main rooms. They are specifically PT100 sensors, Platinum resistance thermometers, that offer excellent accuracy over a wide temperature range. These devices receive the UPS and room temperature from the two main rooms and give it to the general PLC.

The electric board section function is to manage these alarms sending also the information to the general alarm section.

3.1.4 PLC error

This section pretends only to guarantee that the PLC is working correctly and there are not global errors inside.

The own CPX will do the self-diagnosis to check its state. This error will be send of course as an alarm to the general alarm part.

Figure 3.16: CPX

3.1.5 General Alarms

The alarm section is the last one of this module. It will manage, as it has been anticipated, every general alarm sent from the other devices. The final objective is to catch the people attention in order to realize the general problems and actuate rapidly.

Every general alarm, the most important ones has been sent from the other devices to be treated here. This treatment has been feasible thanks to the function block SB-Alarm-Zone. The diagram 3.17 will help to explain how the function block works.

The two principal elements of the block are:

- **Alarm block**: it is composed by the general alarms sent by an external device.

- **Acknowledge button**: Its function is to check that the person has received the alarm information.

Also, there are three main variables giving the information to understand what is happening:

- **all Int:** it is the state of the diagram

    - 0: there is no alarms present
    - 1: the alarm is present and nobody has realized it
    - 2: the alarm continues being present but someone has realized it.

- **Color out:** it allows to compare the gravity between alarms at the same time
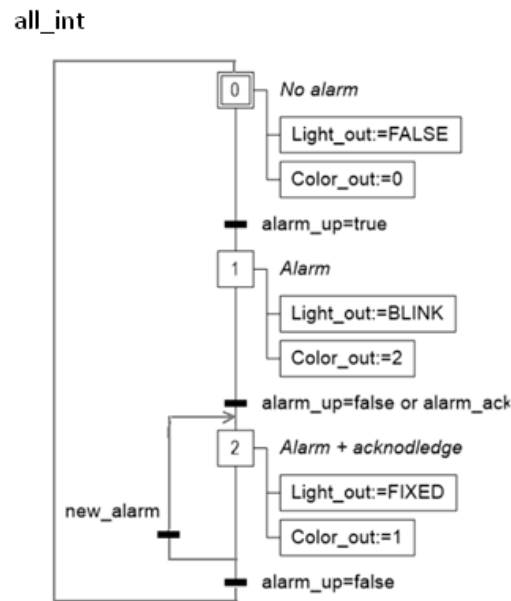
Figure 3.17: Alarm Zone Diagram

  - 0: no alarm
  - 1: medium gravity, alarm known.
  - 2: high gravity, alarm not known.

- **Light out:** bool which represents the light state. It gives the characteristic to the light, blinking, fixed or null state.

So, to sum up, on state zero it doesnt exist any alarm from the block. On the state one, the alarm appears and nobody has realized it yet so, the alarm light is blinking trying to catch the people attention. Finally, if someone push the acknowledge button, the alarm will be fixed as a symbol that the alarm state is known and it is being solved.

3.1.6 Network Interface

Finally, it has been design a sum up page, where it could be find any problem of the system or any general information.

The next screenshot shows the main Network page. It is divided in the two main rooms, PBX, where could be managed and controlled the electric board and the air conditioner, and CED room where it is possible to manage and control the electric board, three air conditioners and two UPS devices (uninterruptible power source).
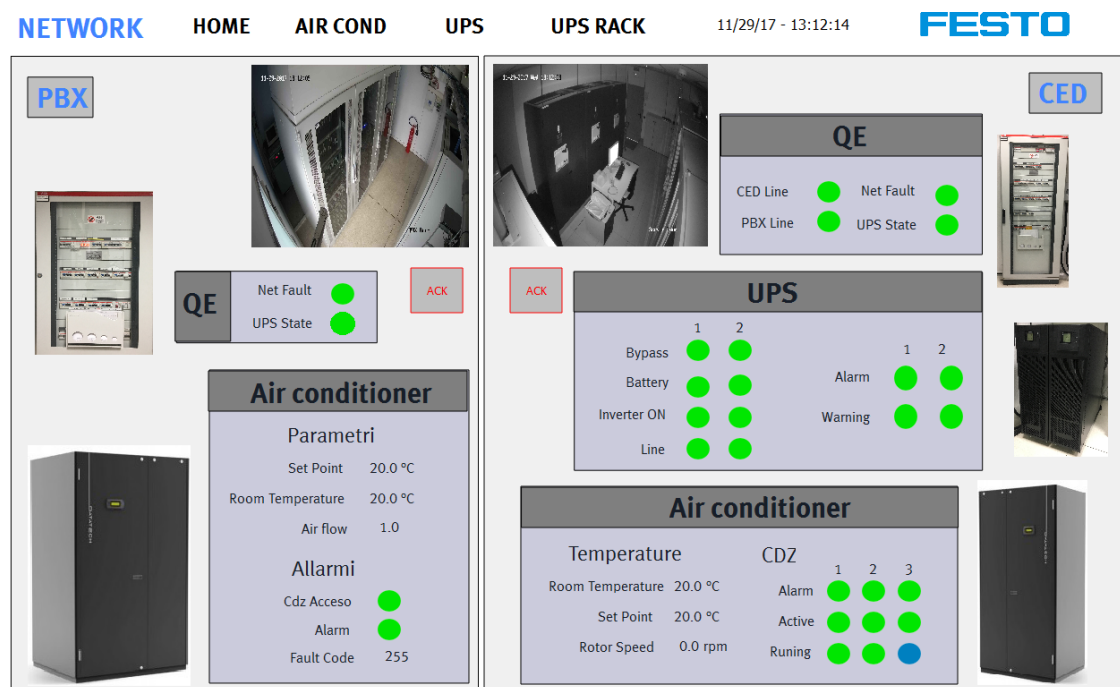
Figure 3.18: Alarm Network Interface

The design elements used on this page are:

- **Guide bar**: It allows the user to be moved into the different parts of the PBX and CED.

- **Alarm lights**: The lights would be in green if it is correctly working, in red if an estrange behavior of the system is happening and in grey if this alarm is disabled. The blue color special into the running state of the air conditioners.

It shows that this specific device is not running. It is not an alarm considering that two air conditioners are enough to obtain a good working condition.

Finally, the last property of the lights is that every alarm could be disabled pushing it on the HMI.

- **Analog Data**: The analog data shows in numbers a specific asked information as the temperature, rotor speed or air flow.

- **Ack button**: It has been explained on the section of the smart building project that, if a main alarm is active, the led on the CDPX and mainly a light on the physical building, will be blinking showing that an alarm exists and anyone has realized it. If the Ack (acknowledge button) is pressed the light will be fixed as it would be known so, on security aspects, less critical.

If it is wanted to know more information about a particular element, Air conditioner or UPS, it could be clicked on it or accessed by the guide bar to it. That click will get us into the pages previously described.

3.2   Electric Project

The electric project objective is to manage and control the energy source of the building. Be aware of the alarms and obtain information from the supply energy elements.

The main component of the electric project is the Medium voltage cabin so the chapter will be divided in the following parts:

- **MV Cabin**

    - Medium Voltage
    - Low Voltage

The importance of this project is based on the necessity of having the power supply control, proper working conditions of the building and, in addition because of consumption efficiency control.

3.2.1   MV Cabin

The Medium Voltage Cabin (**MV Cabin**) is the place where is managed the building electric energy. The substation transforms voltage from medium to low, from 15.000V to 400V.

In the image 3.19 is described the spatial distribution of the cabin. It is possible to appreciate the components that make up it and, some specific information received from them. It will be explained throughout the chapter.

The MV Cabin project is divided in two logical parts, the **Medium Voltage** and the **Low Voltage** part. Furthermore, each part has been divided in the elements that make up it:

- Medium Voltage

    - Absorption reading
    - Temperature probe (NT965)
    - General Switch

- Low Voltage

Figure 3.19: Cabin Planimetry

- Multimeter
- UPS (Socorrittore)
- Earth Differential Relay (Dossena)
- Electric board
- General Alarms

Each block of the Cabin MV has got its own CPX (PLC Festo). The Low Voltage CPX is, a **CECC-D** model with ModBus TCP IP interface but the Medium Voltage CPX is a **CECC-S**, with serial connection, ModBus RTU, totally different of what has been seen until now.

Actually, the complexity of this chapter is overall involved into the connection network. There are four types of connection between the project elements: Modbus

TCP, Modbus RTU, Direct Digital Inputs or by Codesys.

  With the purpose of sum up and clarify the general terms, connection ways and relations that will be explained during this chapter has been design the diagram 3.20 which represents the connection network between the components of the MV Cabin project. It would be advisable to take a look of it before and during the reading.
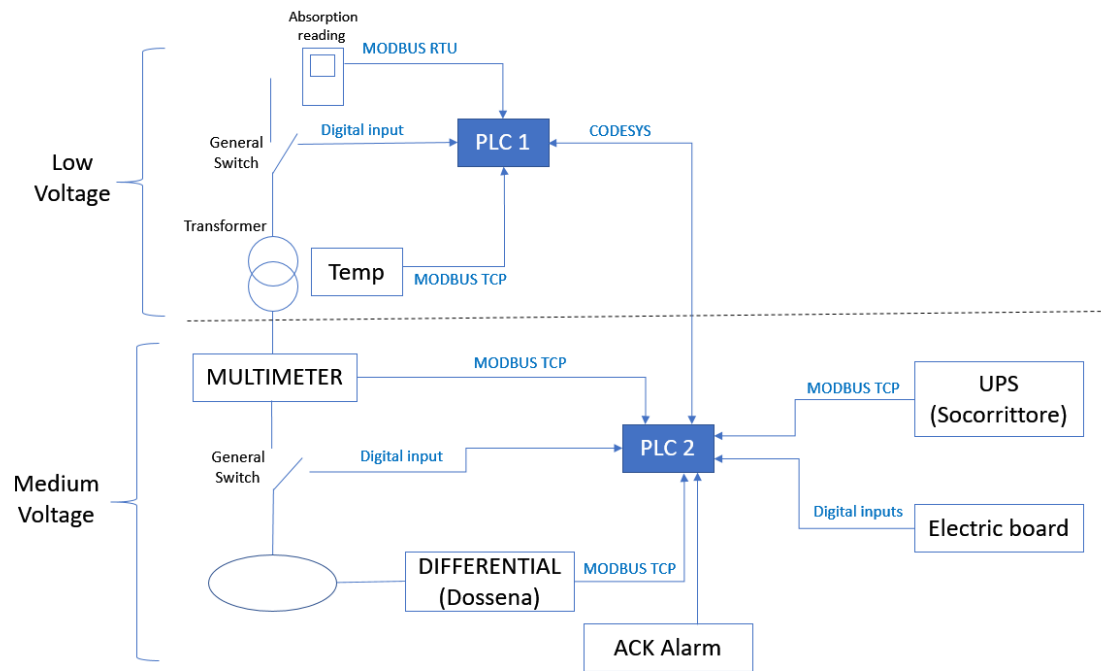
Figure 3.20: Cabin Cabin Network

Medium Voltage

The Medium Voltage section will be explained referring three principal aspects, first of all the absorption data reading and then the two main elements which compound this structure, the NT935 temperature probe and the general switch.

Absorption Reading

The main objective of this module is to obtain four data, the three absorption intensities and the dispersion intensity form the cabin. It seems a simple collect process but it is not due to the Power System-PLC communication.

This reading has been different from every reading done previously as this connection has been done by **RS-485 serial MODBUS RTU** communication. As it has been seen in the introduction chapter **Communication Protocols**, introduction to MODBUS protocols, MODBUS RTU messages are a simple 16-bit CRC (Cyclic-Redundant Checksum).

The process to be followed is to send a message encoded in 16 bits, asking for the information you need. As answer, it will be received another coded message in which the requested information is included.
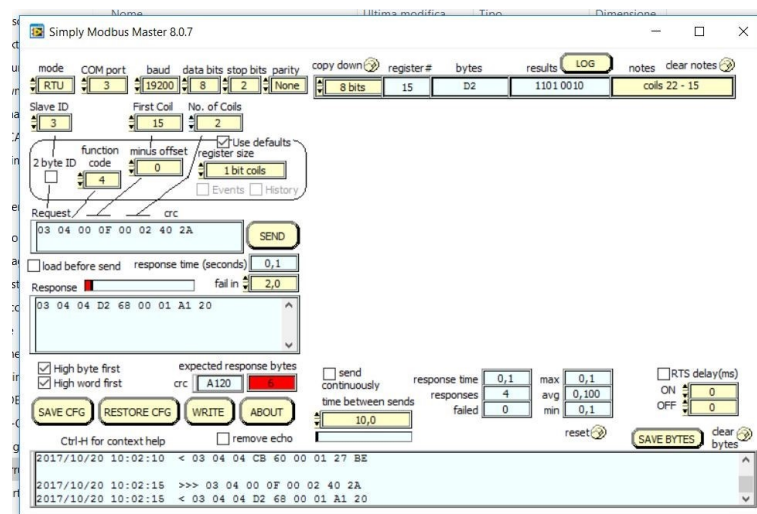
Figure 3.21: Simply Modbus Master

In order to test our encrypted code and our device, in this case a Thytronic element, it has been used the program **Simply Modbus Master**. As it could be

seen in the picture 3.21, the program it simulates a Master Modbus so, this program will be directly connected with the device. It checks if the sent messages had been correctly written and it receives directly the data request.

But then, it is compulsory to use our programming mode by Codesys where the reading is not so easy.

First of all, it has to be extracted from the device the way of communication, the messages that has to be sent to receive the required information. In the picture 3.22, it could be seen a summary of the applied reading method where the information we are interested in is highlighted, taken from the Thytronic Manual [8].
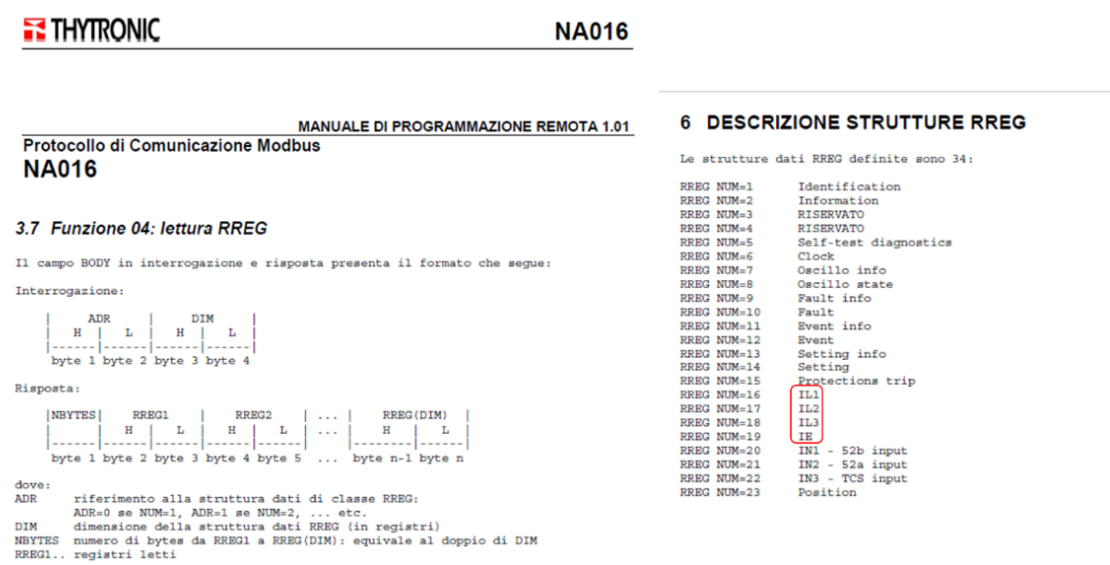
Figure 3.22: Manual Cabin

We want to receive four element information but the Modbus RTU connection gives only one each time. That is why has been created a structure which sends every second, measured by a timer, a different message asking for the different variables.

On the screenshot 3.23, it is possible to see the used reading structure. If the reader pays attention could see that the sent message corresponds with what has been depicted in the previous manual.

The final objective is to realize if the absorption and dispersion intensity values exceed the threshold values that has been created to protect the infrastructure. So, has been created general alarms that will notify warning situations.

```
//****************** Comandi Lettura ******************//   Quando si attiva il timer il contattore incrementa, entrando in ogni numeri pari a scrivere, negli dispari a leggere.
IF T1.Q = TRUE THEN                                 //    (0: Scrittura IL1, 2: Scrittura IL2, 4: Scrittura IL3, 6: Scrittura IE, 8: Scrittura IL1)
    CASE cnt OF                                      //    (1: Lettura IL1, 3: Lettura IL2, 5: Lettura IL3, 7: Lettura IE)
        0:
        OpenCom :=TRUE;
        WriteCom := TRUE;
        sHoScritto[1]:=16#03;        // ADDR
        sHoScritto[2]:=16#04;        // FUNZIONE SRITTURA
        sHoScritto[3]:=16#00;        // BODY: 2 bit ADR -> NUM-1
        sHoScritto[4]:=16#0F;
        sHoScritto[5]:=16#00;        // BODY: 2 bit DIM -> Dimensione
        sHoScritto[6]:=16#02;
        sHoScritto[7]:=16#40;        // CRCH
        sHoScritto[8]:=16#2A;        // CRCL
        1:
        ReadCom := TRUE;
        2:
        IL1 :=  (sHoLetto[4]*16+sHoLetto[5])*1.73205/1000;        //Radice quadrata 3 = 1.73205
        WriteCom := TRUE;
        sHoScritto[1]:=16#03;        // ADDR
        sHoScritto[2]:=16#04;        // FUNZIONE SRITTURA
        sHoScritto[3]:=16#00;        // BODY: 2 bit ADR -> NUM-1
        sHoScritto[4]:=16#10;
        sHoScritto[5]:=16#00;        // BODY: 2 bit DIM -> Dimensione
        sHoScritto[6]:=16#02;
        sHoScritto[7]:=16#71;        // CRCH
        sHoScritto[8]:=16#EC;        // CRCL
        3:
        ReadCom := TRUE;
        4:
        IL2 :=  (sHoLetto[4]*16+sHoLetto[5])*1.73205/1000;
        WriteCom := TRUE;
        sHoScritto[1]:=16#03;        // ADDR
        sHoScritto[2]:=16#04;        // FUNZIONE SRITTURA
        sHoScritto[3]:=16#00;        // BODY: 2 bit ADR -> NUM-1
        sHoScritto[4]:=16#11;
```

Figure 3.23: Codesys Cabin

Temperature probe: NT935

The NT935 is an electronic microprocessor specifically designed for transformers. It is a temperature monitoring unit for transformers, but thanks to the communication system it provides the possibility to check the state of the relays which notifies alarms.

The connection to the Medium voltage PLC has been done via ModBus TCP Master-Slave.

Figure 3.24: NT935

In this case, the interesting data received from the NT935 is:

- Temperature from each transformer module

- Alarms

    - Temperature sensor breaking
    - Temperature limits reached

Furthermore, it is important the reset command in case of device problem.

So finally, as in the Air Conditioner in the Network project, the data is received from the ModBus TCP, in this case provided by the temperature probe NT935. Searching on the instruction manual it has been found the Modbus Mapping Table where it has been searched the required data [10].

In the image 3.25 it has been highlighted three of the four temperature channels. The rest data will be searched in an equivalent way.

The read and the written data are assigned to different variables that will be logically treated to obtain the searched results. Image 3.26

MODBUS MAPPING TABLE

TEMPERATURES channels 1÷4:

Address LO (10)	Data HI	Data LO	Note 1	Note 2	R: read W:write RW: read/write
25	2'compl. sign	2'compl. Ch1 temper.	−10°C ÷ 240°C −48°C÷200°C (*)		R
26	2'compl. sign	2'compl. Ch1 max temperat.	0°C ÷ 240°C 0°C÷200°C (*)		R
27	2'compl. sign	2'compl. Ch1 temper. alarm set point	1°C ÷ 240°C 1°C÷200°C (*)	(AL)	RW
28	2'compl. sign	2'compl. Ch1 temper. trip set point	1°C ÷ 240°C 1°C÷200°C (*)	(TRP)	RW
29	2'compl. sign	2'compl. Ch2 temper.	−10°C ÷ 240°C −48°C÷200°C (*)		R
30	2'compl. sign	2'compl. Ch2 max temperat.	0°C÷ 240°C 0°C÷200°C (*)		R
31	2'compl. sign	2'compl. Ch2 temper. alarm set point	1°C ÷ 240°C 1°C÷200°C (*)	As (AL)	R
32	2'compl. sign	2'compl. Ch2 temper. trip set point	1°C ÷ 240°C 1°C÷200°C (*)	As (TRP)	R
33	2'compl. sign	2'compl. Ch3 temper.	−10°C ÷ 240°C −48°C÷200°C (*)		R
34	2'compl. sign	2'compl. Ch3 max temperat.	0°C ÷ 240°C 0°C÷200°C (*)		R

Figure 3.25: Manual NT935

```
//Ingressi MODBUS
    InTemperature_1        AT  %IW5  : INT;
    InTemperature_2        AT  %IW9  : INT;
    InTemperature_3        AT  %IW13 : INT;

    InRelay_Fault          AT  %IX42.4 :BOOL;      // Breaking of a temperature sensor mounted on the machine
    InRelay_Trip           AT  %IX42.3 :BOOL;      // switch only when the set temperature limits are reached
    InRelay_Alarm          AT  %IX42.2 :BOOL;      // switch only when the set temperature limits are reached after 5 sec

//Uscite MODBUS
    OutReset_Reg_CPU_ERROR  AT  %QX2.2  :BOOL;
    OutReset_Storico        AT  %QX2.1  :BOOL;

//Gestione allarmi Multimetro//
    ALL_NT935: SB_Alarm_Zone;
```

Figure 3.26: Codesys NT935

General Switch

The general switch is the protection element which controls the input electricity of the building. Into the Festo building cabin has been used an ABB general switch. It is connected to the Master MODBUS PLC directly by digital inputs.

The information able to collect will be the following:

- **Normally close switch state**: Normally close state of the general switch

- **Normally open switch state**: Normally open state of the general switch

- **Protection intervention**: it shows if a protection element has intervened

- **Anomaly in working process**: it represents if there have existed anomalies

- **Watch dog state**: it shows if the watchdog is active or not

There are two general switch state variables to double check the truthfulness of them. If they are not opposite, something strange is happening.

MV HMI Design

The picture 3.27 represent the HMI visual page of the Medium voltage page of the MV Cabin.

As it could be seen, it is divided in four sections, that correspond with the physical structure of the system. The first block corresponds with the cabin switch. It gives information about switch state:

- Open or closed

- Protection going off

- Emergency button pushed

- Unknown switch state

The three last messages, as it could be seen, only appear in alarm case, while the first message is always showing its state.
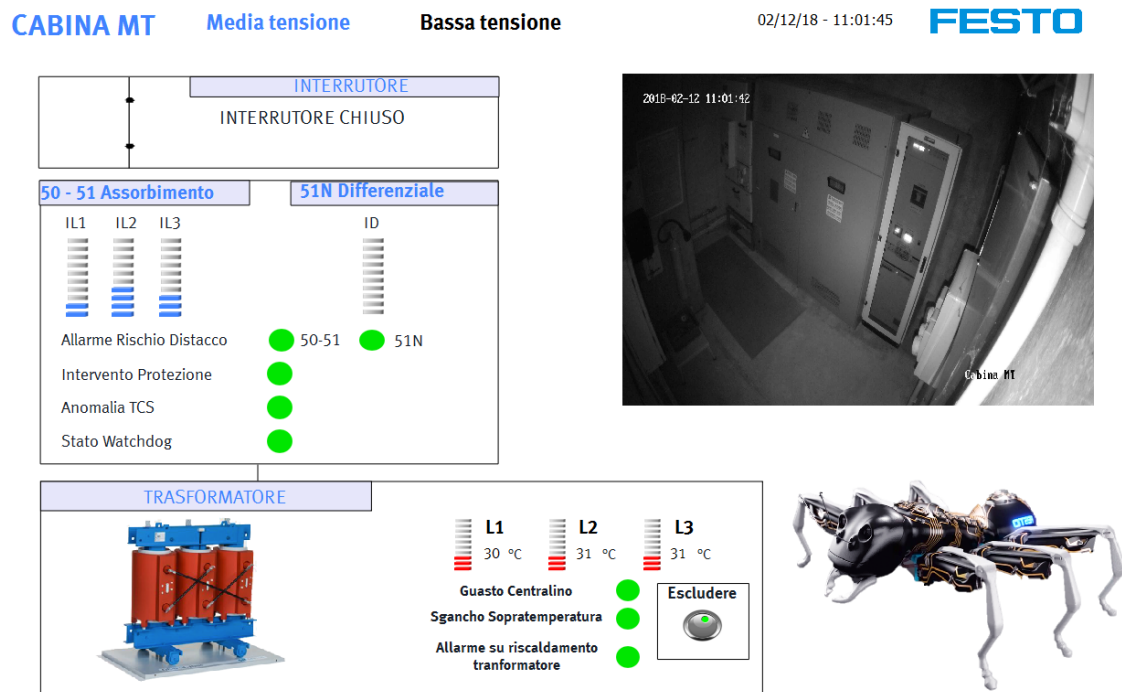
Figure 3.27: MV Interface

The second block gives us information about the absorbed intensity, the three phases intensity (50-51 Assorbimento) as well as the dispersion one (51N Differenziale). This information is represented in a bar having the top as a threshold. If the threshold is reached, the color bar would become red and an alarm would appear.

Finally, the last block shows the transformer state. The three bars represent each transformer temperature while, the three present alarms show:

- Switchboard failure
- Overtemperature dropped
- Transformer heating alarm

These three alarms could be excluded pushing the green button. If it is pushed, the green lights would become grey.

Low Voltage

The low voltage section is constituted by four different control devices, Multimeter, UPS, Earth differential Relay and Electric board. Each one of them will be explained and described.

Multimeter

The used Multimeter at the MV cabin is a Lovato Analyzer 3.28. The information given by the Multimeter will be the principal one about the building energy source. That collected information will be very useful to understand the energy efficiency of the building and furthermore to understand if the building is behaving normally or something is wrong working.

The Multimeter is able to send the information via ModBus TCP IP, making easy to obtain the data.

Figure 3.28: Multimeter

The multimeter collected information will be:

- Three lines Voltage

- Three lines Intensity

- Energy

- Power (active, reactive and apparent)

- Power factor

- Harmonic distortion

- Multimeter alarms

So, searching on the Lovato Multimeter datasheet, the following table, image 3.29 has been found, taken from the Lovato manual [9], where every shown data is important to our project.

Based on the information obtained has been created own logic alarms that notify warning states:

Indirizzo Address	WORDS	MISURA	MEASURE	UNITA' UNIT	FORMATO FORMAT	DMG 110 210	DMG 300	DMG 700	DMG 800	DMG 900	DMG 600 610
		MISURA ISTANTANEA (IN)	ISTANTANEOUS MEASURE (IN)								
0002H	2	Tensione di fase L1	L1 Phase Voltage	V/100	Unsigned long	•	•	•	•	•	•
0004H	2	Tensione di fase L2	L2 Phase Voltage	V/100	Unsigned long	•	•	•	•	•	•
0006H	2	Tensione di fase L3	L3 Phase Voltage	V/100	Unsigned long	•	•	•	•	•	•
006AH	2	Tensione Neutro-Terra	Neutral-Earth Voltage	V/100	Unsigned long					•	
0008H	2	Corrente di fase L1	L1 Current	A/10000	Unsigned long	•	•	•	•	•	•
000AH	2	Corrente di fase L2	L2 Current	A/10000	Unsigned long	•	•	•	•	•	•
000CH	2	Corrente di fase L3	L3 Current	A/10000	Unsigned long	•	•	•	•	•	•
0048H	2	Corrente di Neutro	Neutral Current	A/10000	Unsigned long					•	
000EH	2	Tensione L1-L2	L1-L2 Voltage	V/100	Unsigned long	•	•	•	•	•	•
0010H	2	Tensione L2-L3	L2-L3 Voltage	V/100	Unsigned long	•	•	•	•	•	•
0012H	2	Tensione L3-L1	L3-L1 Voltage	V/100	Unsigned long	•	•	•	•	•	•
0014H	2	Potenza Attiva L1	L1 Active Power	W/100 ❶	Signed long	•	•	•	•	•	•
0016H	2	Potenza Attiva L2	L2 Active Power	W/100 ❶	Signed long	•	•	•	•	•	•
0018H	2	Potenza Attiva L3	L3 Active Power	W/100 ❶	Signed long	•	•	•	•	•	•
001AH	2	Potenza Reattiva L1	L1 Reactive Power	Var/100 ❶	Signed long	•	•	•	•	•	•
001CH	2	Potenza Reattiva L2	L2 Reactive Power	Var/100 ❶	Signed long	•	•	•	•	•	•
001EH	2	Potenza Reattiva L3	L3 Reactive Power	Var/100 ❶	Signed long	•	•	•	•	•	•
0020H	2	Potenza Apparente L1	L1 Apparent Power	VA/100 ❶	Unsigned long	•	•	•	•	•	•
0022H	2	Potenza Apparente L2	L2 Apparent Power	VA/100 ❶	Unsigned long	•	•	•	•	•	•
0024H	2	Potenza Apparente L3	L3 Apparent Power	VA/100 ❶	Unsigned long	•	•	•	•	•	•
0026H	2	Fattore Di Potenza L1	L1 Power Factor	/10000	Signed long	•	•	•	•	•	•
0028H	2	Fattore Di Potenza L2	L2 Power Factor	/10000	Signed long	•	•	•	•	•	•
002AH	2	Fattore Di Potenza L3	L3 Power Factor	/10000	Signed long	•	•	•	•	•	•
002CH	2	CosPhi L1	L1 CosPhi	/10000	Signed long					•	
002EH	2	CosPhi L2	L2 CosPhi	/10000	Signed long					•	
0030H	2	CosPhi L3	L3 CosPhi	/10000	Signed long					•	

Figure 3.29: Multimeter Manual

- High Voltage: as a prevention system, has been included this alarm that shows if any line voltage exceeds the threshold value.

- Low Voltage: it shows if any line voltage is less the threshold value.

- High Intensity: if any line intensity exceeds the threshold value.

Finally, all this information received will be shown on the HMI, since it is the essential information to focus on as the system's normal functioning.

The general alarms, of course will be sent to the main alarm management program.

UPS(Socorritore)

The UPS called soccorritore, rescuer in Italian, is the UPS system of the Cabin. It uses the same function block than the UPS rack 3.1.2 commented in the previous chapter CED supervisor.

It will have the same components, the same information will be given, particularized clearly to this component.

Earth Differential Relay (Dossena)

The Earth differential relay that has been introduced into the cabin MT is the DER3 Dossena. It is perfectly designed in accordance with strict regulations (CEI EN 60947-2:2007 annex M ed.8 and IEC 60947-2:2006 annex M ed.4) satisfying a double need: safety of facility and service continuity of industrial production.

The main information collected from the earth differential relay is:

Figure 3.30: Dossena

- Toroid intensity

- Generic Relay Alarms

Furthermore, has been created a toroid intensity threshold to provide an alarm situation in case of limit current situation.

The specific alarms will be converted on a general one, which will be sent to the alarm manager program 3.2.1.

LV HMI Design

Finally, to clarify the important concepts of the Low Voltage chapter it is shown in the picture 3.31 the CDPX interface where it could be seen every single element explained previously.
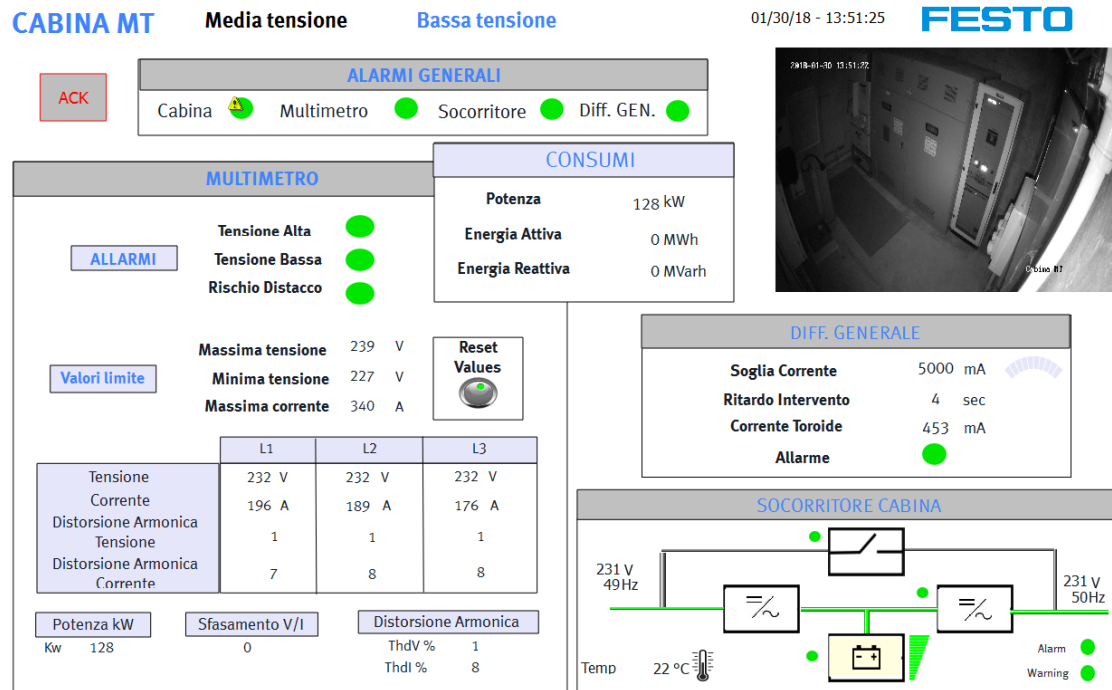
Figure 3.31: LV Interface

The page has been divided in five blocks.

- The first block represents the general alarms. As it has been described in the previous subchapters, each element sends its own state by global variable, making easy to collect them and show it as a changing color led. This alarms has been defined as hmi Enable Allarmi so, pushing on the own alarm, it could be disabled.

- The second block, Multimeter, describes every collected information, device alarms and electric absorbed values as voltage, intensity, and harmonic distortion of each line. Furthermore, it has been included three extra data, the

maximum and minimum voltage and intensity reached. These values could be reset simply pushing the Reset Values button.

- The third block, earth differential relay gives four data, the intensity threshold with the percentage reached, shown by the color bar, the existing delay, the toroid intensity and the device alarm.

- The fourth block, Socorritore shows, as it has been shown at UPS Rack 3.1.2, every property, alarm or malfunction of the UPS devices.

- Finally, the last block corresponds with the energy consumption. This block gives the energy information of the building. That data is of importance on Festos building management because it is directly corresponded with the building energy efficiency. This data will be daily collected to be studied in a future step.

Cabin General Alarms

The general alarms sent from every component that make up the Cabin will be managed in this program.

- DOSSENA
- MULTIMETER
- SOCCORRITORE
- NT935
- GENERAL CABIN

This alarms have been included as SB Alarm Zone so, as its definition says, if an alarm occurs, the general alarm light would blink but if the acknowledge button is pushed, the light would become fixed.

This light in not only seen on the HMI device but also as a physical alarm light connected of course to the CPX digital output port.

3.3   Air Compressed Circuit

The air compressed circuit aims to supply compressed air to the complete building. The compressed air is really important on Festos building because pneumatic tests are done every day.

The air compressed circuit project has been divided in three sections

- Circuit devices management and alarm control.
- Energy efficiency
- Building air distribution.

3.3.1   Circuit devices management and alarm control

In order to give a better explanation about the circuit structure, it is shown in the next picture how the air compressed circuit is.
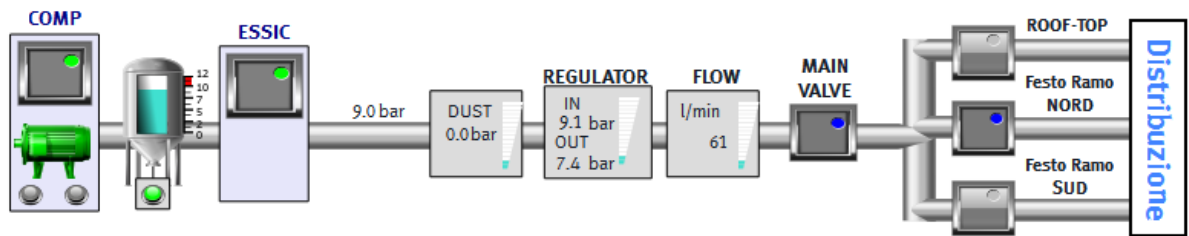
Figure 3.32: Air Compressed Circuit

As it could be seen in the picture 3.32 the circuit is composed by:

- **Compressor**: it gives the requested fluid pression to the air compressed circuit.
- **Tank**: it accumulates the compressed air giving information about the pressure of the system.
- **Dehydrator**: it dries the air. This fluid property is essential to the fluid transport and the useful components life.
- **Filter**: It cleans the air and gives information about how dirty it is, alarming when it has to be cleaned.

- **Regulator**: it gives general information about the circuit pressure

- **Valves**: Open or close the different flow ways.

The air compressed circuit program lets the manager choose between manual or automatic control.

On the one hand, on the manual control, the manager could open and close the valves and turn on or off the main elements, compressor and dehydrator.

On the other hand, the automatic control lets the circuit works automatically:

At eight oclock am, every working day, the compressor and the dehydrator turn on. When the air pressure achieves the 7,5 bars, the main valve turns on, turning on the rest of the valves when the air pressure circuit achieves the 6 bars. Although the automatic control is chosen, every valve could be manually turns on/off by the manager.

At six pm, the circuit turns off automatically.

The alarms management is like the other project systems. In this case gives information about:

- **Compressor fault**

- **Tank automatic exhaust**

- **Serious pressure loss**: , it will be logically programmed as a high-pressure difference between parts of the pressured air circuit.

- **Dirty filter**: managed also logically by threshold reached of pressure difference between filter input and output.

Also, it has been measured some analogic data:

- **Pressure** : tank, before and after filter, before and after regulator pressure,

- **Air flow**: measured just before the valves.

These data have been directly connected to PLC inputs. In this case it has been not necessary any communication protocol to transmit the information, everything has been done via physical connection.

3.3.2   Energy Efficiency

Thanks to the air pressure circuit collected data it has been possible to calculate:

- Air Consumption

- Energy compressor consumption

- Working time

- Number of compressor turn on/off

Thanks to the air flow data received by the CPX, it has been programmed the diary building air consumption. It has been calculated each minute the air flow average l/min so, as a result, we have obtained liters in one minute. It has been passed to cubic meters and each minute this value will be raised.

It has also been measured the circuit active time and the compressor working time. It has been done by incremental counter of 10 seconds TON timers. The next scheme would represent its working mode.
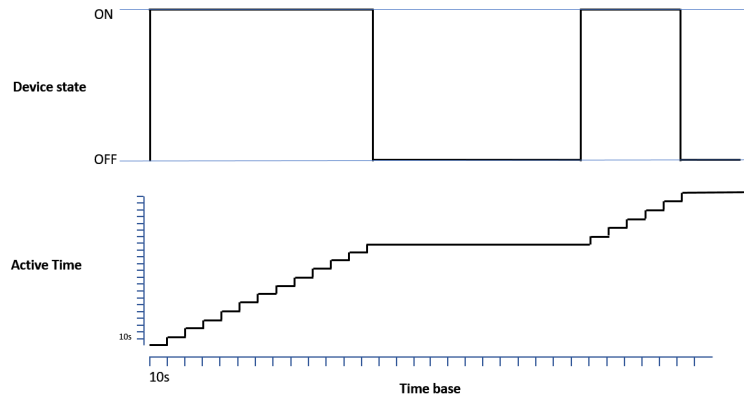

Figure 3.33: Time Calculation

And finally, it has been calculated the compressor energy consumption. The received data is the compressor intensity supply so, first of all it should be calculated the power supply. Assuming that the supply voltage is 400V and cos(phy)=0,8:

$$P = V * I * cos(phy) * 3$$

In order to calculate the energy consumption, it has been measured the power average per minute. If that average power is divided by 60 min/h and by 1000 W/kW it is obtained the energy consumption E [kW*h]

The number of activation of the compressor daily has been developed by flags use.

The purpose of the collection of this data is the energy saving. It was thought that the compressor used is too big and too powerful respect to what it is needed. So, it was thought to change it for a smaller one. Thanks to the collection of this data has been analyzed that it would be cost-effective to change it to a new smaller one so probably, it will be changed in the next months.

In the following picture 3.34, it could be seen how the HMI page has been designed.
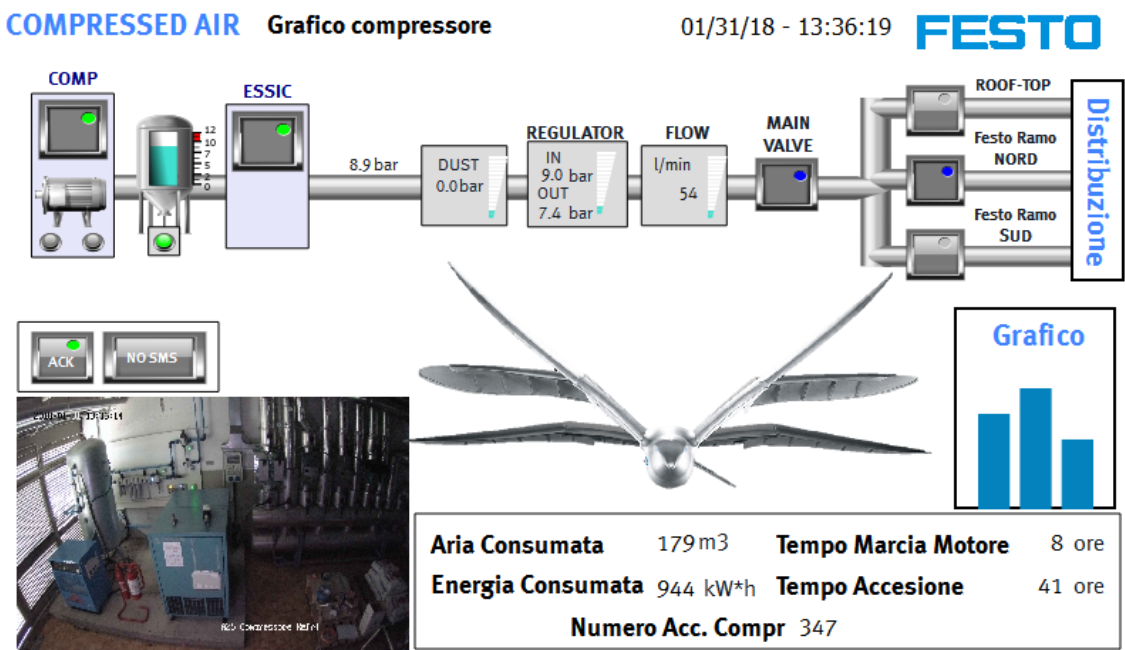

Figure 3.34: Interface Air Compressed Circuit

The screenshot shows how the circuit could be managed. Pushing each one of the buttons, it would be activated the compressor, dehydrator in the first two cases and in the fourth right cases would be opened the precise valves. The lights inside the buttons show the feedback from the elements, highlighting if everything is ok.

There are some pressure and flow data on the circuit indicating the current values, it is useful to obtain a great control and also helps to see if the circuit is working properly.

Finally, there are two more buttons: **ACK** and **NO SMS**, these buttons are related with the alarm system. The first one sends the acknowledge message, reducing gravity to the alarm situation. The NO SMS button block the SMS signal to be active on alarm case.

3.3.3 Building air distribution

Finally, it must be mentioned that has been thought, designed and finally installed a new pressured air distribution inside the building due to air connectivity problems. On the initial case, the compressed air circuit was distributed in only one distribution line. By this way, if a problem appears on the line, the following rooms would be last without air.

On the new contemplate idea, there are two distribution lines, the north and south line, every room is connected to both lines. Working by this way, in case of a circuit problem, a room could be always connected to the other line.

This configuration is only accessible to technical people so, it has been created a hidden button with a password to configure it. This page is shown in the next picture.
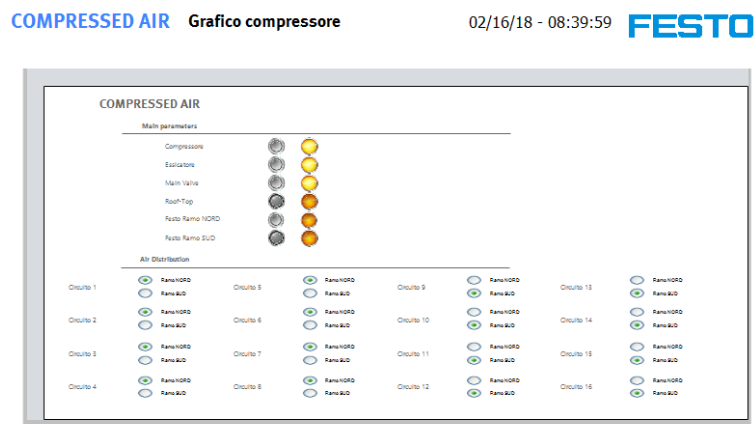

Figure 3.35: VISU compressor 1

As it could be seen, the shown page has been designed in a different way. It has been design directly from Codesys, called WebVISU page. The advantage of this design way is that it is running directly within the PLC, it gives a faster access and control to the main program. The disadvantage is that it is not as beautiful and easy designing as Designer Studio.
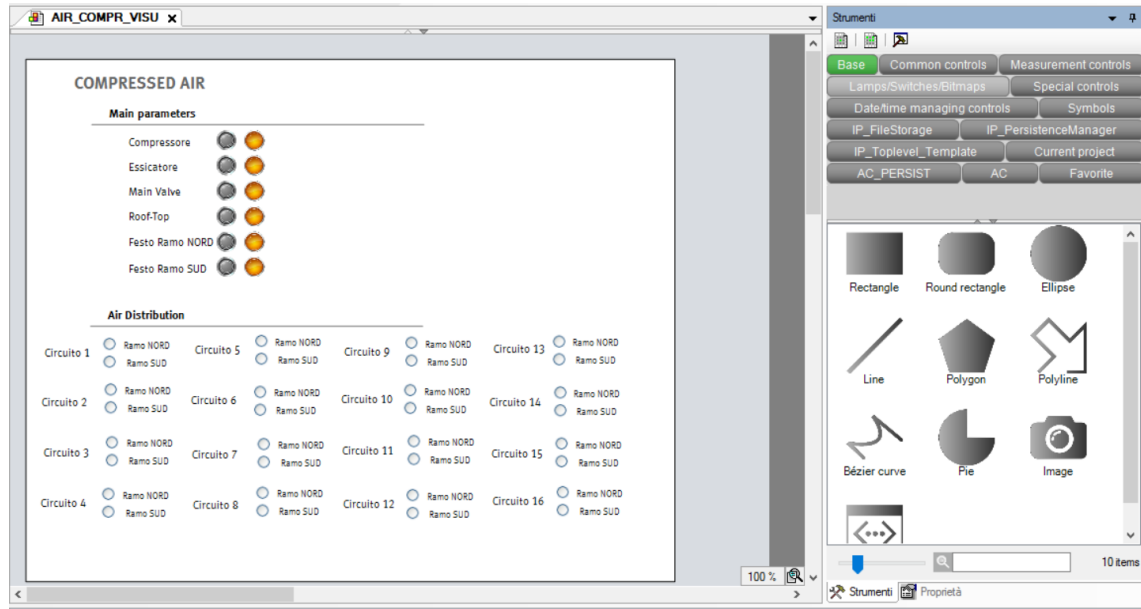

Figure 3.36: VISU compressor 2

Finally, it has been designed a page to control the access of the compressed air circuit to every room. It gives the control, opening and closing the valves, and the feedback of the air compressed achievement with four states, not in pressure, loading, alarm and in pressure.

The followed logic used on the programming phase would bethe one shown on the table 3.37.

IN – COMMANDO VALVOLA	OUT – VALVE FEEDBACK	STATE – CIRCUIT STATE
0	0	0 – Circuit non on pressure
1	1	1 – Circuit on pressure
1	0	2 – Circuito in carica
0	1 – Delay 5 Minutes	3 – Guasto Perdita
1	0 – Delay 60 Seconds	3 – Guasto Perdita

Figure 3.37: Circuit Air Distribution Table

The picture 3.38, shows the designed interface to the Air Distribution circuit

where it could be seen sixteen switches, one by each circuit that will command from the HMI the opening or closing of the circuit valves.
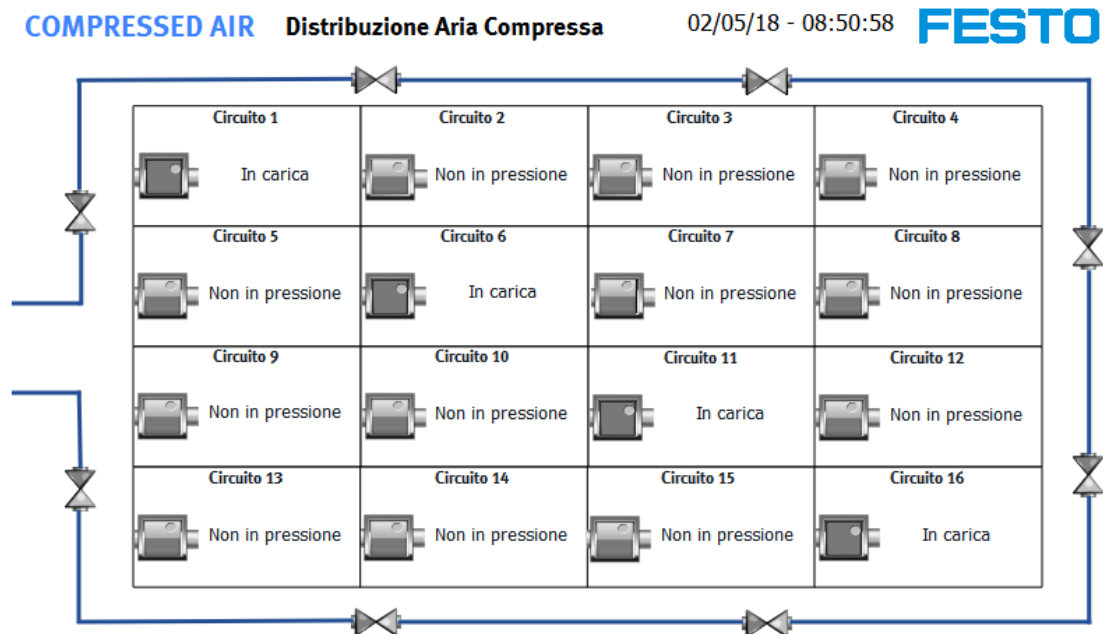

Figure 3.38: Circuit Air Distribution

In conclusion, it is a complete system. Complex inside but really easy to use. It has been used since it has been finished by the maintenance operator giving always satisfactory results.

3.4 HVAC System

Heating, ventilation and air conditioning, HVAC. The HVAC goal is to provide thermal comfort and acceptable indoor air quality.

It is a complex system composed by many different field elements. In order to develop this project has been required a general knowledge about PID control, automation, thermodynamics and fluid dynamics.

The HVAC system will be explained through the following modules:

- **Hydraulic Plant**
- **Cooling Plant**
- **Thermic Plant**
- **Fan-coil Circuit**

And finally, the singular HVAC main elements:

- **Boiler**
- **CLIVET**
- **BROAD**
- **Air Handling Unit (AHU)**

In order to obtain a schematic view of the HVAC system, has been design the diagram 3.39:
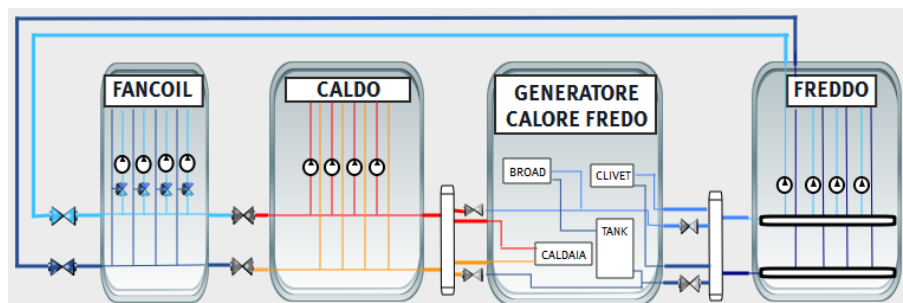

Figure 3.39: General HVAC Diagram

In the next subchapters, it will be explained each of the implied elements.

3.4.1 Hydraulic Plant

The hydraulic plant is the most complex of this project. It is composed by many control elements whose logic implementation is a sort of sensor and regulate combination. The system objective is to distribute warm water throughout every single potable water pipe inside the building. The following image 3.40 shows the distribution of the plant, both real and schematic view.
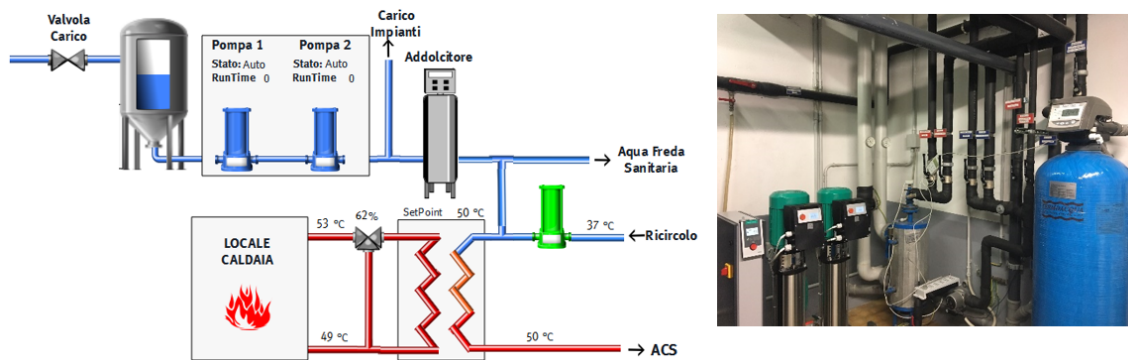

Figure 3.40: Hydraulic System

The control elements of the hydraulic plant are, **Water Loading valve, Tank, Two tank pumps, Heat exchanger valve, Recirculation pump**

The chapter will be divided in the three main control systems which will be:

- Water Tank level control

- Water temperature control

- Advance settings

Water Tank level control

The water level on the tank is controlled by two water level sensors and a water loading valve as actuator. The reading of the sensors and also the writing signal of the valve are directly electrical connections with digital signals on the CPX.

The two sensors have been introduced into the tank, the first one on the upper part of the tank and the other one on the middle of the tank. The control is, when the water reaches the top sensor, the valve should be closed until the water level was lower than the middle sensor. In that moment, the valve must open.

Figure 3.41: Water Level Sensor

On the next graph, image 3.42, it could be seen the real behavior of the water level tank system.
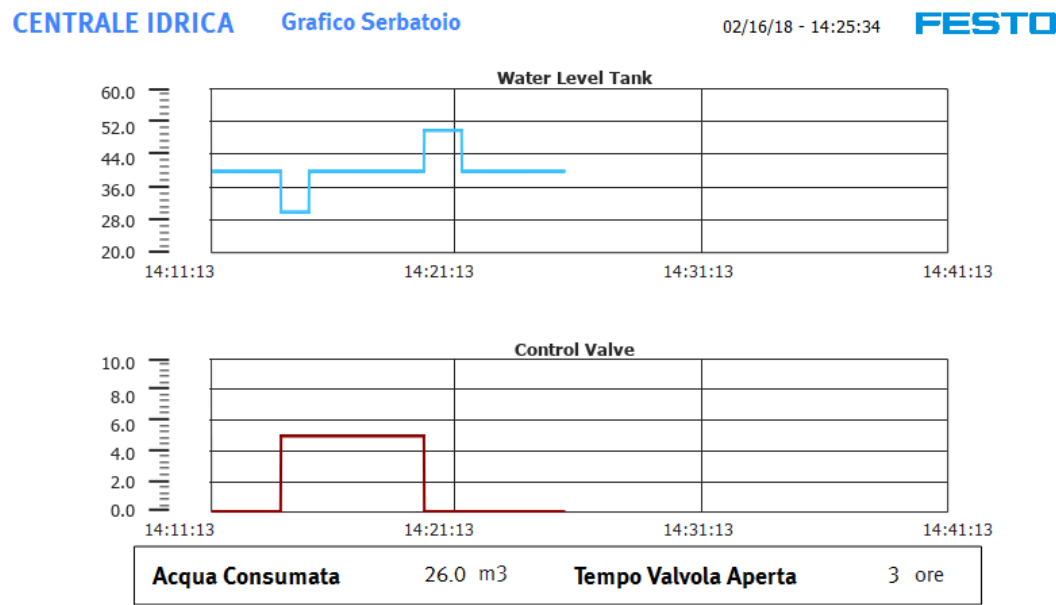

Figure 3.42: Water Level Diagram

Knowing that the tank capacity is 2000 liters, and that the middle sensor is situated just on the middle of the tank, each time that the valve is activated, the water consumption is 1000 liters. So, counting the number of rising edge signal of the valve, it has been calculated the number of liters spent each day by the company.

$$WaterConsumption = 1000 * RisingEdges$$

This number allows the company to know the daily sanitary water consumption.

Water temperature control

As it has been said, the hydraulic plant objective is to distribute warm water throughout every single potable water pipe inside the building. There are three different water circuits: The Hot water circuit, the Sent water circuit and finally the Return water circuit.

The sent water temperature into the pipes is managed by the con-

Figure 3.43: Hydraulic Plant Scheme

trol valve introduced into the hot water circuit. The more open the valve is, the hotter water will pass into the first circuit and the higher temperature will be reached into the Sent water circuit.

With the aim of obtaining an autonomous control of the temperature, it has been introduced a PID control system to obtain the required temperature into the tap.

Finally, the objective of the last circuit, the Return water circuit, is to distribute hot water into the pipes in order to obtain in a faster way the hot temperature when the tap is open, not having to travel so long distances.

This last circuit will be useful during the working time so, in order to save energy, the pump will be active from 7:00 to 20:00 into the working days. Of course, this particular schedule could be modified actuating as an administrator on the HMI.

Furthermore, it is important to mention the legionella cleaning. The genus **Le-**
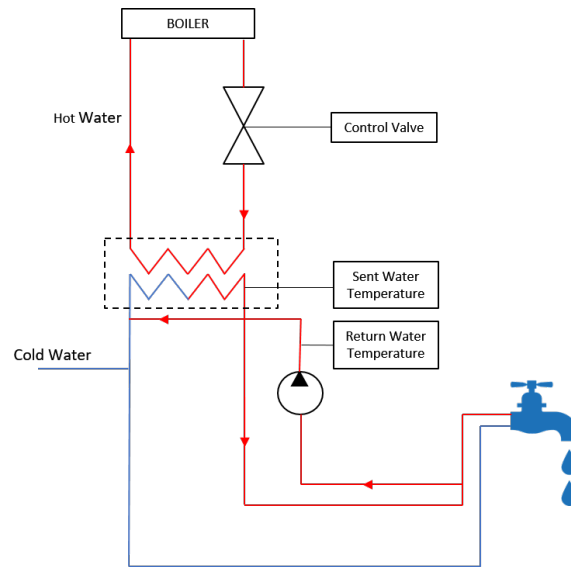
gionellais a bacterium that causes legionellosis, a pneumonia-type and mild flu-like illness. It is common in aquatic systems as the hydroelectric plant witch it is been talking about. The easier mode to destroy this bacterium is to raise the temperature more than 51 °C once a week. This destroying process has been also automated into the hydroelectric plant project.

In the picture 3.44 is shown how has been programmed in a schematic mode the hydroelectric plant control project. That programming mode is called **CFC (Continuous Function Chart)** and it is a schematic and more visual way of programming.
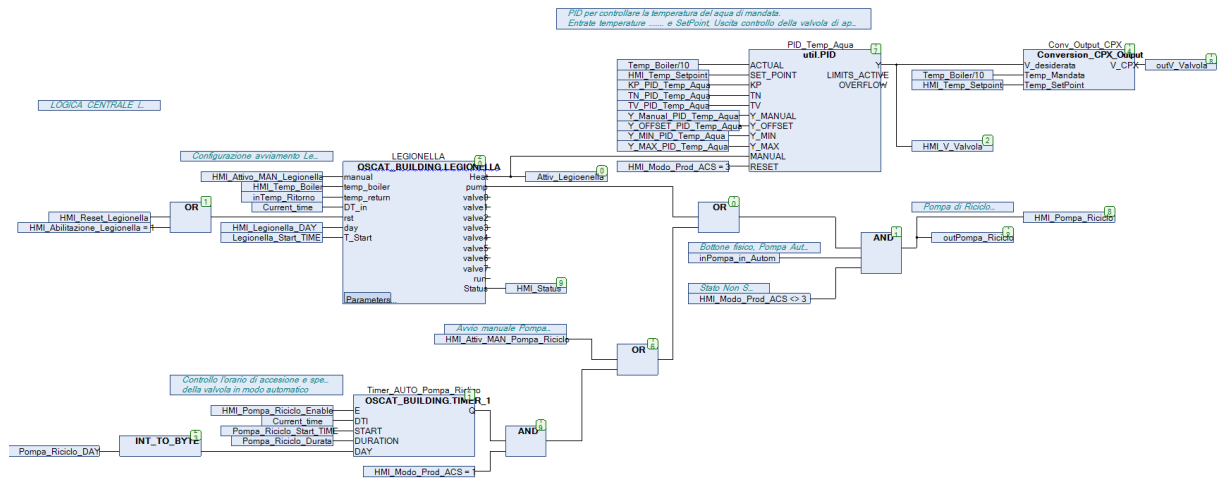

Figure 3.44: Hydraulic Plant CFC

The program is composed by three main blocks:

- **Automatic working schedule**: Where it is determined the working cycles.

- **Water temperature PID**: Where it is managed the control part of the system.

- **Legionella block**: Where the parameters of the disinfection process are located.

The physical system has been analyzed and it has been implemented a reference theoretical PID controller.

The project, hydraulic plant, has been tested using a Festo CPX composed by both digital and analog modules. In the next pictures 3.45, could be realized that the system has been tested in two different environments, firstly on table test and then in situ.

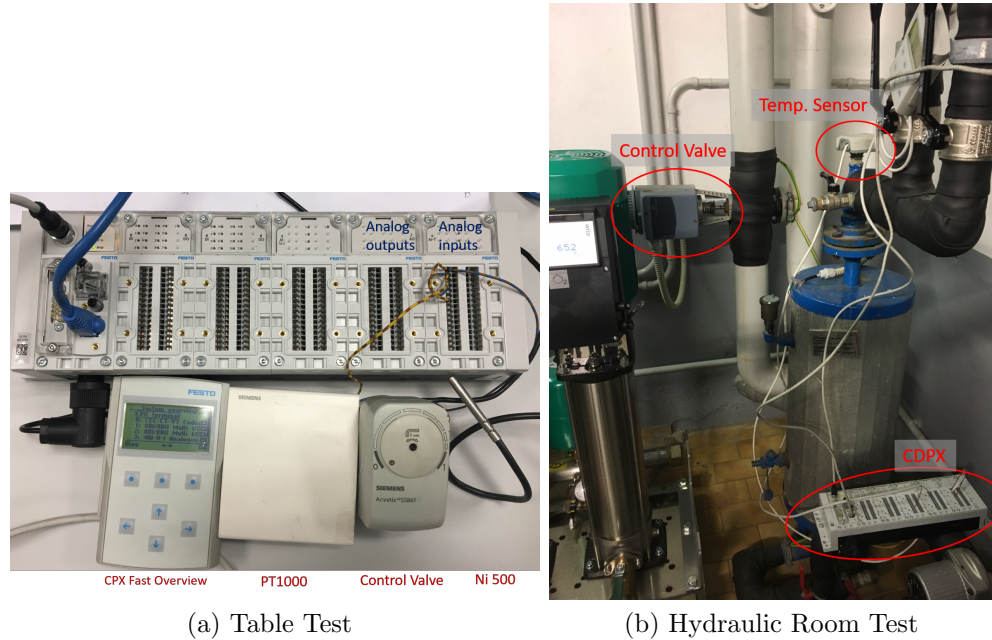(a) Table Test (b) Hydraulic Room Test

Figure 3.45: Hydraulic Plant Tests

As the theoretical formulas of the system were not accurate, the results were not entirely successful. To solve this problem, the PID values were adjusted manually by testing.

The final results are shown in the graphs 3.46 and 3.47

These graphs show the behavior of the system in a set point temperature change from 50 to 30 degrees. The blue line from the first circuit shows the set point while the green one shows the current temperature. As it could be seen, the set point temperatures are followed in an accurate way, it is not necessary to be a fast system since the set point will change only twice per day.

The second graph shows the valve behavior. The opening of the valve is controlled by the input voltage, being 0 Volts completely close and 10 Volts completely open.

Due to the data analysis, has been realized that the valve is sometimes blocked,
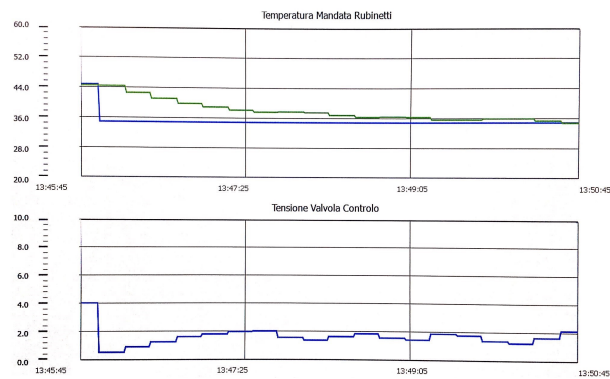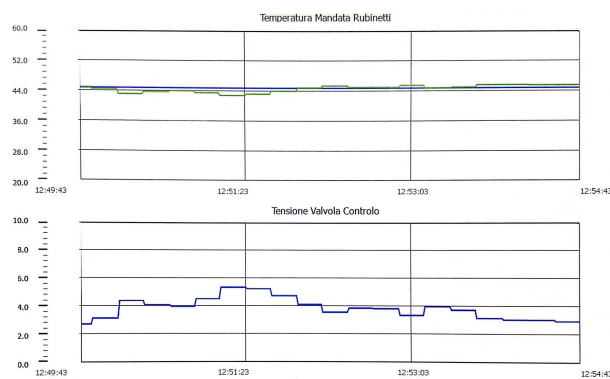
Figure 3.46: Step Graph

Figure 3.47: Continuous Graph

as it could be appreciated in the picture 3.48 To solve this problem, it has been developed an anti-block system. Whose function is to put a high voltage pulse into the valve in blocking case. Thanks to this action, as it is the system returns to the properly work condition when it realizes that the temperature difference increases endlessly.
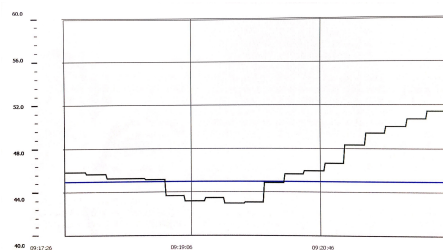

Figure 3.48: Blocking Graph

Advanced Settings

The advance settings page is accessible only to technical people. That page has been divided in two configuration parts, the ACS (acqua calda sanitaria), sanitary warm water and the legionella.

The sanitary water could be controlled automatically or manually, this parameter could only be changed going to a physical switch inside the Thermic Room. In the automatic choice, everything is controlled automatically, while the manual one is the security choice, giving fixed parameters that control the system correctly.

On the automatic way, it has been created schedule variables to change the temperature Set Point automatically during the day and the night. The temperature Set Point during the day has been stablished at 45 °C while during the night has been stablished at 30 °C. It is a process that allows the company to save an important amount of energy. Furthermore, only clicking on the set point number could be change on a easy way.

The legionella section gives the possibility to choose the precise moment of the week when the legionella desinfection starts or could be also manually activated.

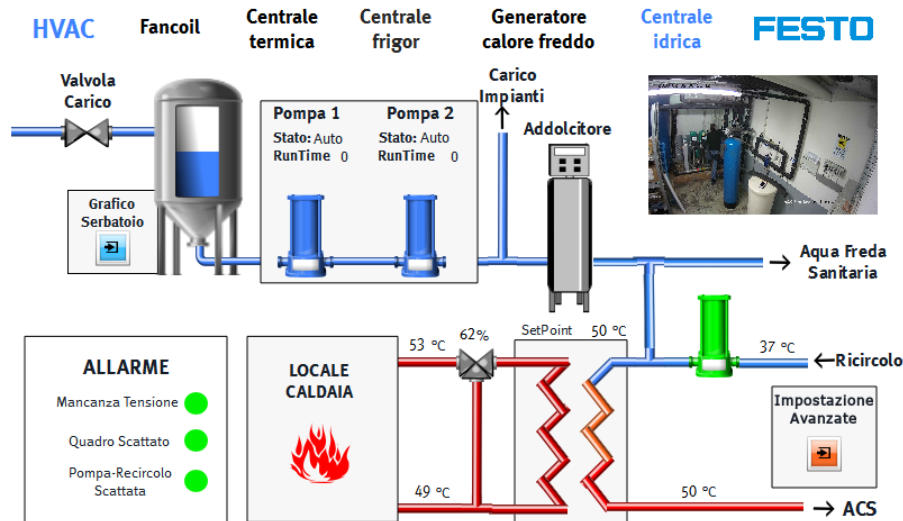Figure 3.49: Hydraulic Plant Advanced Settings

Design page

Figure 3.50: Interface Hydraulic System

The design page gives the information of every single element of the system, temperatures, pumps working state and mode, valves state.

It is also shown the general alarms included on this system that are referred to the distribution panel. The page, as it could be seen is connected to the specific pages and also to the other HVAC systems.

The last page to show on this plant is the VisuWeb page. It is a page designed to emergency cases, for example CDPX broken or impossible access. So, it is a more schematic page with the basic commands of the system.

That page, 3.51, as it has been explained in the previous chapter, AIRCOM-PRESSED is programmed directly from Codesys so, it accessible in a faster and easier way. That page could be seen from Codesys, charging the own program or directly form internet, knowing the PLC IP and the appropriate password.
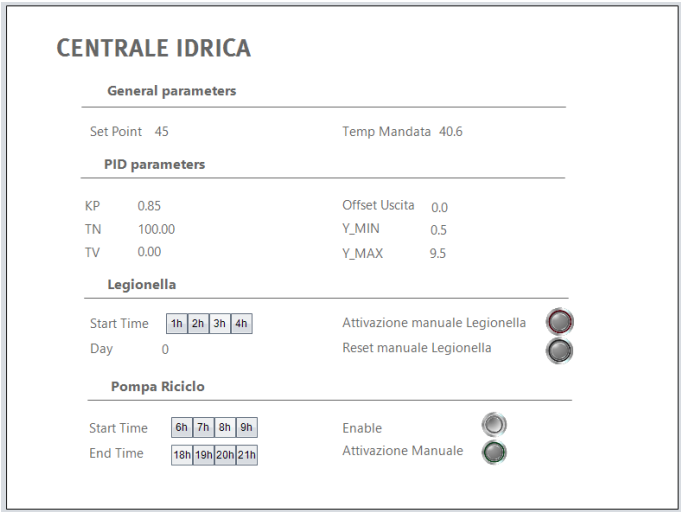
Figure 3.51: VISU Hydraulic System

3.4.2 Cooling Plant

The cooling plant is the one which distributes the cold water to the devices that need it, as it will be explained in the next chapters, the AHU and the fan-coil systems.

Inside this system, thanks to his own PLC, the temperature and the loading water will be controlled.

The main controlled devices are the four water pumps, three to the UTA system and the last to the Fan-Coil system. The pumps, on this project are everyone WILO brand so, this explanation will serve to understand every single pump used.

The information is sent and received by the WILO CANBus protocol [12], which includes:

Figure 3.52: Wilo Pump

- Reading Information

  - Pump State (Anomaly, Good working)
  - Input Power
  - Estimated pressure
  - Medium Temperature

- Writing information

  - Set Point
  - Control Mode (Speed, Frequency, Power, Flow, Pressure, Temperature)
  - Turn ON/OFF

This communication will be used to manage the activation/deactivation of the pumps, alarms provided by a wrong working condition and finally set working point and working mode conditions.

On the next images will be shown how the CAN Open works on Codesys.

ON the image 3.53 could be seen that there are many collected parameters. The three first are the written ones, Bus Set Point, where the set point is specified, Bus control Mode, where the control mode is written and finally Bus Command.

This last parameter, Bus command is the more important one. Inside this byte are included the ON/OFF pump parameter and also the enable bits. These parameters

Figure 3.53: CAN Open Cooling Plant

allow to write or not the rest of parameters, the Set Point, the Control Mode and also the ON/OFF command. In the picture 3.54 could be appreciate the activation of these two enable bits.

Figure 3.54: CAN Open Cooling Plant 2

The rest of important parameters are reading parameters so, it is only necessary to collect them with the proper bit or byte addresses.

Many problems have been found because of the CANBus communication protocol, specifically because of the Heartbeat mechanism. This mechanism allows the

network master to detect a loss of communication from the network slaves, and it also allows the network slaves to react a loss of communication from the master. This mechanism must be properly configured from the master and the slaves CANBus devices, as it is shown in the next picture 3.55.
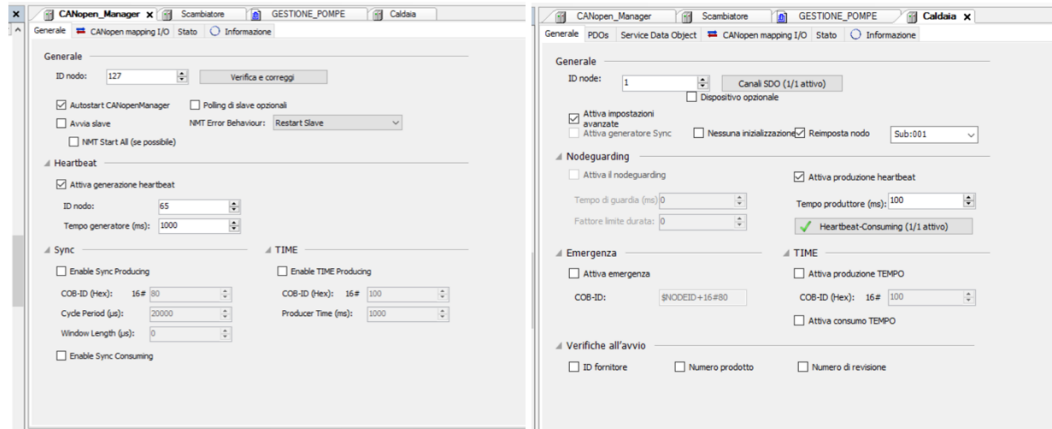
Figure 3.55: Heart Beat Configuration

Configuring well the previous characteristics, it was possible to see the response of the system when acting on the writing commands.

There are in total four different pumps on this cooling system. Each one of them work with independent parameters, in different systems. In particular, the fan-coil pump will depend on the fan-coil circuit which includes other four pumps. It will be explained on the next subchapter 3.4.3. The rest of the pumps will be controlled by different UTA systems, 3.4.8.

It has been created a function block on Codesys to manage the general characteristics of the pumps:

The left part of the block would be the inputs while the right part would be the outputs of the function block.

As it could be seen is important if the control is done in automatic or manual mode, if the pump is working or there are some problems and finally the commands that the user want to introduce.

The manual mode could be called security mode. It introduces fixed parameters which assure proper working on the pump.
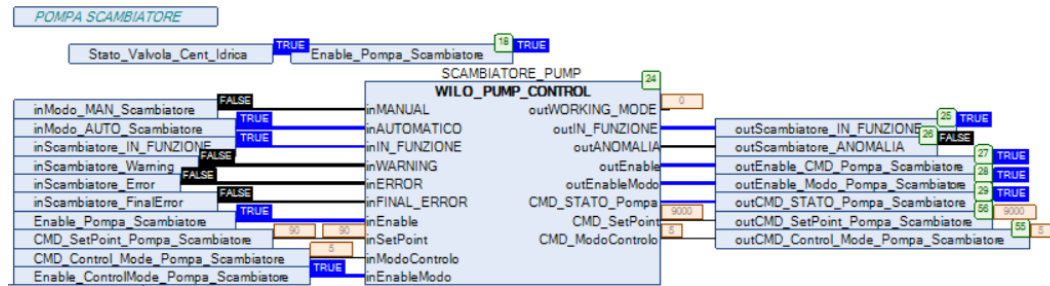
Figure 3.56: CodesysPump

On the other hand, the automatic mode introduced the parameters obtained from the system, set point and Control mode adjusted by the operator and the enable and ON/Off parameter will follow a logic independent form the other pumps, for example on the picture case, it would be only active in case that a valve from other connected system is open.

Figure 3.57: NI1000 Sensor

Finally, it is to say that the water temperature will be measured directly with the NI1000 sensors connected to the Festo CPX by analog reading connection.

HMI Design

The picture 3.58 shows the Cooling plant. As it could be seen, there are four schematic double pumps and its behavior, working or anomaly. That visualization gives us enough information to realize if an abnormal behavior of the pumps is happening.

Also, it could be seen every water pipe temperature on the plant with the going and return line.

As the pump management needs a technical intervention, the Set Point and mode selection is not visible from the main pages. That is why a hidden button with its appropriate password has been introduced on the page to control the Set Point parameter while the Working Mode has been set fix.

The page shown when the button is pressed is a VisuWeb where it could be seen and modified the Set Point Parameters.
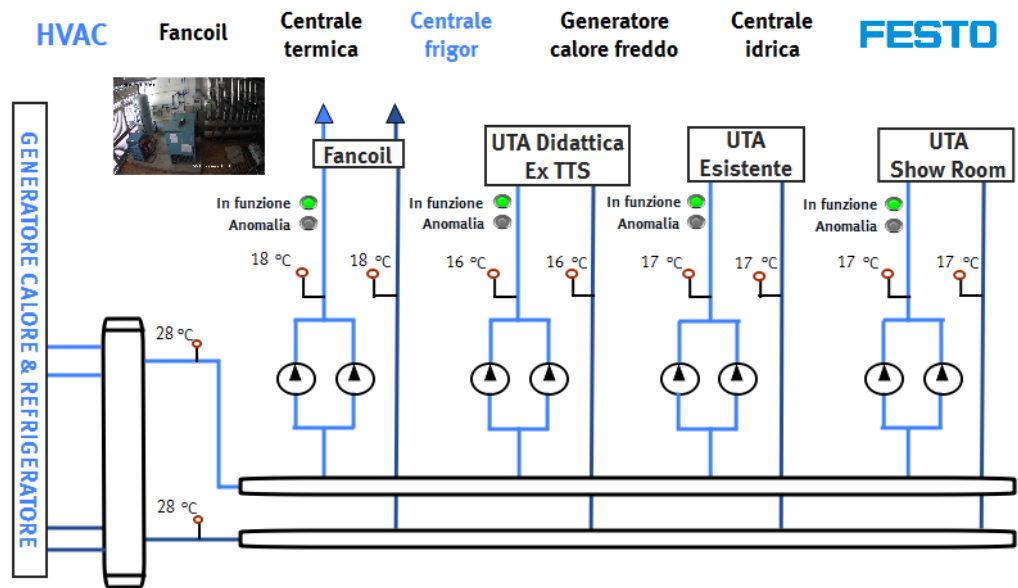
Figure 3.58: Interface Cooling Plant

Figure 3.59: VISU Cooling Plant

3.4.3 Fan-Coil Circuit

The fan-coil is a system which regulates the air temperature of the building, heating and cooling, depending on the season. On summer, the system has the mission of cooling the building so, it takes the water from the Refrigerating Plant. On the other hand, on winter, the water has to be taken from the thermic plant. On the left part of the image refHVAC it was seen how the water distribution is managed. The control of the season is manually controlled by physical control valves.

On the next image ref could be seen the structure of the Fan-coil circuit. There are four circuits, each one composed by a double pump and a mixing valve. The mixing valve is composed by two inputs and one output. It is possible to regulate the pump water temperature mixing the direct input and the recirculation one.
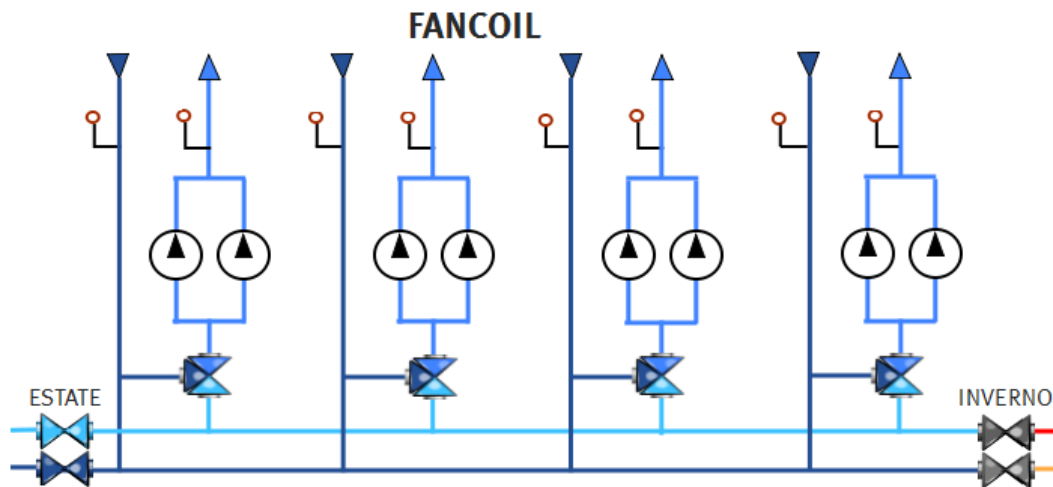
Figure 3.60: Fan-Coil Circuitt

However, to set the water temperature is not easy. It is compulsory to differentiate between season. In the next paragraph it will be explained each one of them:

- **Summer**: the water temperature on the summer season is based in the called, fix point control. That control consists on set a temperature set point and try to follow it with a simple PID control. The set point could be set directly form the HMI system. That set point is strictly followed during the working time. However, during the night, in order to save energy, that strict temperature is ten degrees decreased.

In the next picture, it is show the HMI interface of the summer season. As it could be seen, the activated valves are the left ones, putting inside the freezing water. The water temperature set point selection, as it is done by fix point control, it as been configured directly by the selection of the set point and the check button.
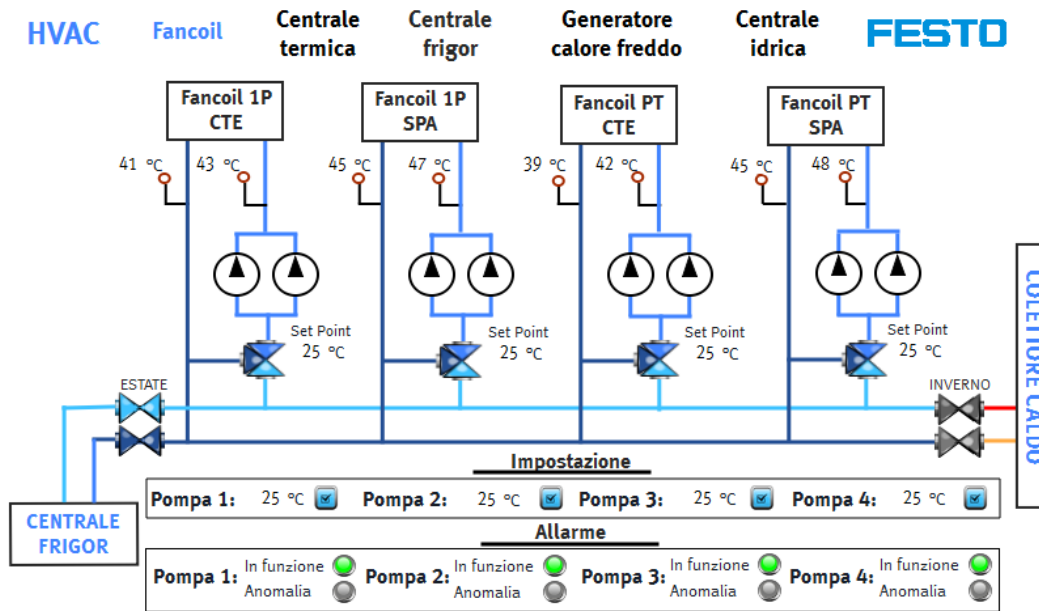
Figure 3.61: Summer Fan-Coil Circuit

- **Winter**: On the other hand, the temperature during the winter season is controlled by the called Climatic Curve. During this season, the climatic control system is the more efficient way of controlling temperature and offers the greater energy savings.

  The amount of heat required to maintain conditions of comfort in a room is linked to external temperature and a buildings heat loss. Heat requirements increase with decreasing external temperatures and increasing building heat loss. A climatic control system allows you to select a heating curve from among a set of curves, allowing the settings to be adjusted to the specific building. The next picture shows the used climatic curve. The horizontal scale sets the external temperature while the vertical left one is the water temperature result.
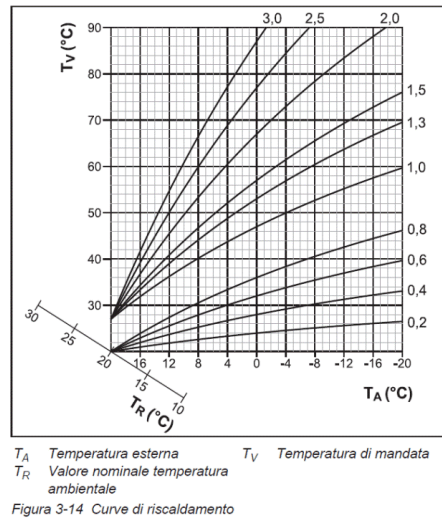
Figure 3.62: Climatic Curve

Once the heating curve has been set, the flow temperature to the system is regulated automatically according to external temperature, adjusting the heat input to the heat demand of the building and thereby ensure continued optimum comfort.

The next picture 3.64 shows how has been programmed by blocks using the OS-CAT BUILDING library. Introducing as inputs the external temperature and the internal one, with the convenient Kappa parameter, it calculates directly the winter set point that has to be introduced on the system.
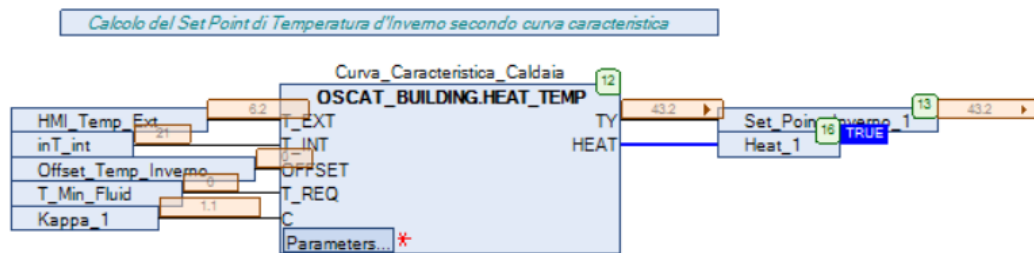
Figure 3.63: Codesys Winter SetPoint

The next picture reffig:WinterFanCoilCircuit describes how the HMI interface of the winter season has been designed. In that case the important parameter to set is the Kappa so, it is the parameter that could be modified in the HMI

interface.
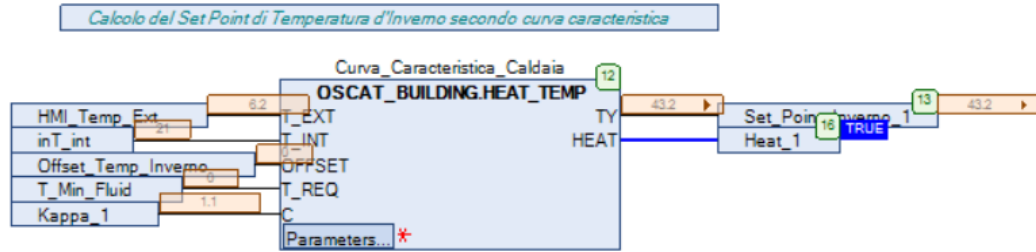
Figure 3.64: Codesys Winter SetPoint

Finally, when the set point temperature has been decided, the objective is to make the temperature control. It has been developed taking PID and, conversion and filter blocks.

In the next picture it is shown how has been programmed by CFC method.
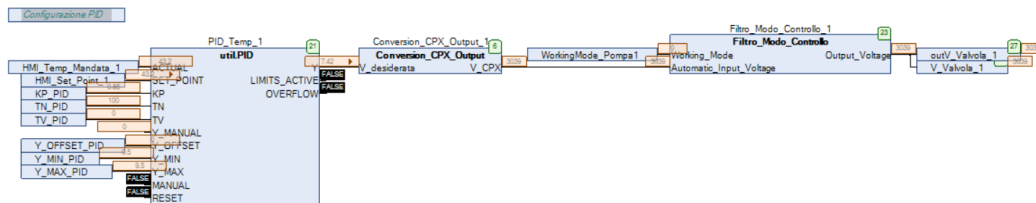
Figure 3.65: Codesys PID Control

It has to be highlighted the input parameters working on PID block.

- **Actual Temperature**: Taken from a NI1000 sensor directly introduced on the water pipe.
- **Set point**: Chosen following the steps studied previously
- **PID parameters**: Only accessible for technical people, implemented by Visu Web
- **Offset parameter**: It sends a plus or minus on the set point depending on the time. For example, the set point is decreased ten degrees on winter nights while it is increased ten degrees on summer nights. Everything is done with saving energy objectives.

Figure 3.66: VISU Fan-Coil Circuit

Then the conversion block converts the calculated voltage to CPX output, that is ranged from 0 to 2048.

Finally, the filter block behaves as a filter that, depending on the controlling mode, automatic, manual or off mode, it sends different outputs.

As it has been said on the starting point of this chapter, the fan-coil system is composed by four circuits, four room destinations. Each room has different heat characteristics so, each circuit is managed in a diverse way. That is why each one has got its own pump and its own control valve.

On the next picture 3.67, it is shown the physical system, highlighted the main components.

The WILO pumps are controlled, as it has been described on the previous refrigerating plant chapter, by the CANbus protocol. On the other hand, the valves are controlled directly by analog electrical connections, regulated by the voltage output.

Figure 3.67: Real Fan-Coil Circuit

3.4.4 Thermic Plant

The thermic plant is composed by two different actuation modes, the first one would be the heat/cold creation and the second one would be the distribution.

The heat/cold is produced by three elements, the Broad, the Clivet and the Heater. They will be explained individually on the following subchapters ref.....

I the next screenshot, 3.68 is shown how the water distribution has been schematically design and how the circuit is working. Depending on the season we are, the water arriving to the Broad and the tank is different, hot on winter and cold in winter. The valves would change also its color depending on the season.

Finally, it could be seen the heater pump state and some temperatures of the system as it has been explained on the previous chapter.
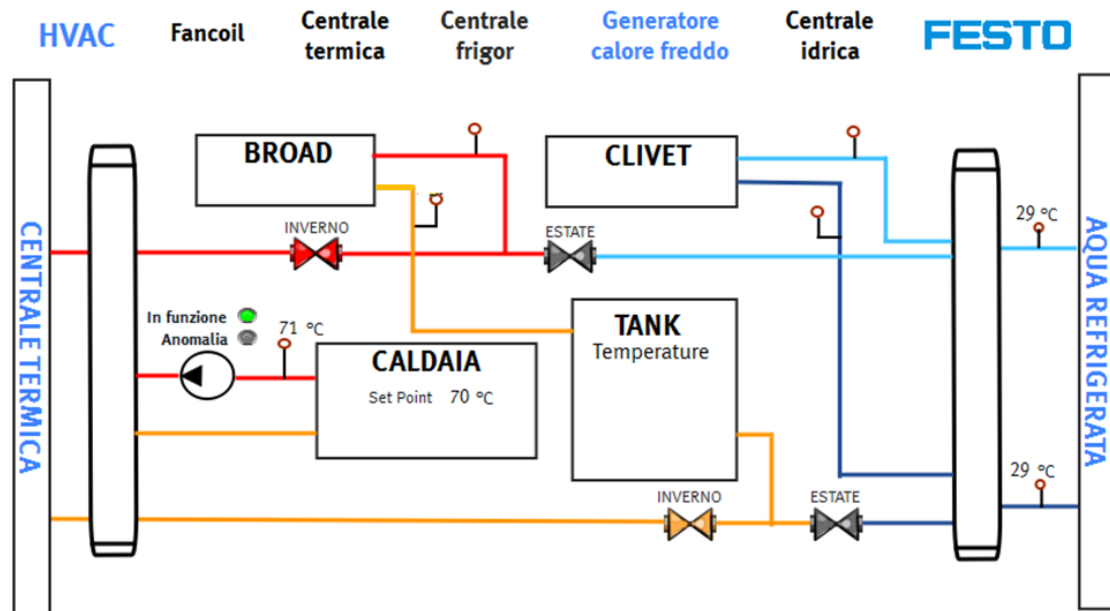
Figure 3.68: Generator Diagram

The second part of the Thermic system would be the water distribution to the other systems. As it could be seen on the schematic picture reffig:ThermicPlantDiagram, the thermic plant is also connected three UTA rooms and finally to the heat exchanger. The heat exchanger is just connected with the Hydraulic Plant. Could be interesting for the reader to take a look again to the chapter refCentrale Idrica to

understand the connection that is being talking about.
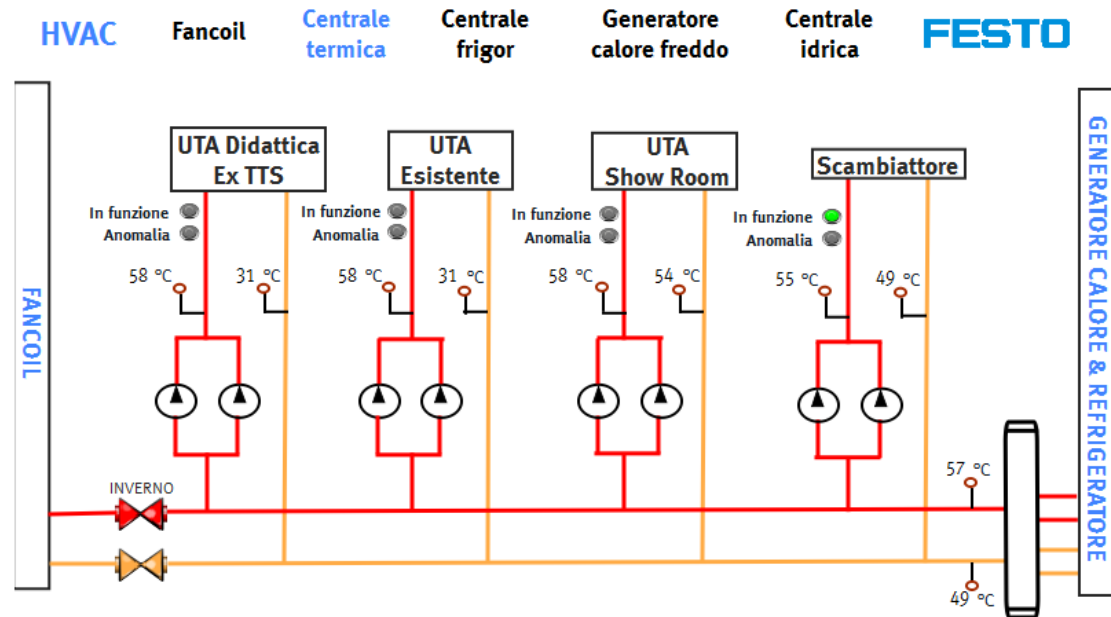
Figure 3.69: Thermic Plant Diagram

So, finally there are five pumps on the thermic plant. The working logic of the pumps is the following one.

- **UTA pumps** will be only avaible to work if the precise UTA is working.

- **Heater Pump** works only when the heater is working. That signal is collected directly from the heater.

- **Heat exchanger pump** is only active in case that the main valve of the hydraulic plant is open.

That logic tratament will help to save energetic energy from the pumps, that have not the necessity of being always working. Furthermore, thanks to this logic, the pumps will never work without the sufficient water of the correct working point, think that could damage the own pump.

To finish the analysis of the thermic plant it is shown by the next pictures, 3.70 how is the physical structure of the system. In the right picture could be seen the heater connection while the left one shows the hot water distribution.

Figure 3.70: Physic Thermic Plant

On the next subchapters how, the heat/cold elements work will be explained, heater, Clivet and Broad.

3.4.5 Boiler

The boiler system brand is VIESSMANN. The connection with this element has been done directly by electrical connection, digital and also analog pins.

Figure 3.71: Viessmann

The Viessmann boiler has been configured for being externally managed [11]. Thanks to this configuration it is possible to set a temperature Set Point from an analog input 0-10V that will be managed form the CPX.

Also, it is possible to collect from this element digital information. An important data to collect is a bit which indicate if the heater is working or if it is on a pause moment. The heater behaves as a thermostat, depends on the temperature set point and the current one. Thanks to this data it is possible to manage the heater pump mentioned on the previous chapter.

The heater depends also on the automatic or manual working mode.

As it was mentioned on the pumps control, the manual mode is a security mode where the selected parameters are fixed and make the system work correctly without failure.

Figure 3.72: Boiler Connection

On the other hand, the automatic mode works depending on the signals sent by the CPX. The main parameter sent by the CPX is the Set Point of the heater.

The logic of the heater consists on automatic temperature change depending on the time it is working on. The scheduler that manages the time of the heater has been programmed directly on the Designer Studio program.

In the picture 3.73 the design of the heater control could be seen. It is shown on the upper part of the page the scheduler with the possibility of change the time when the night and day state is automatically activated.

On the left down part of the picture are the heater commands. The first element is the control mode. If it is in manual mode, any command will work but if the

Figure 3.73: Boiler Diagram

automatic mode is set, then the temperature set point could be modified, either the day or the night one. Furthermore, it is possible to change the day/night state pressing simply on its button. It could be useful for example to active the save energy in case that the hot water is not needed yet.

Finally, on the right part of the HMI page could be seen the general information of the heater temperatures, set point, actual temperature and also the Legionella set point, explained on the chapter refcentrale idrica, and finally it is depicted the heater pump state.

3.4.6 BROAD

BROAD Absorption chiller-heater is a device driven by thermal energy which moves heat from low temperature to high temperature or vice versa. It could be used as Absorption chiller on summer and Heating system on winter.

The BROAD absorption chiller-heater uses a solution of lithium bromide and water, under a vacuum, as the working fluid [4]. Water is the refrigerant and lithium bromide, a nontoxic salt, is the absorbent. The double-effect absorption cycle has two generators - one directly heated by a gas burner and the other heated by hot refrigerant vapor. Refrigerant, liberated by heat from the solution, produces a refrigerating effect in the evaporator when cooling water is circulated through the condenser and absorber.

Figure 3.74: BROAD

Cooling Cycle

The cycle is composed by five principal phases as it could be seen in the image 3.75.

Figure 3.75: Cooling Cycle

- **High Temperature Generator** The gas burner heats dilute lithium bromide solution in the high-temperature generator and, as the solution boils vigorously under a vacuum, droplets of concentrated solution are carried with refrigerant vapor to the separator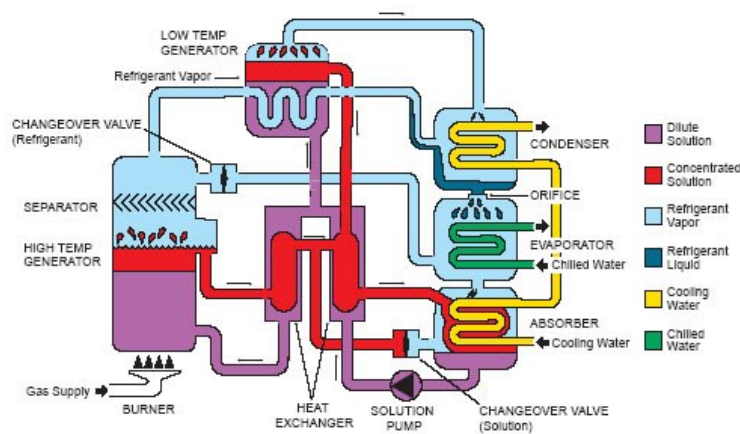. After separation, hot refrigerant vapor flows to the low-temperature generator and concentrated solution is precooled in the heat exchanger before flowing to the absorber.

- **LowTemperature Generator** Hot refrigerant vapor from the separator heats dilute lithium bromide solution in the low-temperature generator. Refrigerant vapor, liberated from this solution, flows to the condenser while solution, which is now concentrated, is precooled in the heat exchanger before flowing to the absorber.

- **Condenser**In the condenser, refrigerant vapor is condensed on the surface of the coil and latent heat, removed by the cooling water, is rejected to a cooling tower. Refrigerant liquid accumulates in the condenser and then passes through an orifice into the evaporator.

- **Evaporator**In the evaporator, refrigerant liquid is exposed to a substantially deeper vacuum than in the condenser due to the influence of the absorber. As refrigerant liquid flows over the surface of the evaporator coil it boils and removes heat, equivalent to the latent heat of the refrigerant, from the chilled water circuit. The recirculating chilled water is cooled to 44.6 °F and the refrigerant vapor is attracted to the absorber.

- **Absorber** A deep vacuum in the absorber is maintained by the affinity of the concentrated solution from the generator with the refrigerant vapor formed in the evaporator. Refrigerant vapor is absorbed by concentrated lithium bromide solution flowing across the surface of the absorber coil. Heat of condensation and dilution are removed by the cooling water and rejected to a cooling tower. The resulting dilute solution is preheated in the heat exchanger before returning to the generator where the cycle is repeated.

Heating Cycle

- **High Temperature Generator** Dilute lithium bromide solution is heated in the high-temperature generator by the gas burner in the same manner as the
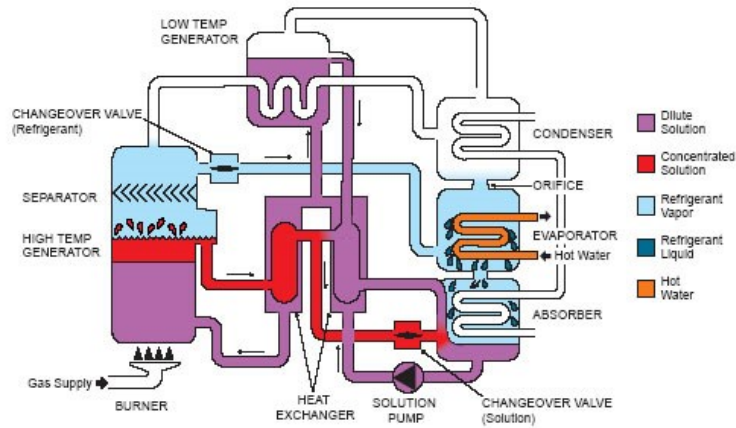
Figure 3.76: Heating Cycle

cooling cycle. The solution boils vigorously and droplets of concentrated solution are carried with refrigerant vapor to the separator. Hot refrigerant vapor flows through the refrigerant changeover valve into the evaporator and concentrated solution flows through the solution changeover valve into the absorber sump.

- **Evaporator**Hot refrigerant vapor condenses on the surface of the evaporator coil and heat, equivalent to the latent heat of the refrigerant, is transferred to the hot water circuit. The recirculating water is heated to 140 °F.

- **Absorber** Refrigerant liquid mixes with concentrated lithium bromide solution and the resulting dilute solution returns to the generator where the cycle is repeated.

Control and Design Process

The BROAD chiller has its own working control process. That is why the control project of the BROAD machine is based on the alarms and malfunctions.

The BROAD machine includes the RS-232 communication protocol. The company has been contacted in order to obtain the protocol information but unfortunately, the company answer has not been the expected one. They asked 5.000 euros for obtaining this information, money that the company cannot afford. So, it has been found a cheaper way, direct sensor connection.

There would be three basic commands from the HMI,

- ON/OFF buttons
- System Reset command

These signals would be directly connected with the command machine relays doing his function properly.

The received information has been summed up in three kinds of alarm:

- General Anomaly
- Pressure switch low pressure
- Pressure switch high pressure

Working mode:

- Warming or cooling working mode

And finally, temperature analysis

- Inlet, Outlet and HTG temperature data

This obtained information would be enough to control the system in a simple and proper way. The design of the BRAOD system is shown in the picture 3.77

During the thesis development, it has been contacted with BROAD company in Italy, Germany and finally China for the protocol to stablish the communication with the BROD element but unfortunately, the answer was not as it was expected to be. The price to add the communication protocol to the system couldnt be afford by Festo so it has been thought different methods that will be implemented on the next months.
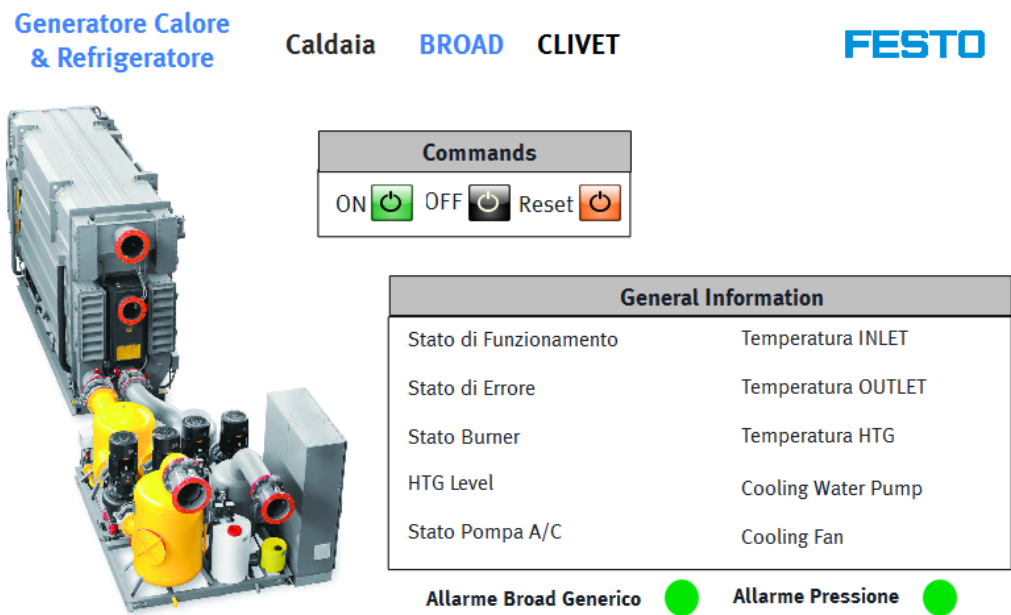
Figure 3.77: BROAD Diagram

3.4.7 CLIVET

The CLIVET system works as a heat pump. This system only provides heat instead of a combination between heat and cool as the BROAD system does but it works in a more efficient way.

Figure 3.78: CLIVET

A heat pump is an electrical device that extracts heat from one place and transfers it to another.

Energy can be extracted from outside air, from water (groundwater, river, or lake) and from the ground, using heat exchangers. This heat then enters in the cycle of the heat pump, where it is brought up to a temperature that meets heating needs.

Heat pumps transfer heat by circulating a substance called a refrigerant through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed in route to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle.

Control Process

Unlike the BROAD machine, the CLIVET one communicates with the system by the MODBUS TCP communication protocol. As it has been explained on the **Communication protocol** chapter, MODBUS TCP information data is received in a huge unspecific block where the important data has to be founded.

Figure 3.79: CLIVET Manual

This time, the CLIVET company has been contacted and they have sent the MODBUS TCP manual protocol [5]. Here it is possible to find the required information thanks to the data addresses as we can see on the next pictures.
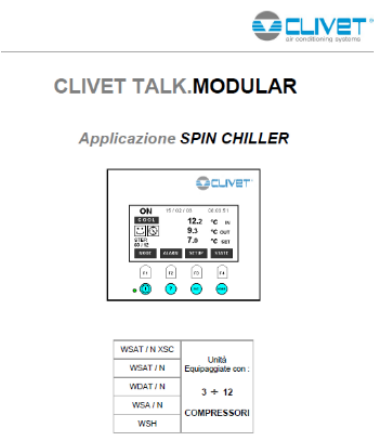
It will be given on the next paragraphs two
examples of how the information is collected from the MODBUS TCC CLIVET
protocol.

The essential information of the machine control will be explained on the next
paragraphs:

The received information will be about the existent modulus that has been
pointed on the picture 3.80, two compressor module unit, one evaporator module
unit and finally one pump module unit. Also there is a central module that exists
neccesarily on every machine, that is why it has been not included on the map.

5.2   MAPPA EEPROM DELLA CONFIGURAZIONE DI MACCHINA

Un valore di word diverso da 0 (zero) indica la presenza in rete CAN del modulo indicato.

| ADDRESS ModBUS | | Descrizione |
Esadecimale	Decimale	
70	112	Presenza del modulo compressore 1 Unit 1
71	113	Presenza del modulo compressore 2 Unit 1
72	114	Presenza del modulo compressore 3 Unit 1
73	115	Presenza del modulo evaporatore 1
74	116	Presenza del modulo compressore 1 Unit 2
75	117	Presenza del modulo compressore 2 Unit 2
76	118	Presenza del modulo compressore 3 Unit 2
77	119	Presenza del modulo evaporatore 2
78	120	Presenza del modulo compressore 1 Unit 3
79	121	Presenza del modulo compressore 2 Unit 3
7A	122	Presenza del modulo compressore 3 Unit 3
7B	123	Presenza del modulo evaporatore 3
7C	124	Presenza del modulo recupero 1
7D	125	Presenza del modulo recupero 2
7E	126	Presenza del modulo recupero 3
7F	127	Presenza del modulo recupero 4
80	128	Presenza del modulo recupero 5
81	129	Presenza del modulo recupero 6
82	130	Presenza del modulo daikin 1
83	131	Presenza del modulo daikin 2
84	132	Presenza del modulo daikin 3
85	133	Presenza del modulo daikin 4
86	134	Presenza del modulo daikin 5
87	135	Presenza del modulo daikin 6
88	136	Presenza del modulo pompe

Figure 3.80: CLIVET Modbus1

Central Module Information

The central module information has been obtained from the table 3.81 where

could e found:

- Machine State

- Machine Mode: in our case will be only used the heating one

- Temperature SetPoint

- Input and Output Temperature

- Number of states involved

Figure 3.81: CLIVET Modbus2

On the other hand, the central module alarm information is picked up from the table 3.82 where there are:

- Failures

  - Water Temperature Probe

- Errors

  - Water Reset Signal
  - Machine configuration
  - Demand Limit Signal

- Alarms

  - Water flow lack

– Pressure lack

– Inconsistent

– Temperature difference

9 ALLARMI

9.1 ALL   ARMI MODULO CENTRALE

Gli allarmi relativi al modulo centrale sono raggruppati in una word all'indirizzo 400, come evidenziato nella tabella sottostante:

Descrizione allarme	ADDRESS ModBus		BIT
	Esadecimale	Decimale	
E001 Guasto sonda temperatura H2O ingresso			0
E002 Guasto sonda temperatura H2O uscita			1
E003 Guasto sonda temperatura Aria esterna			2
E004 Errore nel segnale di Water Reset			3
E005 Guasto sonda UR%			4
E006 Intervento protezioni pompa 1			5
E007 Intervento protezioni pompa 2			6
E008 Allarme mancanza flusso acqua	400	1024	7
E009 Allarme mancanza pressione impianto			8
E010 Intervento monitore rete elettrica			9
E011 Allarme antigelo			10
E012 PREAllarme antigelo			11
E013 Segnalazione avvenuto scambio delle pompe			12
E014 Errore di configurazione macchina			13
E015 Errore nel segnale di Demand Limit			14
E016 Modulo centrale sconnesso da rete CAN			15
E017 Inibita regolazione in Riscaldamento			0
E018 Allarme DeltaT Incongruente	401	1025	1
E019 Allarme bassa temperatura esterna			2

Figure 3.82: CLIVET Modbus3

Following this procedure the rest modules information has been collected. On the next paragraphs will be explained the received data.

Compressor module Information

Then, from the two compressor main modules the state information required is:

• On/Off compressor state

• Active timing

And the alarms will be divided in three types, Failure, Circuit Alarm and Intervention, in order to magage it on a easier way:

- **Failure**

    - Temperature probe Condensator/ Evaporator
    - Pressure probe condensation/evaporation

- **Alarms**

    - High/Low pressure
    - Water flow condensation/vaporation
    - Power Fail
    - Oil differential pressure
    - Ice condensator alarm

- **Intervention**

    - Thermic fan/pump
    - Compressor 1 and 2 protection

Evaporator and pump module Information

The proccedure will be the same as in the compressor module. The alarms will be sum up again on Failure, alarm and intervention.
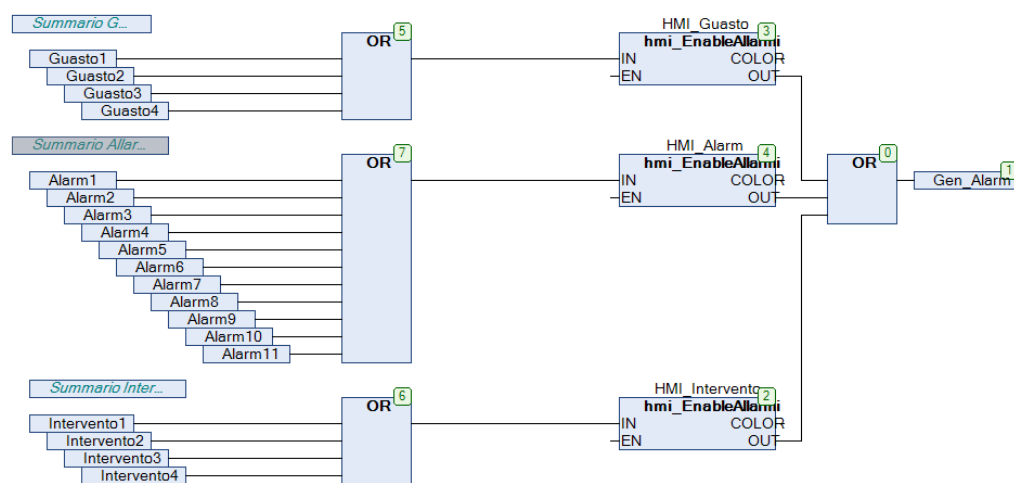

Figure 3.83: CLIVET Codesys

In order to make it easier and compact, it has been created a function block useful on every module that sums up this variables and collects them also as a general module alarm. This basic program could be seen on the picture 3.83.

Commands

Finally, the command block will be basically the same as the BROAD commands:

- ON/OFF

- Reset

Figure 3.84: CLIVET Modbus 4

As it could be seen on the picture 3.84, if a command is wanted to be pushed, an specific number would be needed to be written in a specific direction.

HMI Design

The commands described and the general information will be shown on the image 3.85 where it could be seen the general CLIVET diagram:

If we want to obtain more information about the appeared alarms, it coud be clicked on the alarm button, being guided to the alarm page, shown i the picture 3.86.

On this interface it is depicted every single module with a list of its possible alarms. In a schematic visualization it could be discovered a source of problems.

The CLIVET project has been programmed and designed but the installation phase has not been finished so, unfortunatelly, the program has not been tested directly with the CLIVET element. It will be a close future line of the Smart Building Project.

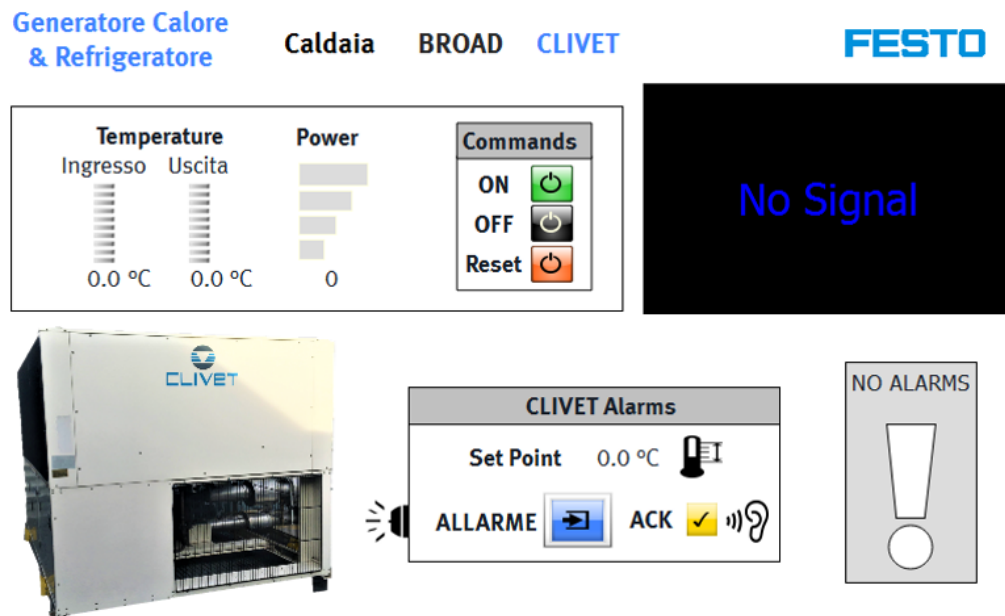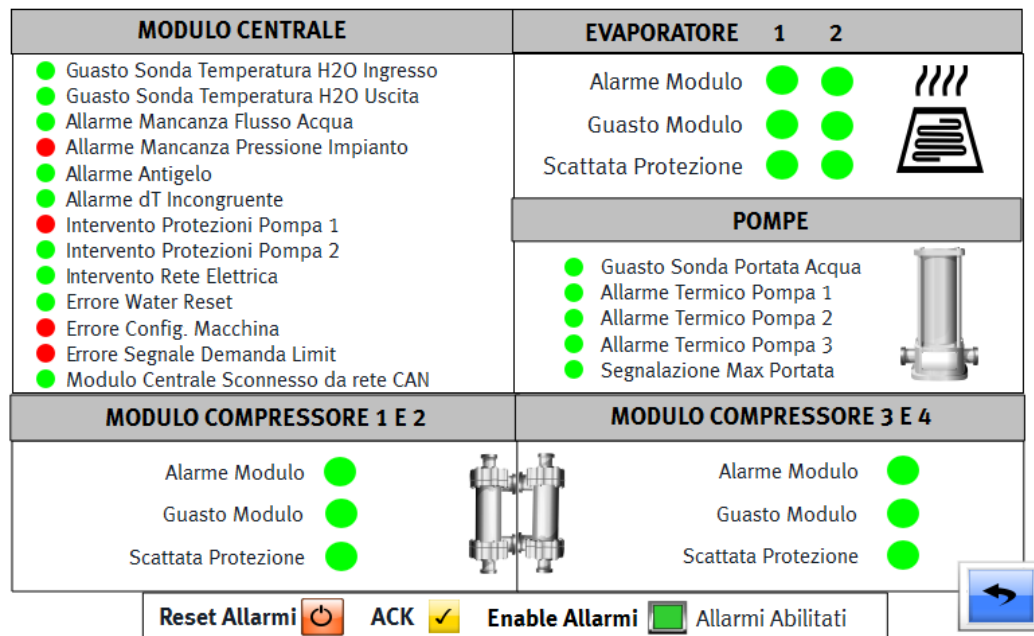Figure 3.85: CLIVET Diagram

Figure 3.86: Advanced CLIVET Diagram

3.4.8 Air Handling Unit (AHU)

The Air Handling Unit (AHU) or, as known in other languages, UTA (unit trata-mento aria), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system. As it could be seen on the picture 3.87,an air handler is usually a large metal box containing a blower, heating and cooling elements, filter racks, dampers and sometimes, as in our system, humidifiers.
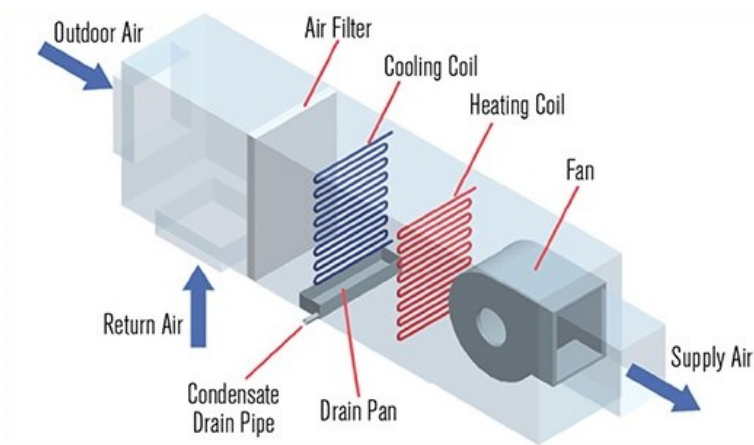

Figure 3.87: Air Handling Unit

It is able to deal with the three elementary parameters of the quality of the climate environment: renovation and cleaning of the air (low content of particles, dust in suspension), temperature control (both in summer and in winter) and the relative humidity.

Its objective is to provide a flow of air treated to be distributed to the inhabited spaces.

In the following paragraphs will be explained some general thermodynamic concepts to understand how the system logic works.

Psychometric chart

The psychometric chart depicts a graphical equation of state according to the following parameters:

- **Dry-bulb temperature (DBT)** as the abscissa (horizontal axis) of the graph,
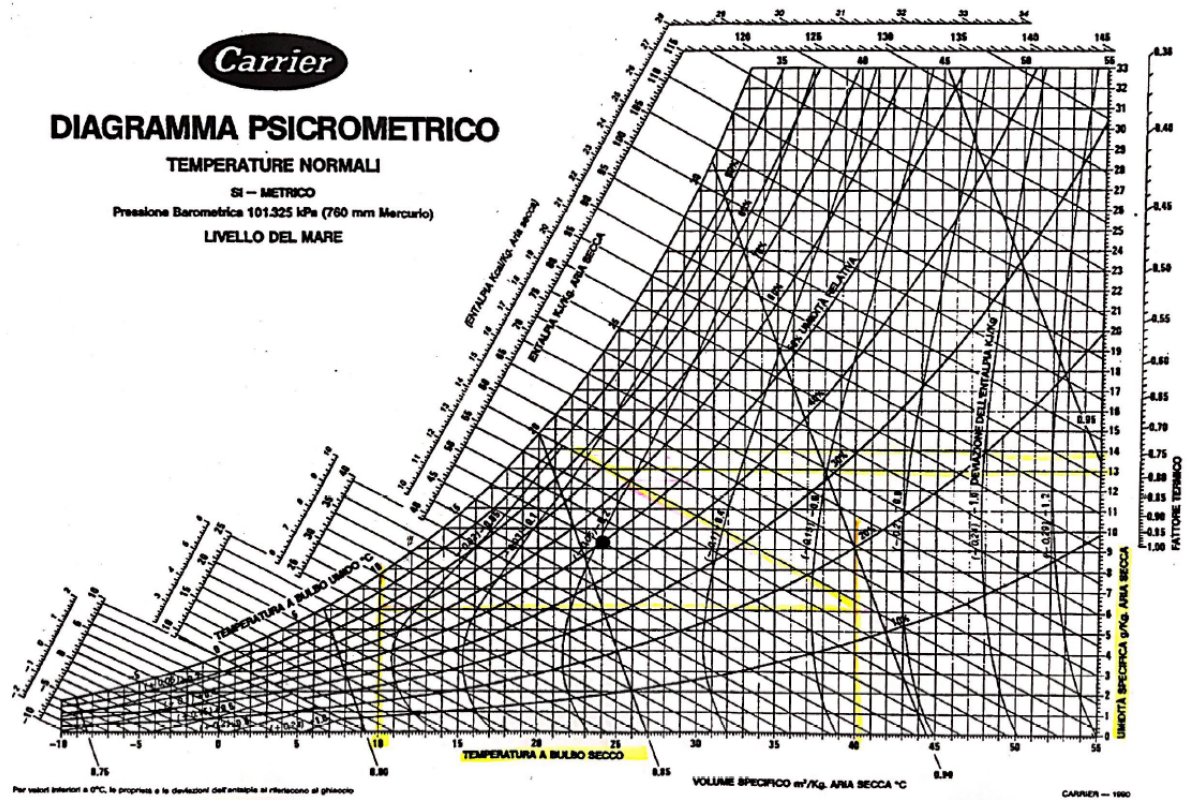
Figure 3.88: Psychometric Chart

- **Relative humidity (RH)** is the ratio of the mole fraction of water vapor to the mole fraction of saturated moist air at the same temperature and pressure.

- **Humidity ratio** is the proportion of mass of water vapor per unit mass of dry air at the given conditions as the vertical axis of the graph.

- **Specific enthalpy**, symbolized by h.

According to our Air Handling Unit, represented on the figure, there will be four instruments to move our state point into the graph, preheating, cooling, adiabatic humidifier, post heating.

Specifically, our system exists two work cases, winter and summer stations.

The winter case will follow the diagram 3.89. It will work with two parameters, temperature and humidity. The ideal work conditions inside the building are approximately 23°C and a 50% humidity.
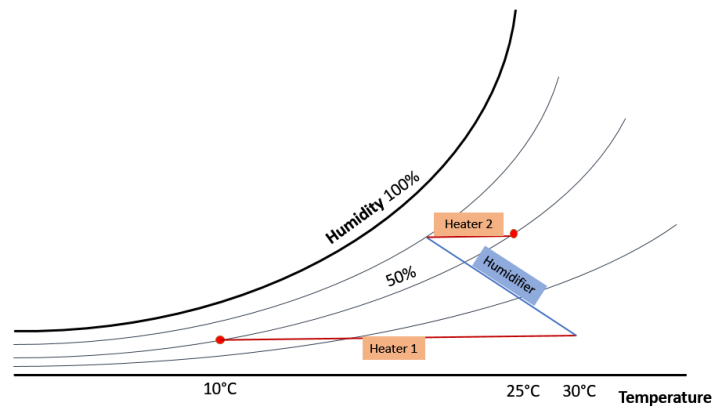

Figure 3.89: Winter Psychometric Chart

On the winter conditions, the outside air temperature is lower than what is needed but the humidity is close to the ideal one.

The first step is increase the temperature by the preheater more than what is requested. As it is possible to see on the graph, the humidity decreases when the temperature increases so, it is compulsory to increase the humidity in a second step. That is why it is included a pump in the process.

During this second step, the humidity has been increased but the temperature has been decreased according to the equality of enthalpy. So, to correct this temperature decrease, it must be introduced a third stem, a post heater, which will reach the ideal point.

Summer case:

The AHU project would control the different elements shown in the picture 3.90:

- **Filter**: It helps to clean the input air. The filter sensor would give an alarm in case of dirt.

- **Fan**: It gives the energy to move the air. It shows an alarm if a belt problem exists.

- **Damper (Serranda)**: It is a security element which will close the door in case of dangerous situation.

The other four elements, **Preheater, Cooler, Humidifier** and **Post heater** will be controlled following the psychometric chart in order to obtain the ideal indoor
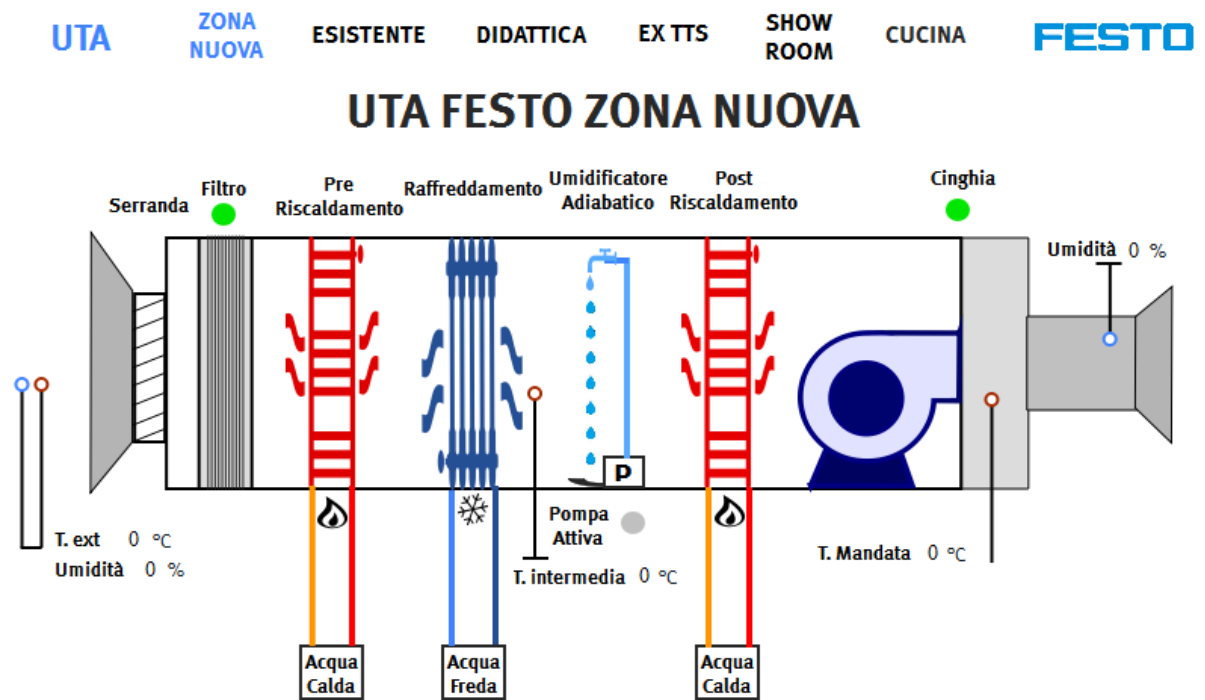
Figure 3.90: UTAInterface

air conditions. In order to achieve these ideal conditions, each one of these elements has requested **PID** controllers and consequently, temperature and humidity sensors trough the AHU.

3.5   Industry 4.0 as OPC UA Connectivity

The so-called **Industry 4.0** is the culminating point of this project. The idea is to collect the most important data in one superior level PLC connected via OPC UA and create an interface of this data via Node-Red.

Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing. Industry 4.0 is commonly referred to as the fourth industrial revolution.

Inside the Industry 4.0, the most trendy way of communication is the **OPC Unified Architecture (OPC UA)**. The OPC UA is a machine to machine communication protocol for industrial automation. It is a secure, open, reliable mechanism for transferring information between servers and clients.
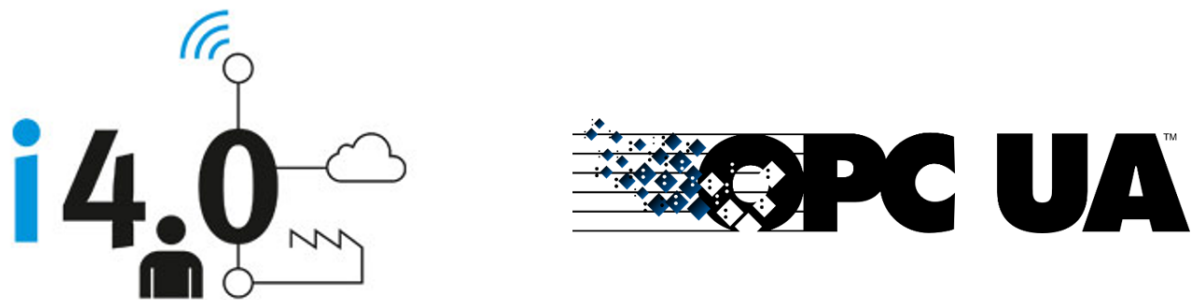

Figure 3.91: Industry 4.0 and OPC UA

Some programs called **QuickOPC, Prosys OPC** or **dOPC** have been used to test the OPC connection and data transfer, and finally read the value of our interesting variables. Finally, using another interface program, as **Microsoft Excel** or **Node-Red**, it has been shown these values in a graphical interface.

On the image 3.92, it could be seen how is the Node-Red working environment. It is a blocking programming mode where every component has its own function to obtain the final result shown on the picture 3.93. The used tools have been divided in, data acquisition, data management and finally data representation.

The picture 3.93 shows the most important data acquired by the Smart Building Project. This data representation has obtained such importance that it could be imagined by the reader. It has been shown in the principal door of Festo in order to
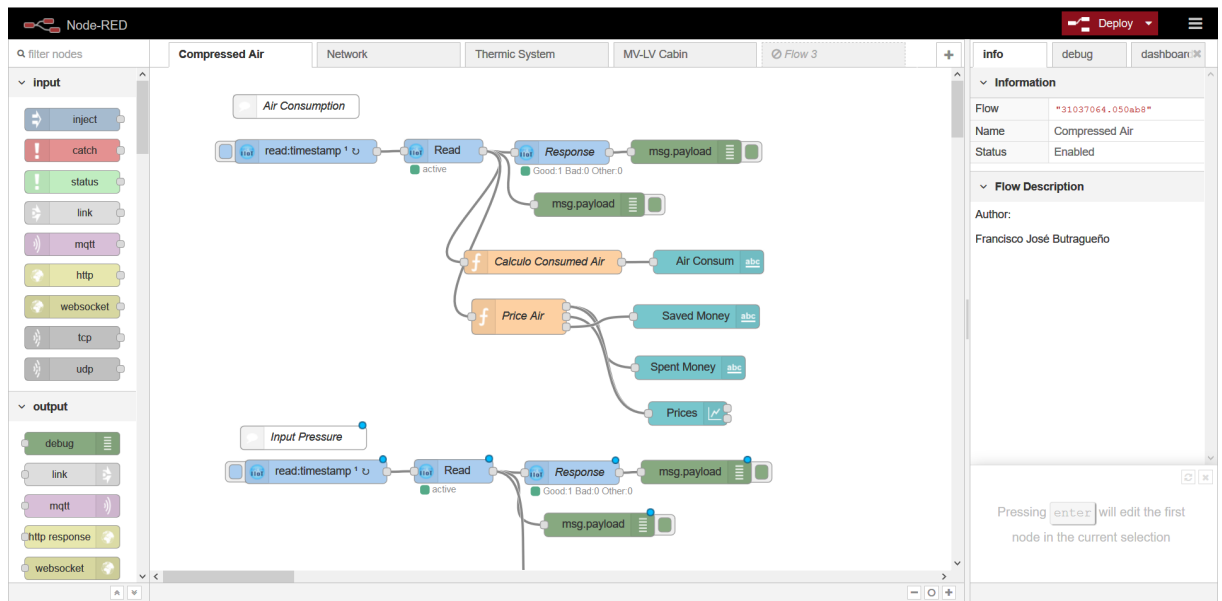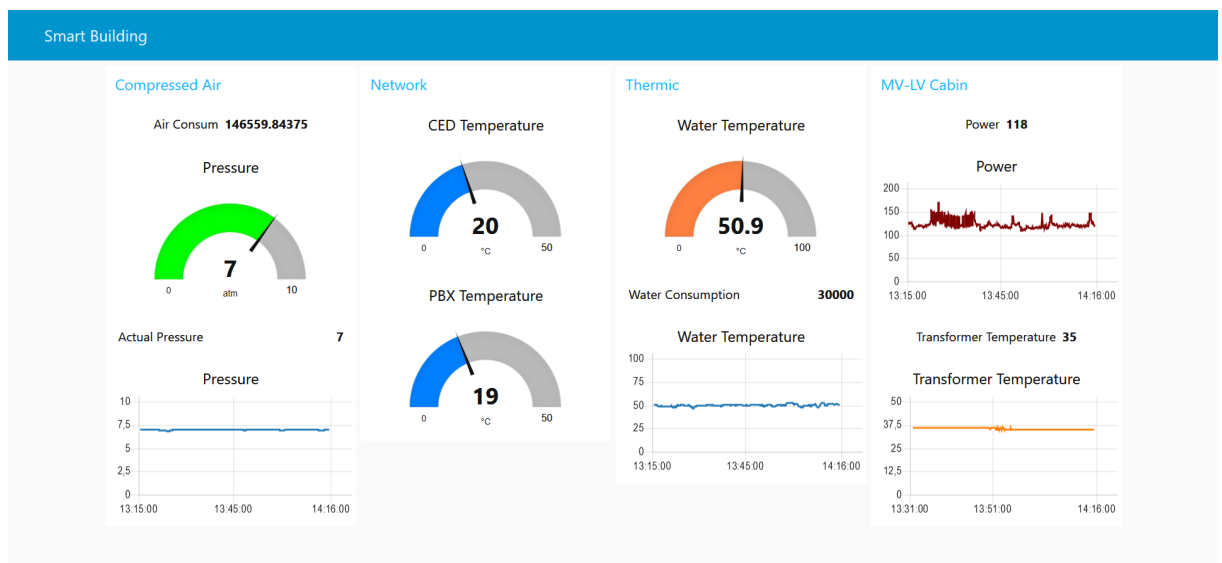
Figure 3.92: Node-Red Programming

Figure 3.93: Node-Red Interface

be seen for every worker and every client that goes into the Festo Company. It has not been a simple data acquisition project, it represents how Festo has implemented its own products and its own means to obtain an energy saving strategy and finally, as any company tries, money saving plan.

Chapter 4

Conclusions

The project started being called Domotics at Festos Building to finally get to be known as **Smart Building Project**. It could seem only a small difference without significant importance but it is not.

The project does not deal with turn on and off the light of a room, it deals with the control the management and the maintenance of the building of an important company. That reference differentiation represents the importance of a single error and the relevance of a management success.

From the initial point of view of the project, it seemed a huge objective, difficult to achieve. Many difficulties have appeared but finally, they have been overcome. From the beginning, the priorities, the systems characteristics and the project ideas have been changing and have been adapting to a final idea, but every step, every change has had a reason and has finally been an apprenticeship.

Although it has not been easy, fortunately there have been more success than failure. It has been found many problems, waiting times, calls to foreign countries, mails around the world etc. But from every step there has always been a learned lesson and a personal and professional improvement.

The acquired knowledge on this project has not been restricted to the unique field of automation, PLC programmer or HMI designer. It has been a complete industrial engineer work. It has been deal with electricity, thermodynamics, materials, electronics, mechanics, and as the main one, software developing.

It has been also satisfactory to depict the system projects from the beginning

until the end. Initiating from an idea and finishing with this idea realized, passing thought the intermediate phases it has been learned how a real project works. Phases as the components shopping, the electrical installation, the programming phase and testing, where step by step it has incremented importance on the final solution.

It has been a successful project and, although it is so big that the project will be continued by at least another internship, it has been created a good road to achieve a satisfactory and complete Festo Smart Building in the future.

It has been an amazing period, I strongly believe that the choice was the right one because this project had opened my mind to the real mechatronic world where I think, I could happily continue my career.

Future Lines

The next steps of the project involve the installation, real control and test of the systems that are still on the initial phase. Their logics have been started but they have not been connected and developed with the real devices. It is referred to the UTA, Clivet and Broad systems.

Also, it has been thought to manage the building lights and the web cams from the HMI and web pages. It would be useful as security and also safety functions.

Finally, in general terms, the Smart Building Project will not finish in this building. The idea is to expand the project to the rest of Festo buildings around the world and why not, sell it as a new product to other interested companies.

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