Critical Design Review

MISCE project

Mechatronics for Improving and Standardizing Competences in Engineering

Competence: Automation Technology

Workgroup: University of Cagliari

University of Cassino and Southern Latio

This document is the Critical Design Review of the technical competence ‘Automation Technology.
Its details the complete design of the pneumatic/electropneumatic test bed..

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Visit https://misceproject.eu/ for more information.

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1.1 Scope

This document presents the detailed design of the pneumatic/electropneumatic test bed control platform developed in the framework of MISCE project.

The final objective is to use the developed platform in the practical lectures of engineering degrees to contribute to the technical competence:

A1. Automation Technology

which related skills are (see Table I):

Table I. Skills of Automation Technology

S1.1.	To know the main electric/pneumatic and hydraulics elements
S1.2.	To be able to design the functional behavior of the system
S1.3.	To be able to understand the technical documentation of a project/product
S1.4.	To program the functional behavior of the device
S1.5.	To debug the final planned behaviour of the system

1.2 Preliminary definition

This experimental test-bed can be widely used for teaching purposes. It is composed by:

- PLC S-7 1200 CPU 1215C AC/DC/RLY;
- Arduino UNO R4 WIFI;
- SCALANCE XB005 Ethernet Switch;
- SIEMENS HMI Panel KTP700;
- h20 temperature sensor (Arduino kit);
- Tds h20 sensor (Arduino kit);
- ph h20 sensor (Arduino kit);
- Temperature and humidity sensor (Arduino kit);
- Air co2 sensor (Arduino kit);
- Peristaltic pumps (DC motors);
- 1 channel 5V Relay module;
- RC engine type "Boat Drive";
- Float water level sensors;
- Wireless Wifi Extender and Tp-Link Access Point.

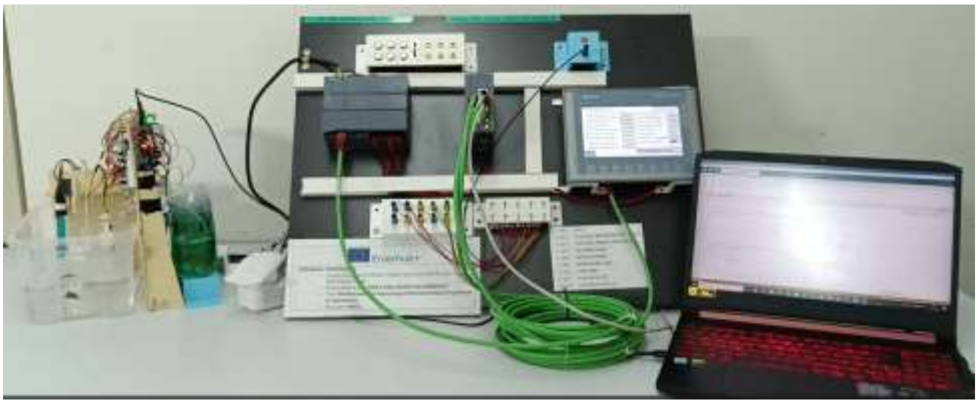


Figure 1. Suitable experimental test bed realized

The experimental platform aims to implement an automatic control system for hydroponic crops that can actively monitor and control the process. The system is implemented using low cost sensors with the use of Arduino (see Figure 1) and actuators managed through the use of a PLC equipped with HMI interface. The system must be able to meet requirements such as reliability, ease of use and versatility. The aim is to create a system capable of reading as input data the desired values for the control of process variables and informing the human controller on all process parameters, printing the values of the process variables and displaying the status of the actuators on the HMI screen, as well as storing the same data in files.The realization of the control system is based on, of course, on the acquisition of data by sensors and the ability to provide feedback to the system via actuators. In the following sub-chapters we will list these tools. The main advantage of this test bed is related to the possibility to be used widely in different academic activities

1.3 Technical requirements

The main advantage of this test bed is related to the possibility to be used widely in different academic activities. In addition, the behaviour of the cylinder is well-know and easy to be achieved and offers a very illustrative way to introduce in all the skills of automation technology.

1.3.1 Arduino R4 Wi-Fi

The aim of the experimental platform is to implement an automatic control system for hydroponic crops capable of actively monitoring and controlling the process. The system is implemented using low-cost sensors with the use of Arduino (see Figure 2) and actuators managed through the use of a PLC equipped with HMI interface. The system must be able to meet requirements such as reliability, user-friendliness and versatility. The aim is to create a system capable of reading as input data the desired values for the control of process variables and informing the human controller about all process parameters, by printing the values of the process variables and displaying the status of the actuators on the HMI screen as well as storing the same data in files.

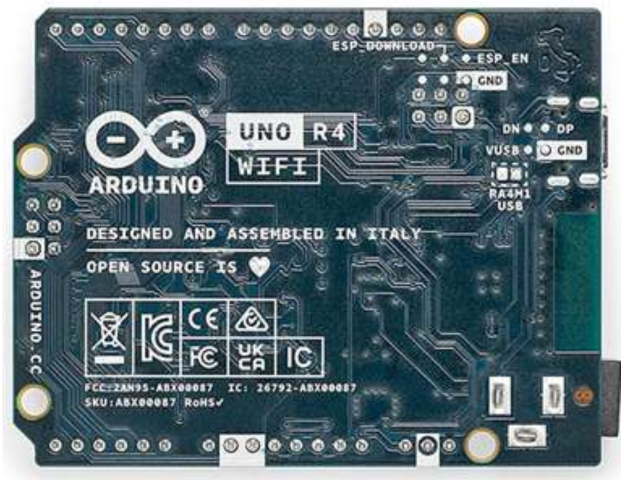


Figure 2. Arduino R4 Wi-Fi

The realization of the control system is based, of course, on the acquisition of data by sensors and on the ability to provide responses to the system through actuators. In the following sub-chapters will list these instruments.

Arduino® UNO R4 Wi-Fi is the first UNO board equipped with a 32-bit microcontroller and an ESP32-S3 (ESP32-S3-MINI-1-N8) Wi-Fi module. It is equipped with a Renesas RA4M1 series microcontroller (R7FA4M1AB3CFM#AA0), based on an Arm® Cortex®-M4 48 MHz microprocessor. The memory of the UNO R4 Wi-Fi is larger than its predecessors, with 256 kB flash, 32 kB SRAM and 8 kB EEPROM. The operating voltage of the RA4M1 is fixed at 5 V, while the ESP32-S3 module is at 3.3 V. Communication between these two MCUs is performed via a logic level translator (TXB0108DQSR). An input voltage between 6 and 24 V (VIN) is recommended for the Barrel jack while it will be 5 V through the USB-C (used both to power the board and as a communication interface with the PC for programming. The following is a front view of the card (see Figure 3) and a descriptive table (see Table II).

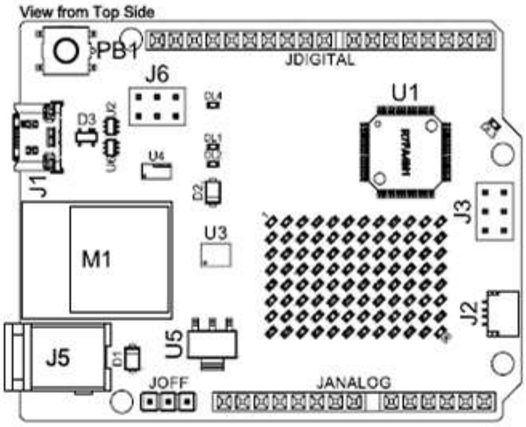


Figure 3 Front view Arduino Uno R4 Wi-Fi

Table II Description front view hardware Arduino Uno R4 Wi-Fi

Ref. Description	**Ref. Description**	PB1	RESET Button
U1	R7FA4M1AB3CFM#AA0 Microcontroller IC	JANALOG	Analog input/output headers
U2	NLASB3157DFT2G Multiplexer	JDIGITAL	Digital input/output headers
U3	ISL854102FRZ-T Buck Converter	JOFF	OFF, VRTC header
U4	TXB0108DQSR logic level translator (5 V - 3.3 V)	J1	CX90B-16P USB-C® connector
U5	SGM2205-3.3XKC3G/TR 3.3 V linear regulator	J2	SM04B-SRSS-TB(LF)(SN) I2C connector
U6	NLASB3157DFT2G Multiplexer	J3	ICSP header (SPI)
U_LEDMATRIX	12x8 LED Red Matrix	J5	DC Jack
M1	ESP32-S3-MINI-1-N8	J6	ESP header
DL1	LED TX (serial transmit)		

1.3.2 Peristaltic pumps

A circulation pump is required to push water into the ducts or pipes of irrigation of the plant, 3 precision pumps, peristaltic pumps, (see Figure 4) for nutrient dosage control and pH control.

Figure 4. Peristaltic pumps

- Motor voltage: DC12-24V;
- Current: 80 mA;
- Rotation speed: 0.1-100 r/min;
- Engine speed: 5000 rpm/min;
- Flow rate 0-100 ml/min.

You can control the flow direction through the positive and negative connection to the DC motor.

- Wide application: this pump is suitable for aquariums, irrigation, liquid dispensing for experiments, chemical liquids, dosing additives, etc.

1.3.3 Relay module

To connect the peristaltic pumps and the mixer, one-way relay modules for Arduino are used. These modules (see Figure 5) have a working voltage of 5 V, with an excitation current of about 70 mA in each direction, with the relay's LED status indicator. It is a very versatile module as it can connect to multiple voltages as reported in the list of specifications:

- Output drive capacity: 250 V AC-10 A, 125 V AC-10 A, 30 V DC-10 A, 28 V DC-10 A;
- Each group emits a simple 3-wire structure and 6 output terminals are reserved;
- It is equipped with holes for fixing screws;
- On one side there are the 3 pins of power, ground and signal and on the other side a terminal block with 3 screws for connecting the outputs (normally closed, common and normally open).

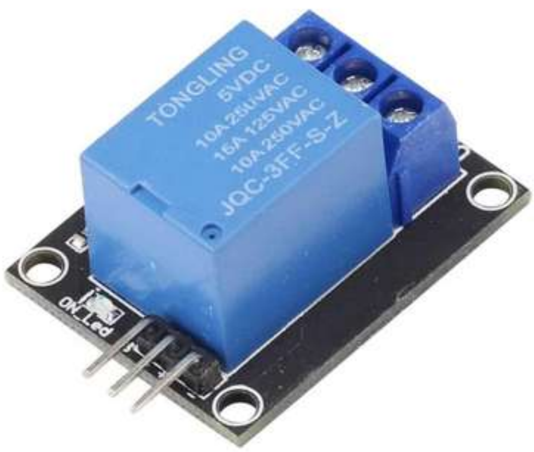


Figure 5. Relay module

1.3.4 LICHIFIT 130 Engines RC Boat Drive

To mix the water has been installed a simple propeller shaft kit powered by motor DC (see Figure 6).

Figure 6 LICHIFIT 130 Engines RC Boat Drive Set Engine Kit Shaft Propellers

- Voltage: 3V, current: 80MA, rotational speed: about 10,000 revolutions;
- Voltage: 6V, current: 150MA, rotation speed: about 20,000 rpm;
- Product dimensions: 16.74 x 1.78 x 2.79 cm; 20 grams.

1.3.5 TL-WA850RE Wireless Repeater

The Arduino UNO R4 Wi-Fi board is internally equipped with the ESP32 Wi-Fi module with which it can communicate wirelessly. The PLC provides the possibility of communicating via Ethernet cable with the HMI, so the physical system requires a Wireless Access Point (see Figure 7) to allow Arduino and PLC to communicate.

Figure 7 TL-WA850RE Wireless Repeater

- TL-WA850RE Transmission speed up to 300 Mbps with frequency 2.4 GHz;
- The wall installation makes sufficient the presence of an electrical outlet for the use of the product;
- Simply press the WPS button on the source access point/router followed by pressing the Range Extender button to put the product into operation;
- The LAN port can be used to connect Ethernet devices, turning the product into an adapter: suitable for Smart TV and Decoder;
- Profile management also allows for device portability, which will remember networks the wireless to which it was previously associated;

- One press of the Pair key is enough to associate any device wireless to the network;
- Supports Microsoft Windows 98SE, NT, 2000, XP, Vista or Windows 7, 8, 8.1, 10, MAC OS, NetWare, UNIX or Linux.

1.3.6 Sensor TDS Meter

TDS (Total Dissolved Solids) indicates how many milligrams of soluble solids dissolved in a liter of water or particles per million (ppm). In general, the higher the TDS value, the more solid solubles are dissolved in water and less clean is the water (see Figure 8).

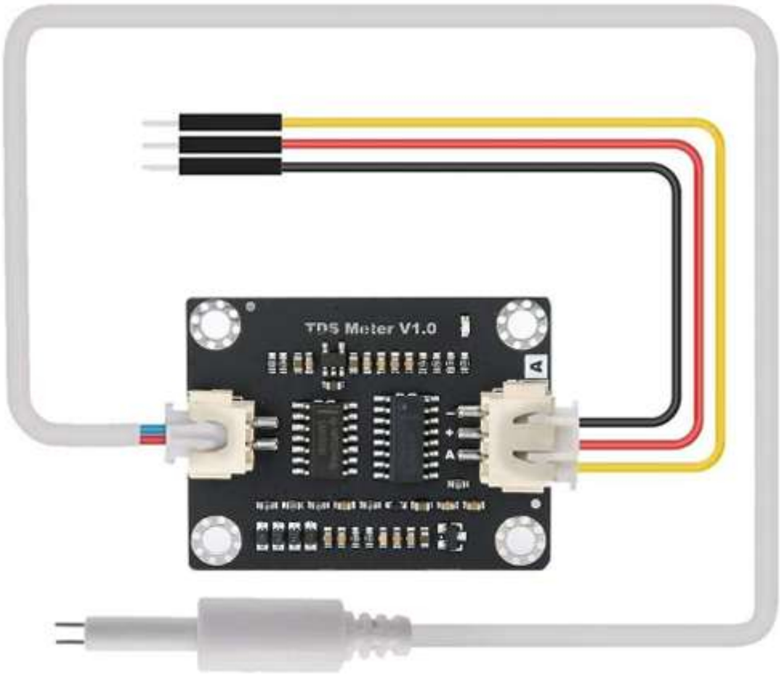


Figure 8 Sensor TDS Meter

The sensor is then connected to the 5 Volt of the arduino (central pin), to the ground (right pin) while the signal is flanked by a 5 kΩ pull-up resistor and connected to the analog pin A1 of the Arduino Uno (see Figure 8 and Figure 9).

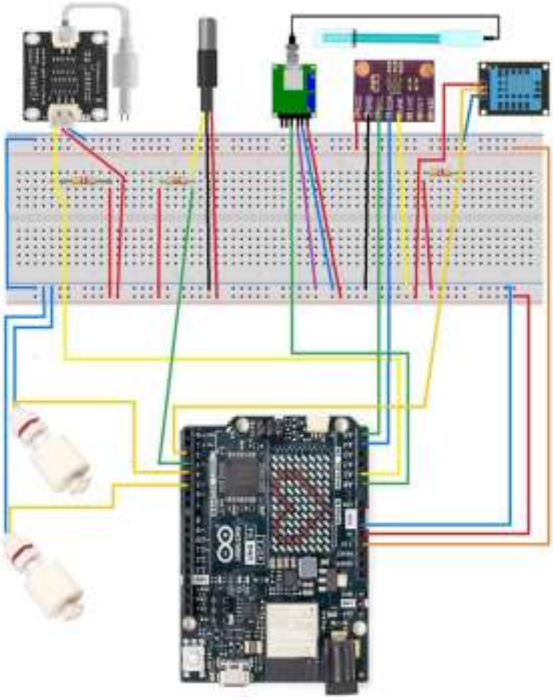


Figure 9 Schematic of sensor connections to the Arduino

1.3.7 Sensor PH Meter

The sensor consists of a solder and a card which can be connected to each other via a BNC connector (see Figure 10).

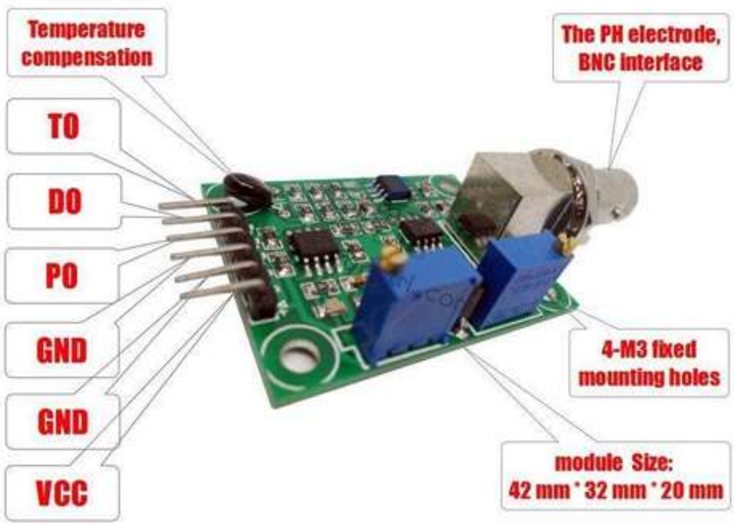


Figure 10 Sensor PH Meter

Features:

- Module power supply: 5.00V;
- Circuit board size: 43mm 32mm;
- pH measurement range: 0-14;
- Measuring temperature: 0-60°C;
- Accuracy: 0.1 pH (25);
- Response time: 1 min;

- pH sensor with BNC connector;
- Interface PH2.0 (3 foot patch);
- Gain adjustment potentiometer;
- LED power indicator;

The following table (see Table III) shows the reference values for the probe.

Table III Probe reference values

VOLTAGE (mV)	pH value	VOLTAGE (mV)	pH value
414.12	0.00	-414.12	14.00
354.96	1.00	-354.96	13.00
295.80	2.00	-295.80	12.00
236.64	3.00	-236.64	11.00
177.48	4.00	-177.48	10.00
118.32	5.00	-118.32	9.00
59.16	6.00	-59.16	8.00
0.00	7.00	0.00	7.00

It is recommended to supply the sensor with a voltage of 5 V in order to the accuracy of the pH reading. Calibration can be done by calibrating the software or hardware through a potentiometer. Software calibration is simpler than hardware calibration. With the software calibration you write the calibration values in the EEPROM library of Arduino, so you calibrate once and for all unless you replace the Arduino board. The mathematical method used is to draw a line using two points, e.g. Using the acid standard solution, pH = 4.00 and alkaline pH = 10.00 or from 9.18 to trace the linear relationship between voltage and pH value.

- TO – Temperature output;
- DO – 3.3V Output (from ph limit pot);
- PO – PH analog output ==> Arduino A0;
- Gnd – Gnd for PH probe (can come from Arduino GND pin) ==> Arduino GND;
- Gnd – Gnd for board (can also come from Arduino GND pin) ==> Arduino GND;
- VCC – 5V DC (can come from Arduino 5V pin) ==> Arduino 5V pin;
- POT 1 – Analog reading offset (Nearest to BNC connector);
- POT 2 – PH limit setting.

For the link diagram refer to Figure 10 and Figure 9.

1.3.8 Temperature and humidity sensor DHT11

The DHT11 (see Figure 11) module is a composite sensor combining a thermometer and a hygrometer in one body. The DHT11 module is the simplest and cheapest. The module measures humidity and temperature values and, through an 8-bit microcontroller enclosed in it, transforms them into digital signals.

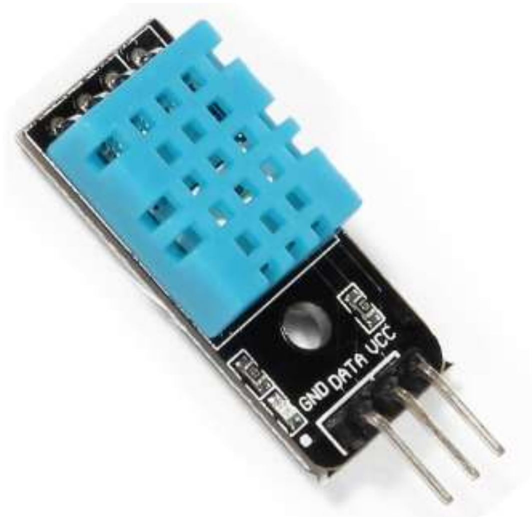


Figure 11 Temperature and humidity sensor DHT11

It is therefore an evolved component, composed of a resistive type humidity sensor, a NTC (Negative Temperature Coefficient-an analog sensor that decreases the impedance of a resistance as the temperature increases) and a microcontroller.

This sensor, on the request of Arduino, transmits a train of forty bits on the pin:

- 8 bits to indicate the whole part of the moisture value;
- 8 bits to indicate the decimal part of the moisture;
- 8 bits to indicate the whole part of the temperature;
- 8 bits to indicate the decimal part of the temperature;
- 8 bits to indicate the control number (to validate the value of the previous 32 bits).

The signal management is obviously handled by a library (DHT.h) which must be downloaded and installed before compiling the program.

This digital sensor requires special libraries for reading the signal and its transformation into "int" value. The installed library is the SimpleDHT available from the Arduino IDE library manager. The sensor connection involves the use of 3 pins: GND connects to the neutral pin of the board, Vcc to the power supply (5 Volt) and the Data pin to a digital input pin, as described in Figure 12 and 9.

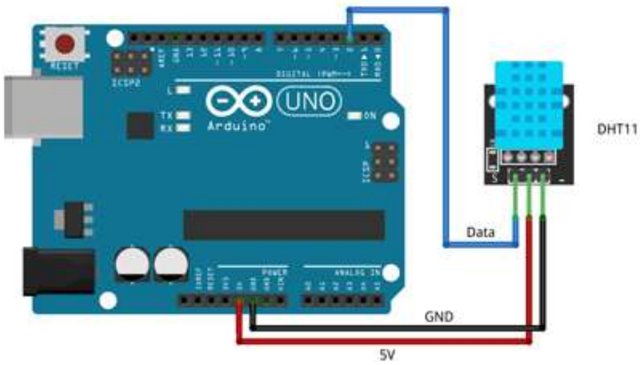


Figure 12 sensor connections DHT11

1.3.9 CO2 concentration sensor CCS811

The CCS811 (see Figure 13) is an ultra-low power digital sensor designed for indoor air quality monitoring. Uses micro-hotplate technology to detect a wide range of volatile organic compounds

(VOCs) in the air. The sensor integrates a microcontroller (MCU) with an analog-to-digital converter (ADC) and an I 2 C interface for communication. To measure the amount of CO2 equivalent (eCO2), the CCS811 uses intelligent algorithms to process sensor raw measurements and return a TVOC value or eCO2 levels.

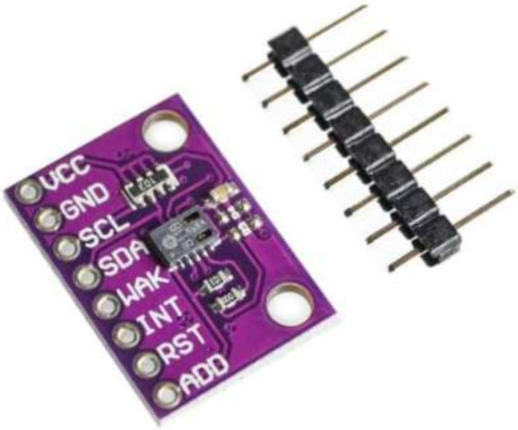


Figure 13 CO2 concentration sensor CCS811

These values are calculated based on the concentration of detected VOCs, mainly from human sources. The sensor supports several measurement modes optimized for low power consumption, both during active measurement phases and in sleep mode to extend battery life in portable applications. The sensor pinout is shown below (see Figure 14).

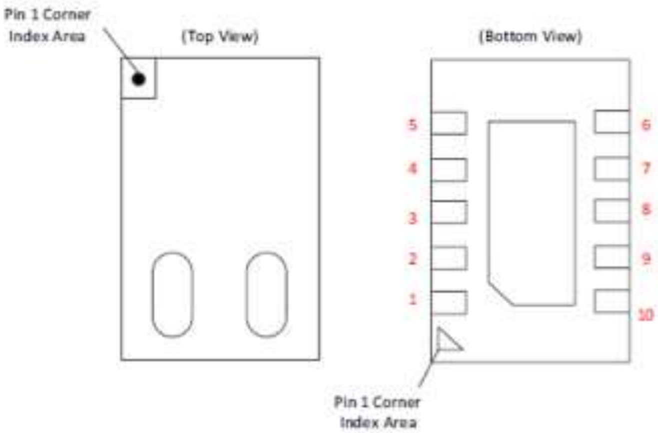


Figure 14 CO2 sensor

1.3.10 Water level sensor; Model n: ZP4510

The ZP4510 (see Figure 15) water level sensor is a compact and reliable float switch, well-suited for monitoring liquid levels in various applications, from domestic tanks to industrial systems. Thanks to its simple installation and magnetic operating principle, it offers an effective solution for level detection in university projects.

Figure 15 Water level sensor; Model n: ZP4510

Features:

- Max Switching Voltage: 220V DC/AC; Max Switching Current: 1.5 A; Max Breakdown Voltage: 300V DC/AC; Max Carry Current: 3A;
- Max Contact Resistance: 100 Ohm; Temperature Rating: -10 / +85 degree Celsius; Float Ball Material: P.P; Float Body Material: P.P;
- Thread Dia (approx): 9.5mm / 0.374", Switch Body Size: 23.3 x 57.7mm / 0.9" x 2.27" (Max D*H); Cable Length: 36cm / 14.2".

1.3.11 Temperature sensor DS18B20

This type of sensor (see Figure 16) is suitable for measuring the temperature of the environment, but also of soil or liquids thanks to the waterproof weld connected by rubber-coated cable. The DS18B20 is accurate enough to measure temperatures from -55°C to +125°C with an accuracy of 0.5°C and the integrated chip converts the analog signal into a digital signal from 9 to 12 bits (configurable).

Figure 16 Temperature sensor DS18B20

The module is powered by a 3-to-5.5-volt source and has its own serial number (each DS18B20 module has its own unique serial number). This particular feature allows to have several modules connected to the same port of Arduino because the software present in the libraries is able to recognize the number and then provide the temperature of each individual environment where a module is placed.

The module can also be powered by the energy present on the line in which the data flow, so it is possible to limit the connections to only ground and data line.

The sensor is based on the OneWire protocol introduced by Dallas Semiconductor now Maxim and requires two libraries. The first is the library and Dallas Temperature by Miles Burton, the second is the OneWire library, both retrieved from the Arduino IDE library manager.

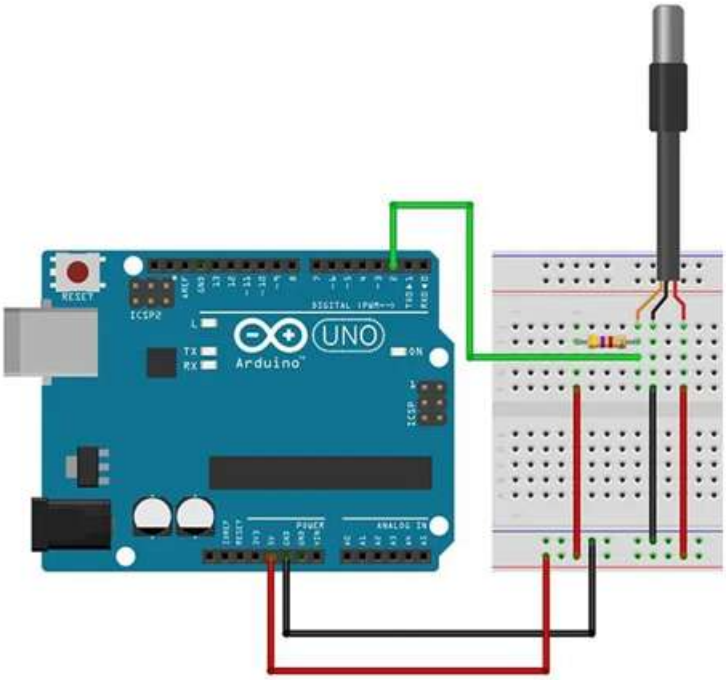


Figure 17 connection diagram temperature probe

The connection is extremely simple, as shown in the image below connect the red cable to 5V or 3.3V on 3.3V cards, the black cable must be connected to the GND and the "Out" signal cable, usually yellow, white or other colour, connect it to a digital pin, in the example is connected to pin 2 with a Pull-up resistance of 5 kΩ between the signal and the power supply pin (5 V or 3,3 V). (see Figure 17 and Figure 9).

The sensors are held in position by interlocking in special housings made in the wooden structure, more precisely it is "cable pass" for the TDS sensors and the temperature probe and a specific saddle for the pH sensor, so that it is positioned as close to the bottom as possible, so that it can carry out measurements even in the presence of little water. The height of the TDS and Temperature probes can be adjusted by simply pulling or releasing the cable. Connections are shown in figure 9.

The Arduino UNO R4 Wi-Fi board is internally equipped with the Wi-Fi module ESP32 which can communicate wirelessly. The PLC provides the possibility to talk via Ethernet cable with the HMI, so the physical system needs a Wireless Access Point to talk Arduino and PLC. The complete system can then be depicted in the diagram below shown in Figure 18, by inserting a properly set Wi-Fi repeater to become an Access Point, equipped with its own IP address and Mac.

Figure 18 Schematic of ethernet connections

The computer will be connected to the system for simple loading of the Ladder program into the PLC, then the system will be operated from the operator panel without the use of the computer. The S7-1200 CPU has 14 24 Volt digital inputs, 10 digital outputs, 2 analog inputs and 2 analog outputs, while the Arduino has 14 digital I/O (including 6 pin PWM) and 6 analog channels.

The sensors are held in position by interlocking in special housings made in the wooden structure, more precisely it is "cable pass" for the TDS sensors and the temperature probe and a specific saddle for the pH sensor, so that it is positioned as close to the bottom as possible, so that it can carry out measurements even in the presence of little water. The height of the TDS and Temperature probes can be adjusted by simply pulling or releasing the cable. The connections have already been described in chapter 2 dealing with the individual components, so here we propose a graphical view of all the sensor connections, in Figure 9.

2 Hardware Design

The hardware design includes some functional parts that can be easily acquire in the market.

2.1 Functional Parts

The hardware design includes some functional parts that shall be easy to find and to acquire by the teaching professionals. In this case, the following functional elements:

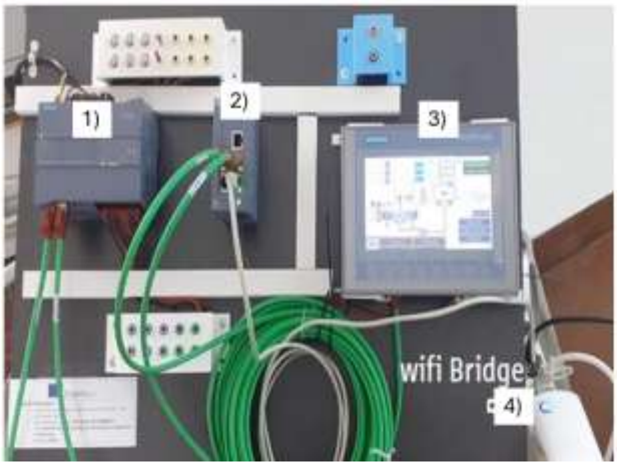
- PLC S-7 1200 CPU 1215C AC/DC/RLY;
- Arduino UNO R4 WIFI;
- SCALANCE XB005 Ethernet Switch;
- SIEMENS HMI Panel KTP700;
- h20 temperature sensor (Arduino kit);
- Tds h20 sensor (Arduino kit);
- ph h20 sensor (Arduino kit);

- Temperature and humidity sensor (Arduino kit);
- Air co2 sensor (Arduino kit);
- Peristaltic pumps (DC motors);
- 1 channel 5V Relay module;
- RC engine type "Boat Drive";
- Float water level sensors;

• Wireless Wifi Extender and Tp-Link Access Point

2.2 Mechanical Design

The hardware design includes some functional parts that shall be easy to find and to acquire by the teaching professionals. In this case, the following functional elements have been selected or printed:



1. PLC S-7 1200 CPU 1215C AC/DC/RLY;
2. SCALANCE XB005 Ethernet Switch;
3. SIEMENS HMI Panel KTP700;
4. Wireless Wifi Extender and Tp-Link Access Point.

Figure 19. Test bed scheme

Figure 20 Relay and actuator wiring

Figure 20 shows the front view of the connections to the actuators and the control circuit supplying the relays. The bus of the control signals of the Arduino starts from the digital pins 6,7,8,9 and 11 and branches each towards a relay. The power supply is ensured by others 2 cable buses (one for the phase and one for the neutral) running laterally on the left until connecting to the phase and the neutral of the Breadboard.

Figure 21 Test bench in operation

3 Software Design

The software is designed to be usable by any user (professors/students). This type of software will require a license, or you can use the trial version for a limited time. In this way, the PLC S71200 was programmed using its software TIA Portal, https://www.siemens.com).

3.1 Ladder Software

The code of the Ladder software is available, under demand, in MISCE project webpage.

The Ladder software programme has been designed and shown in the following figures

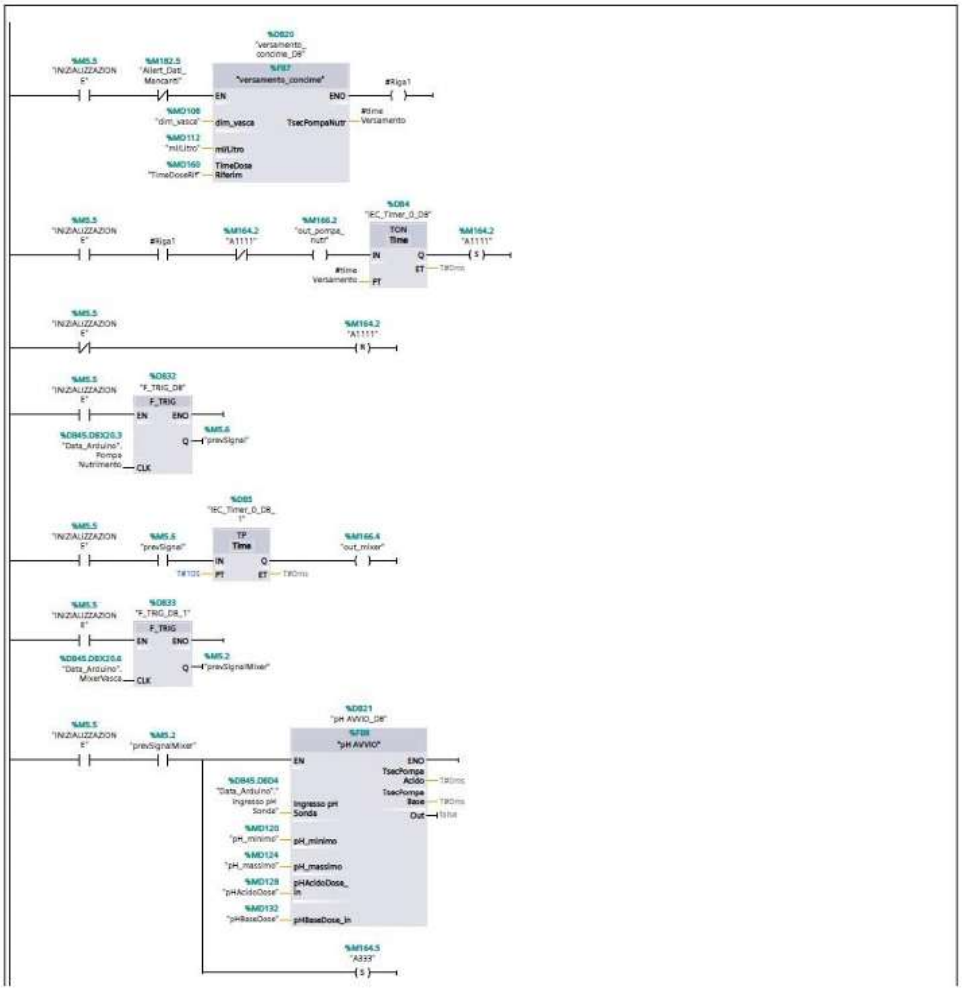
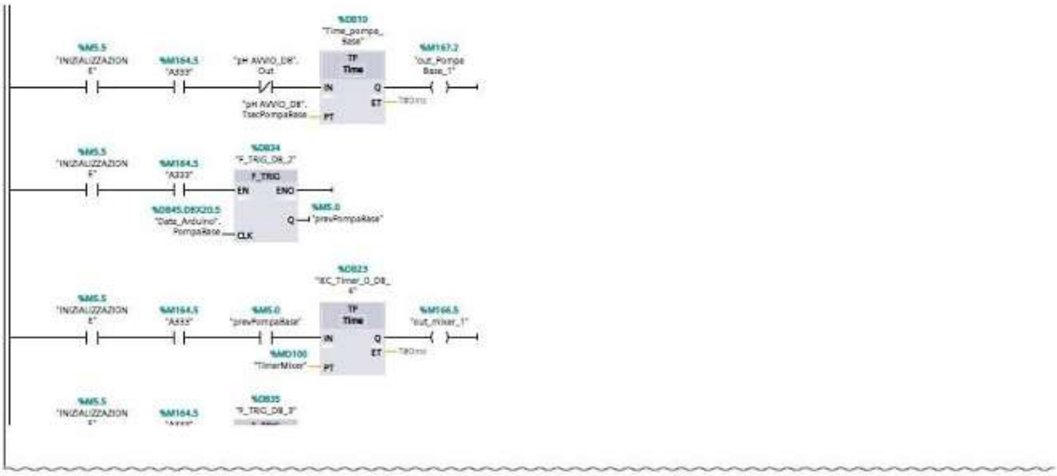


Figure 22 Network 1: the preparatory phase for the start-up of the plant, Network 1.1



2.1 (Page1 - 3)

Totally Integrated Automation Portal

Network 1: Primo Avvio impianto (2.1 / 3.1)

1.1 (Page1 - 2)

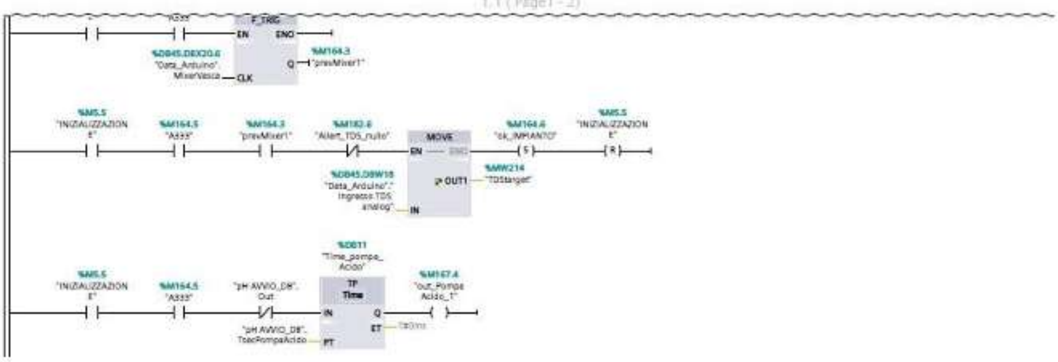


Figure 23 Network 1.2

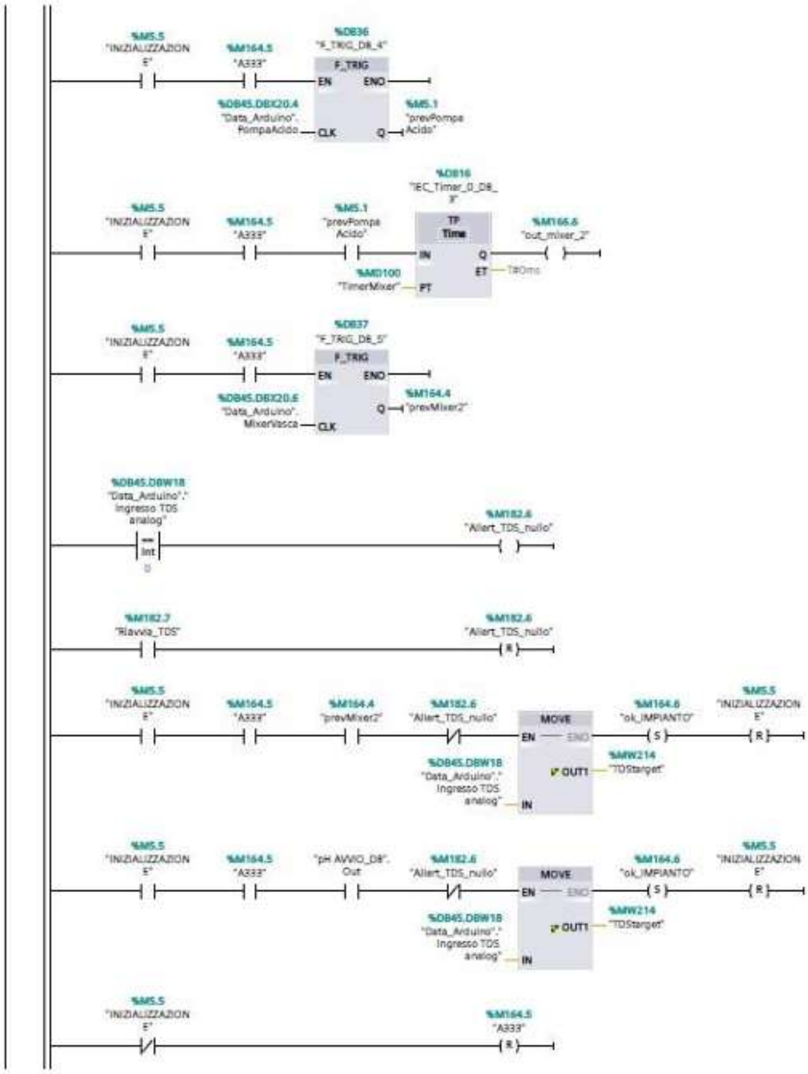


Figure 24 Network 1.3

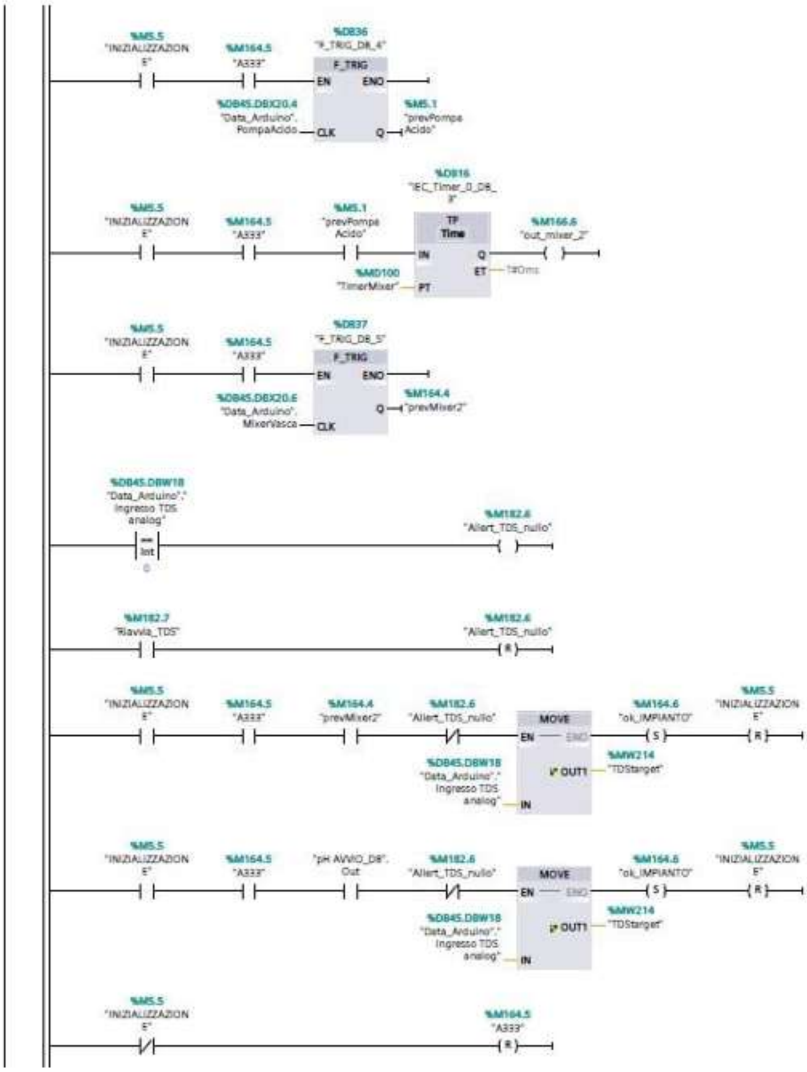


Figure 25 Network 2: start and stop buttons

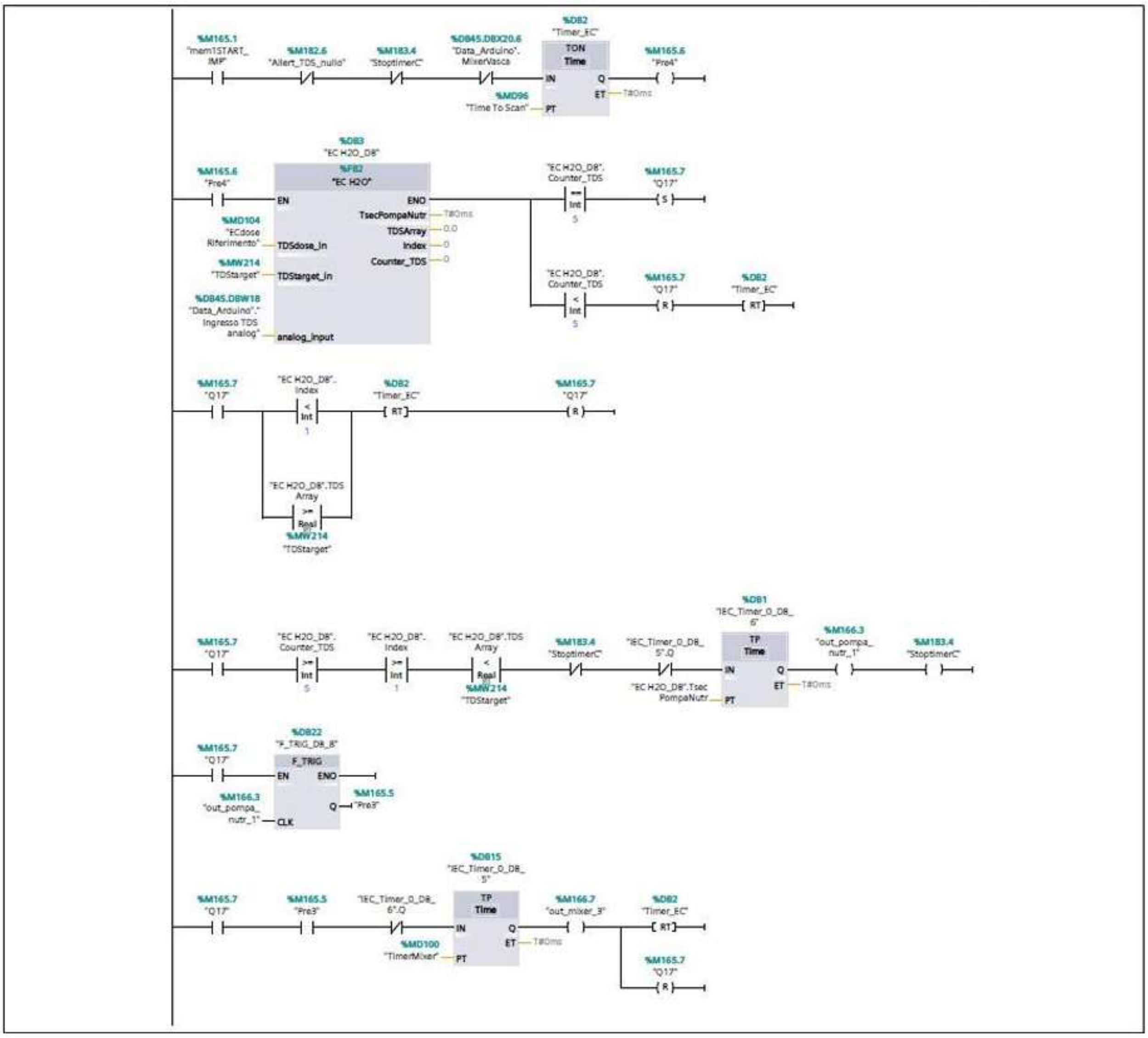


Figure 26 Network 3: TDS Control

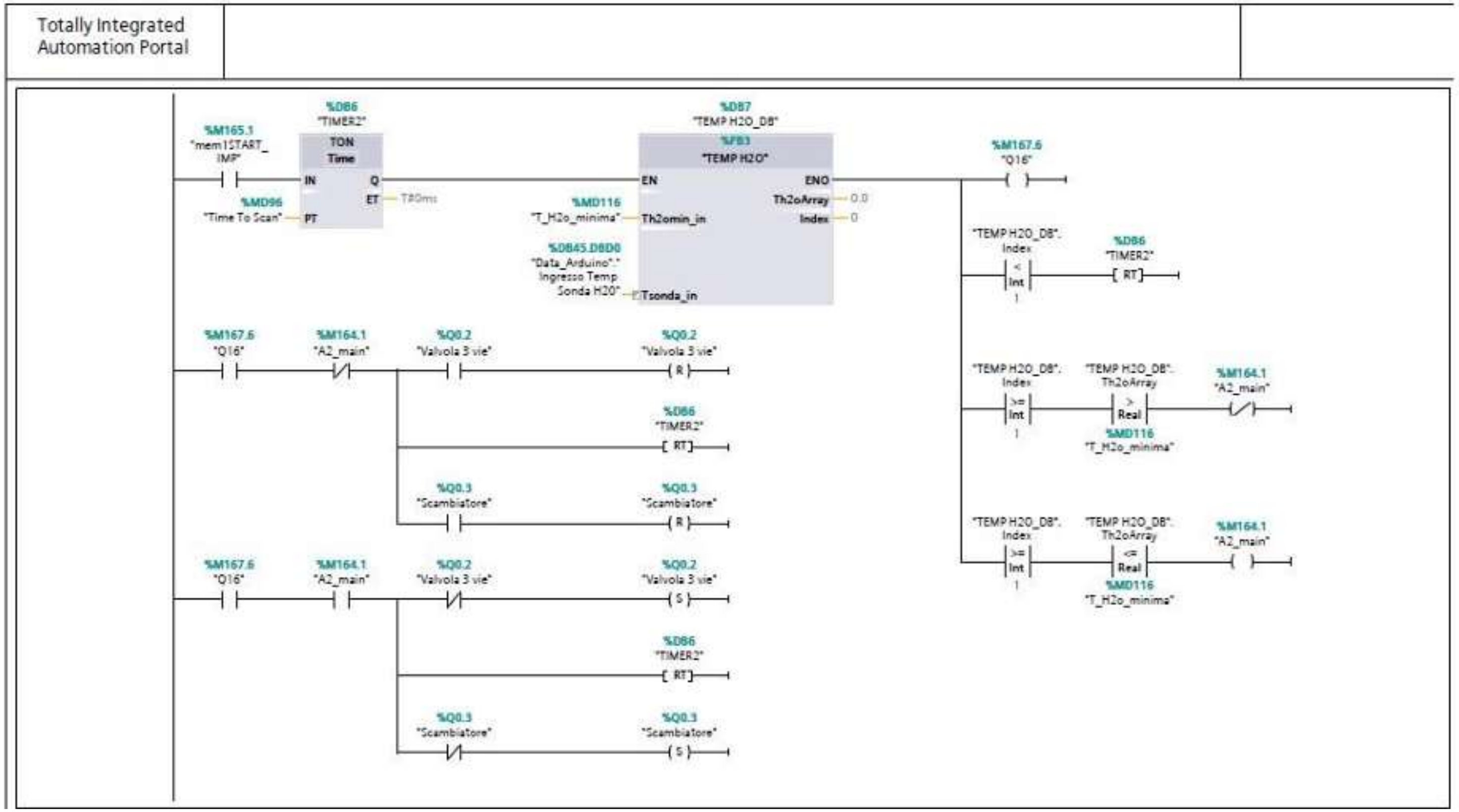


Figure 27 Network 4: water Temperature Control

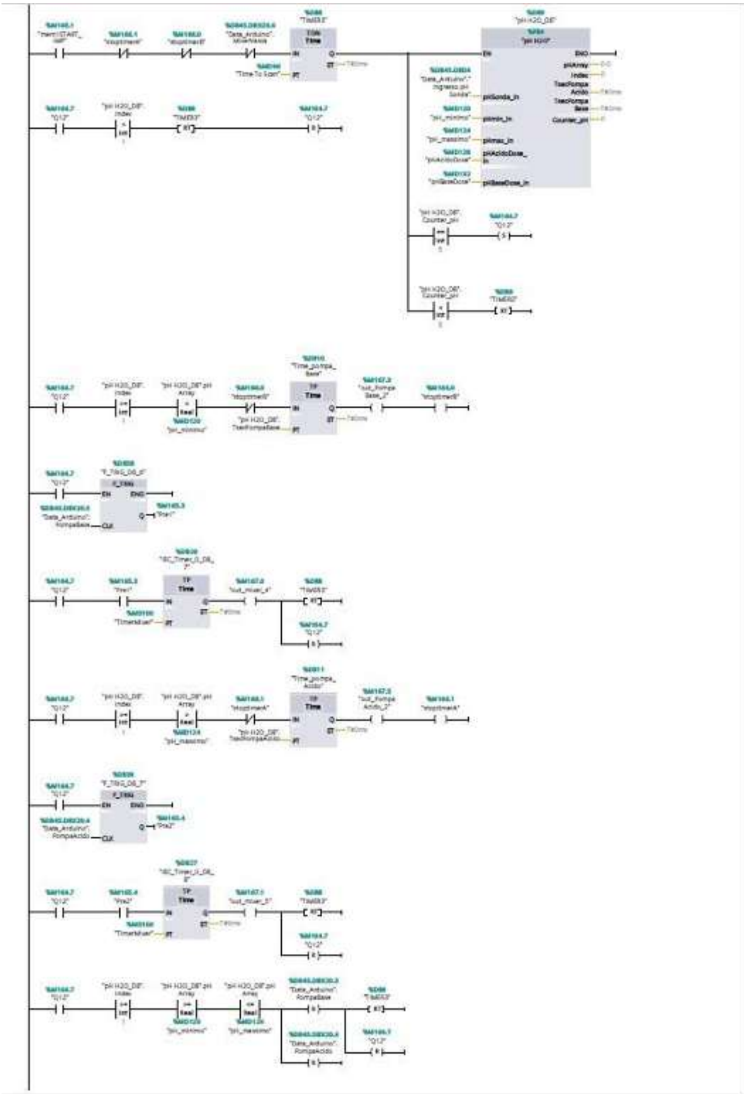


Figure 28 Network 5: PH control of the solution

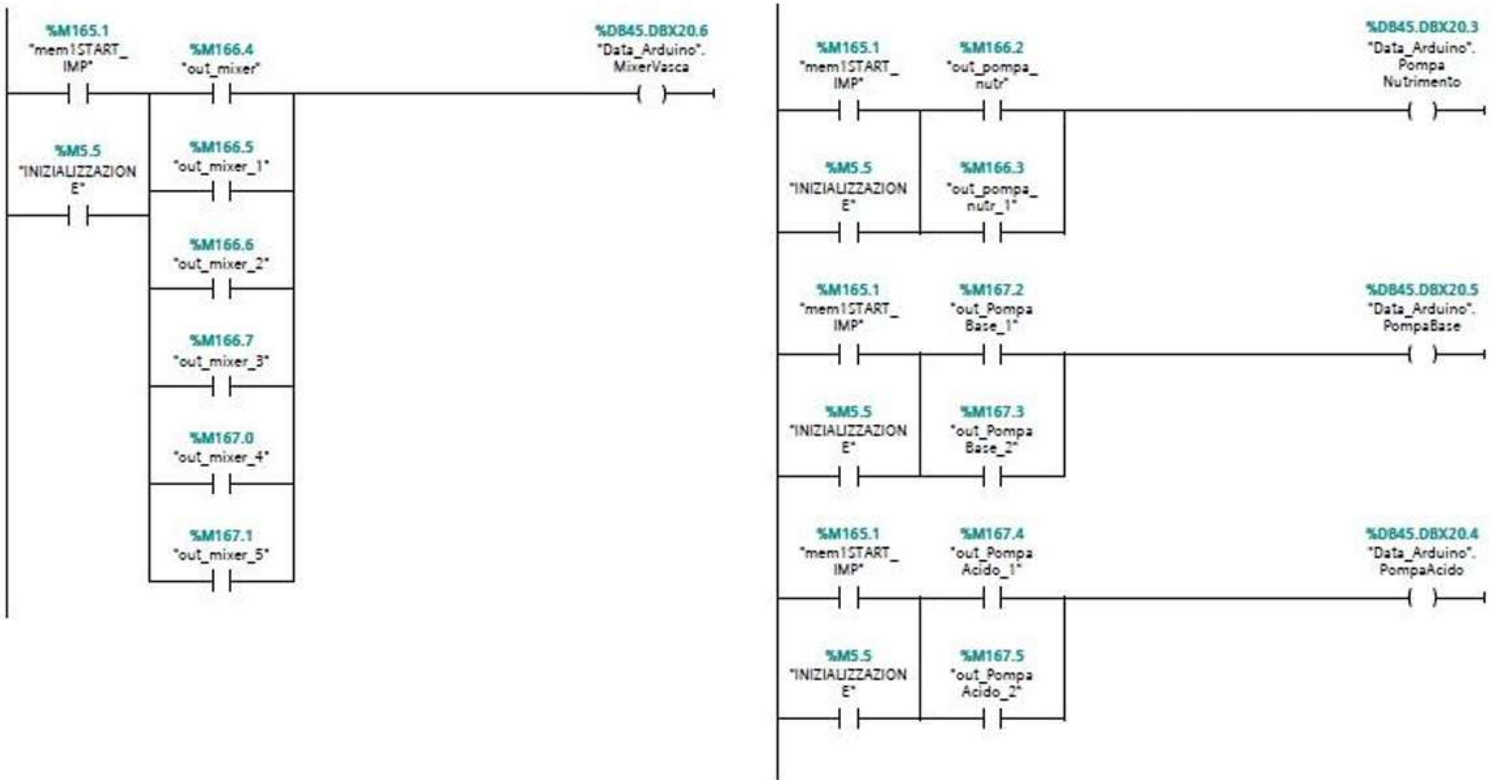


Figure 29 Network 6: activation Coil Tank Actuators

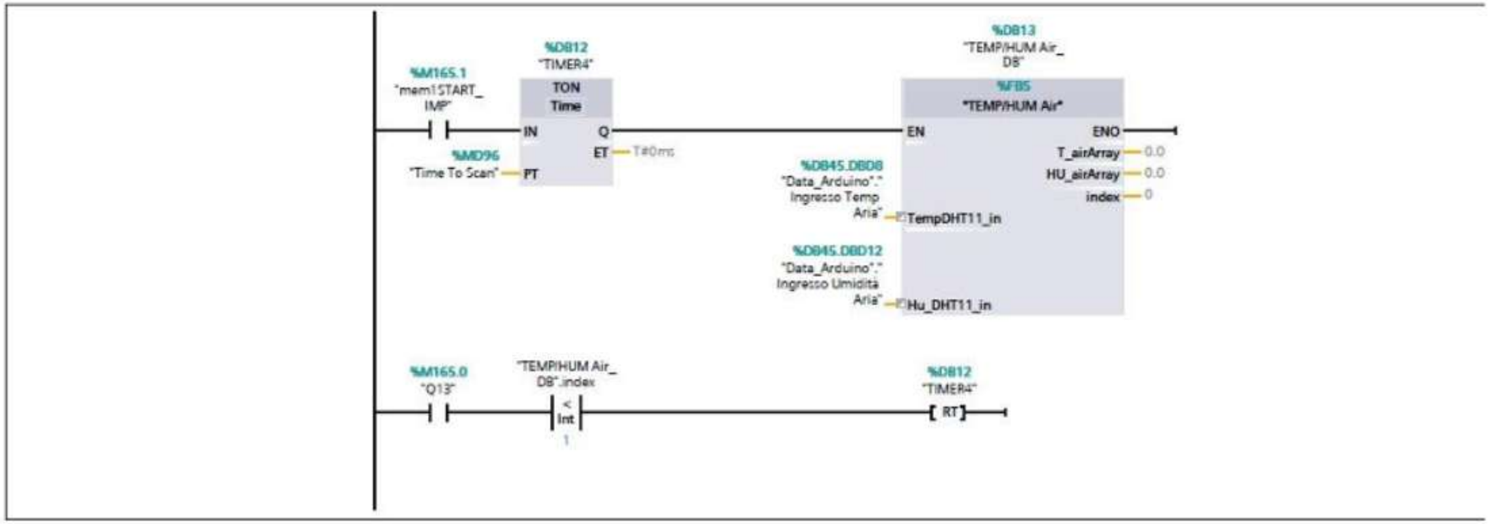


Figure 30 Network 7: ambient temperature and humidity control

In the Networks from the eighth to the 16th are summarized the possibilities given by the various cases where the system can be found (Figure 31):

Figure 31 Case studies of the system

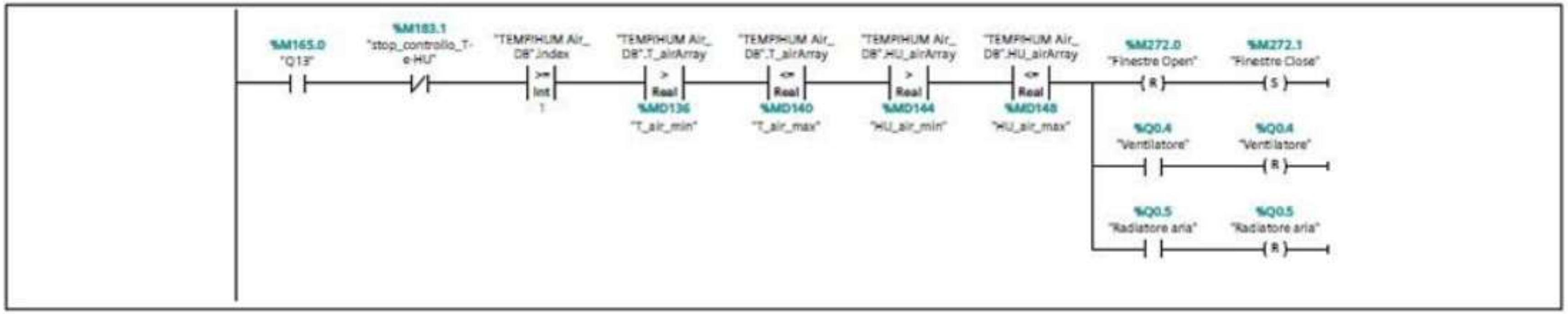


Figure 32 Network 8

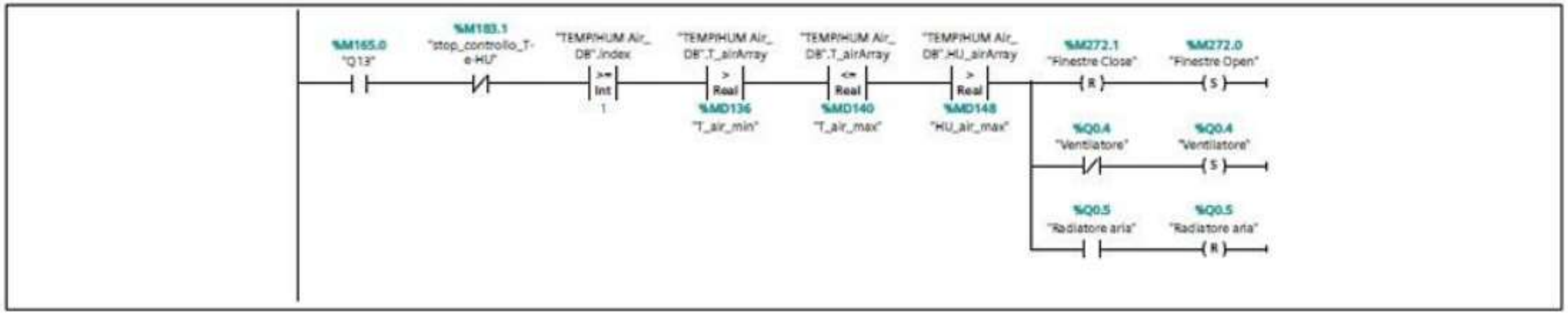


Figure 33 Network 9

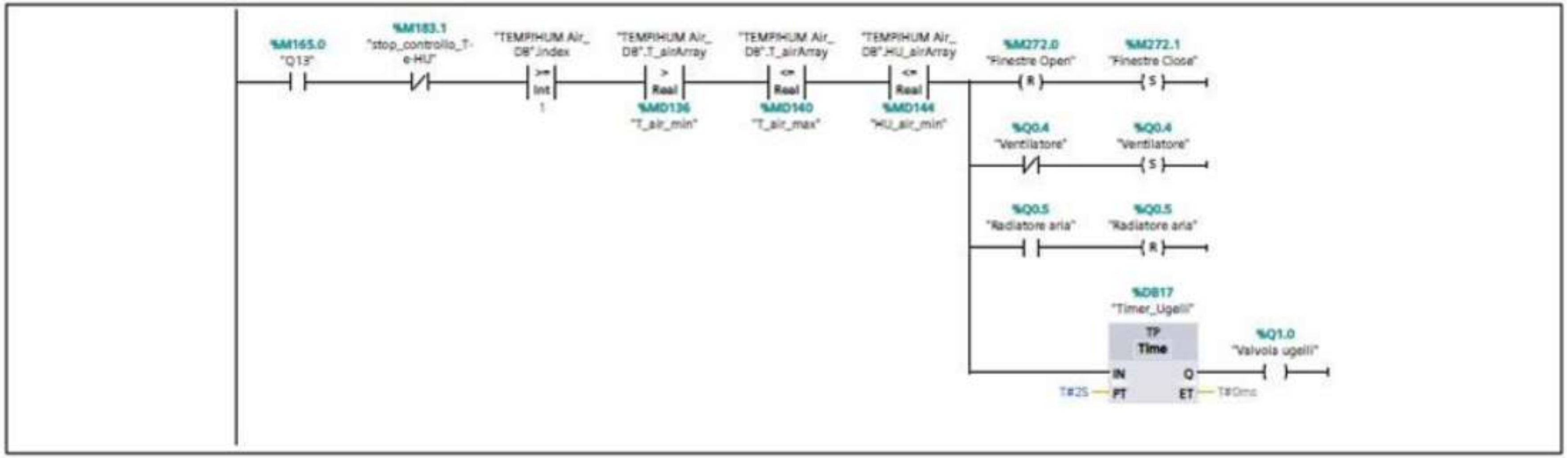


Figure 34 Network 10

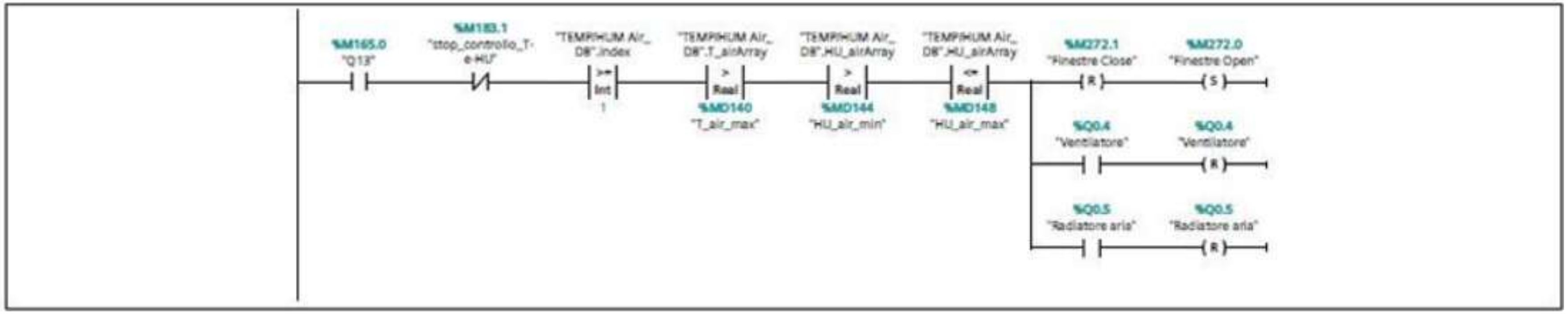


Figure 35 Network 11

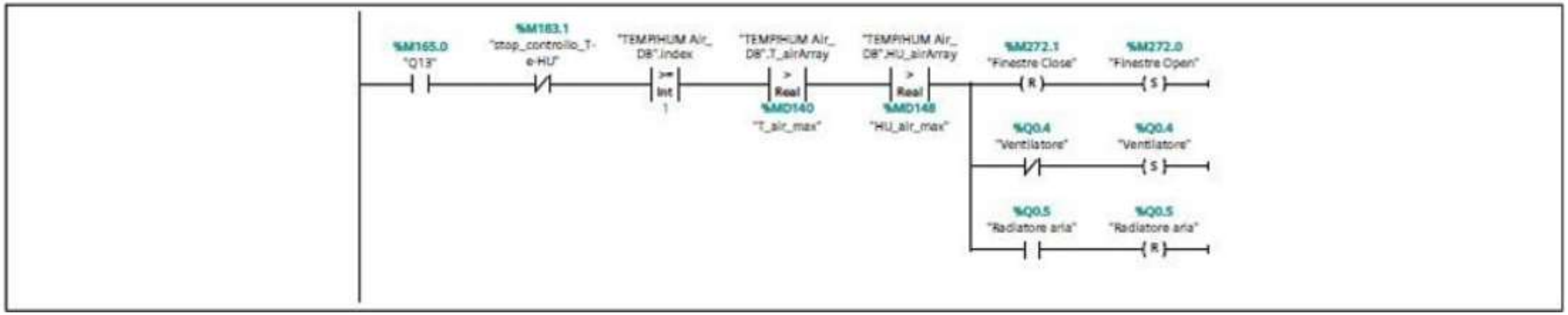


Figure 36 Network 12

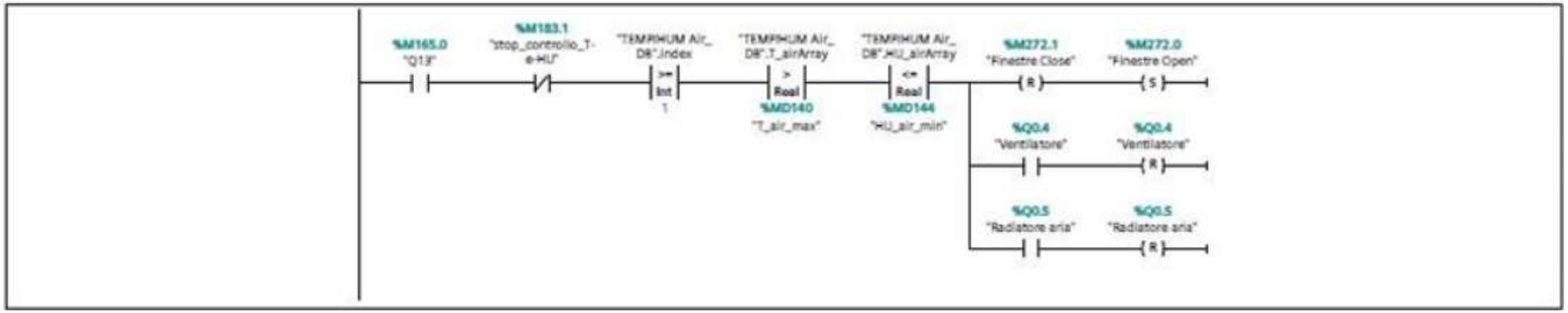


Figure 37 Network 13

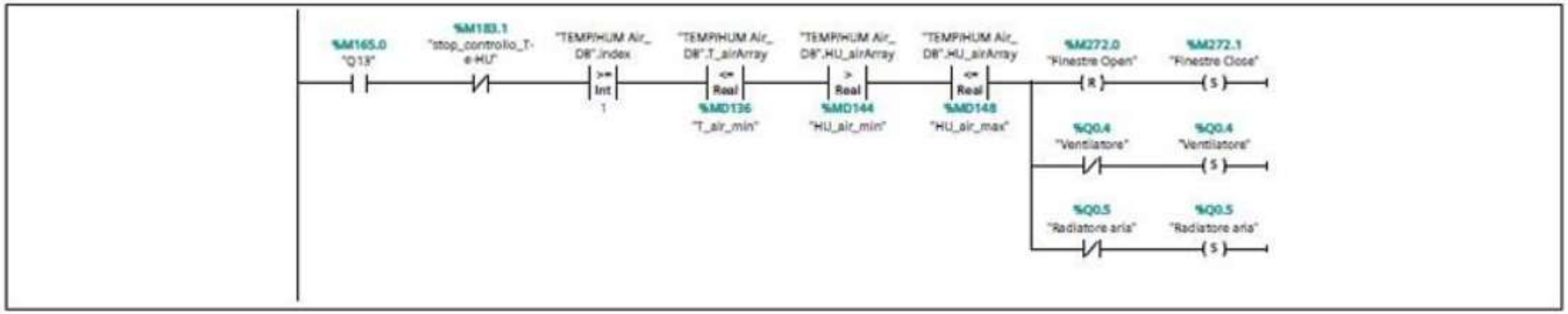


Figure 38 Network 14

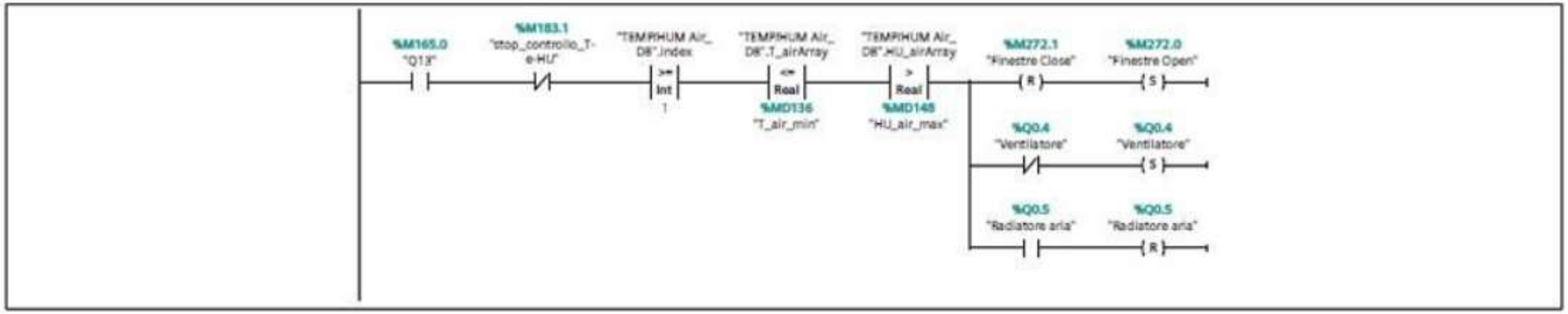


Figure 39 Network 15

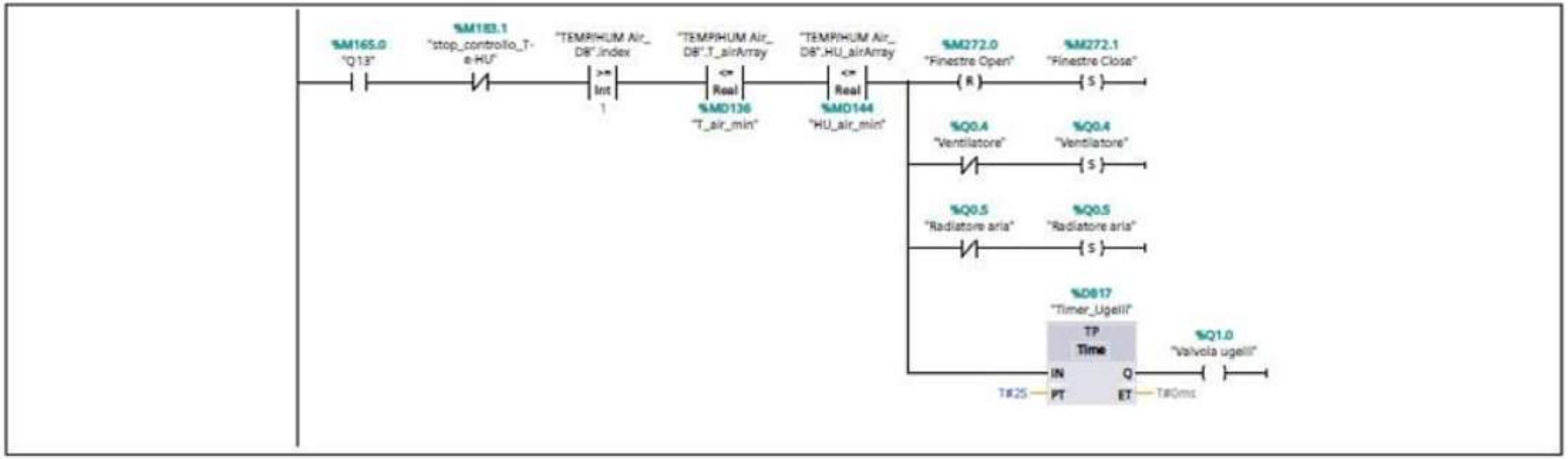


Figure 40 Network 16

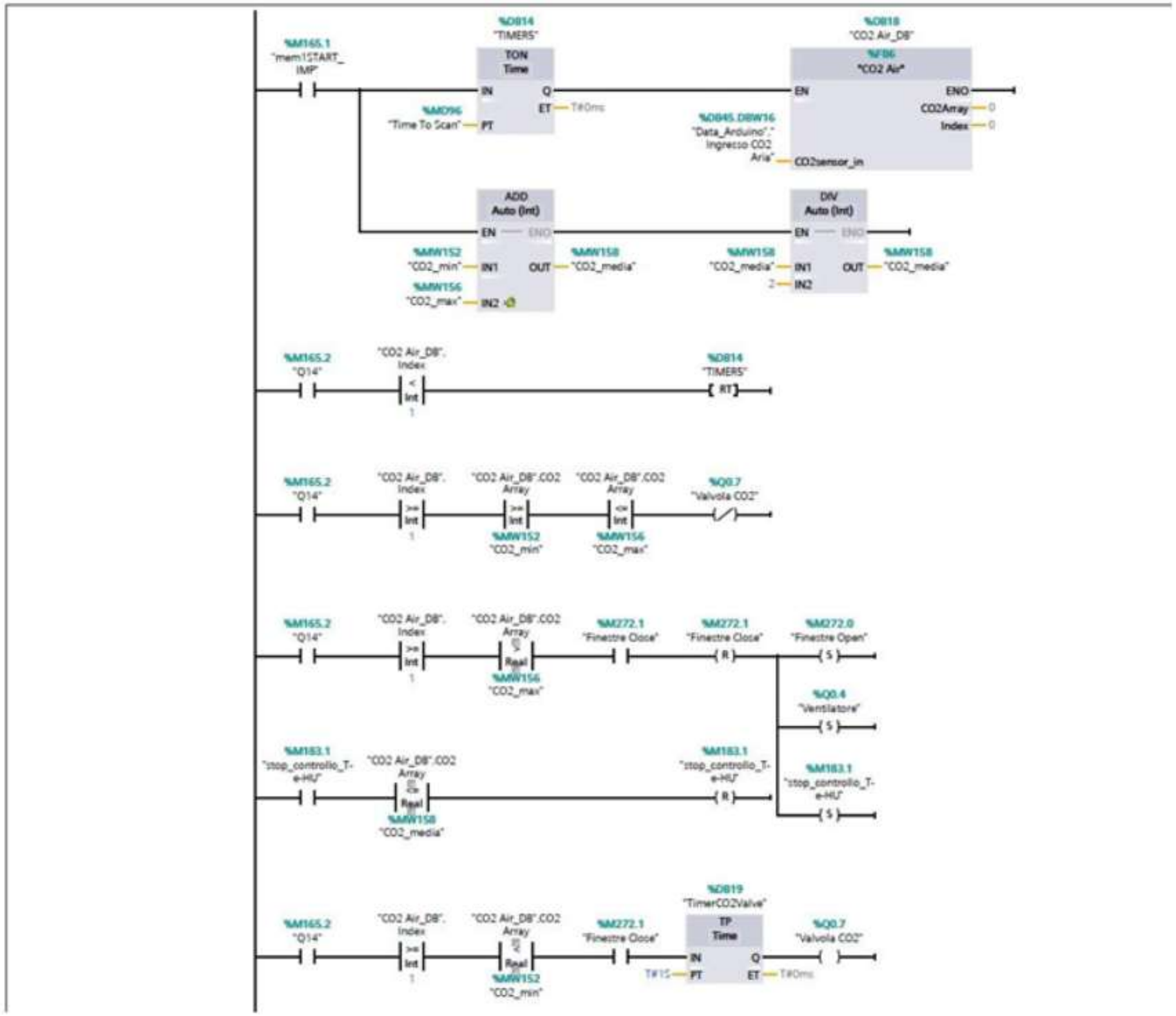


Figure 41 Network 17: CO2 control

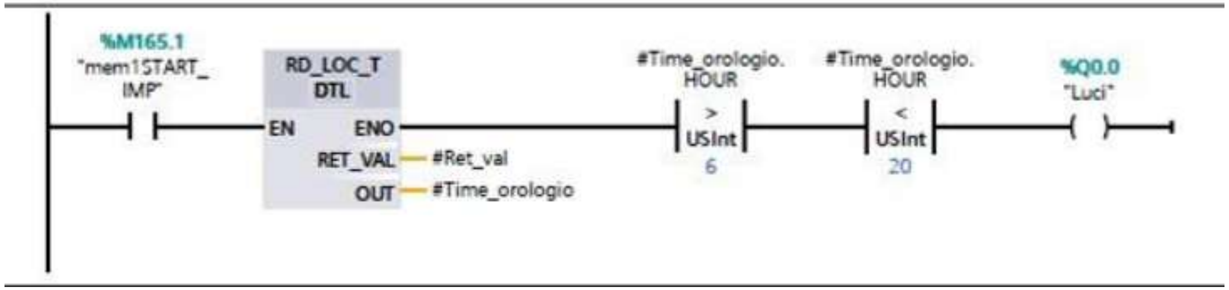


Figure 42 Network 18: light control

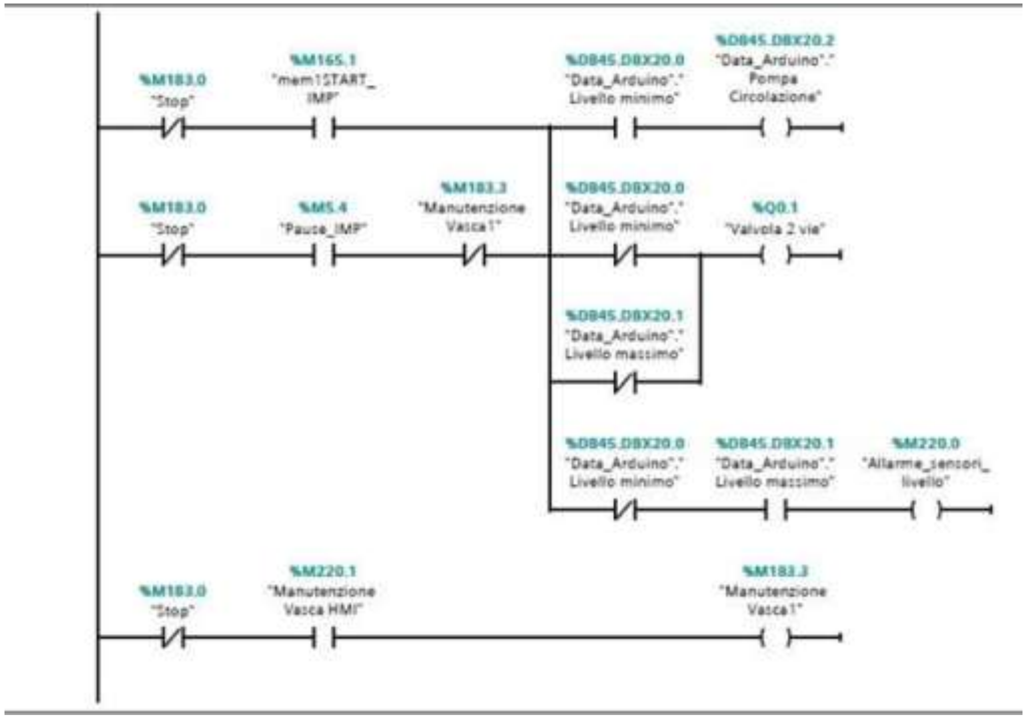


Figure 43 Network 19: circulation pump control

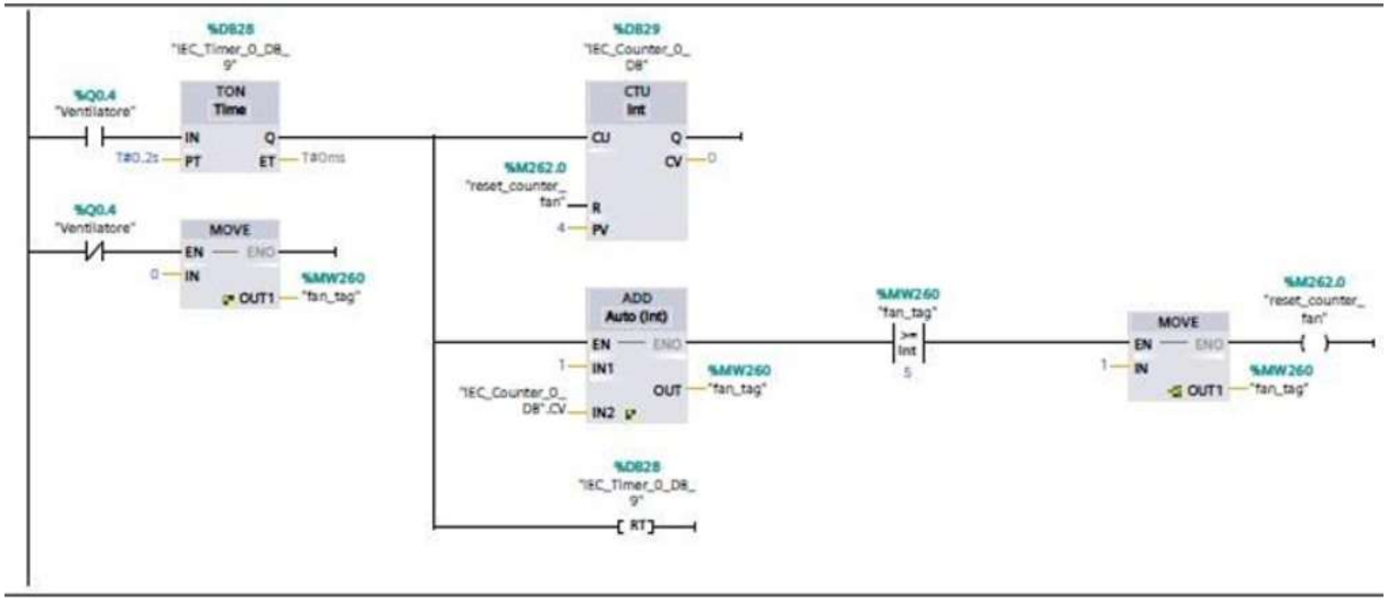


Figure 44 Network 20: fan Graphic Creation

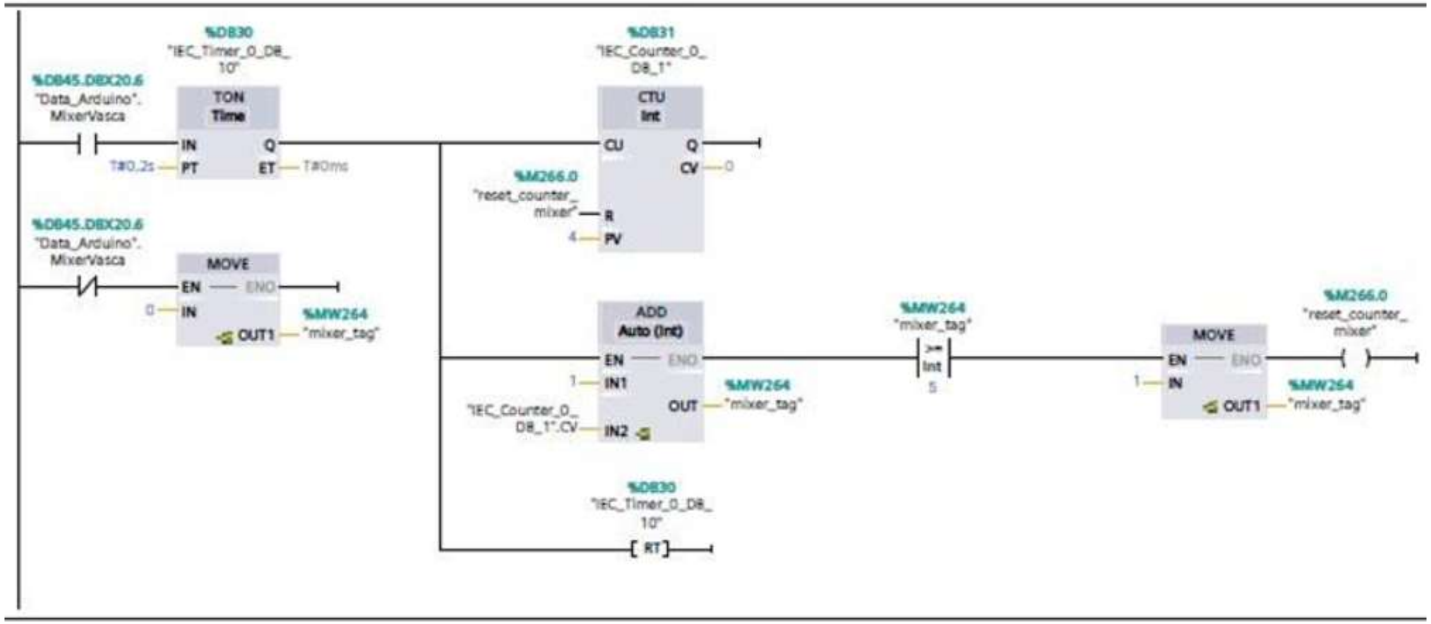


Figure 45 Network 21: graphic Creation of the Mixer

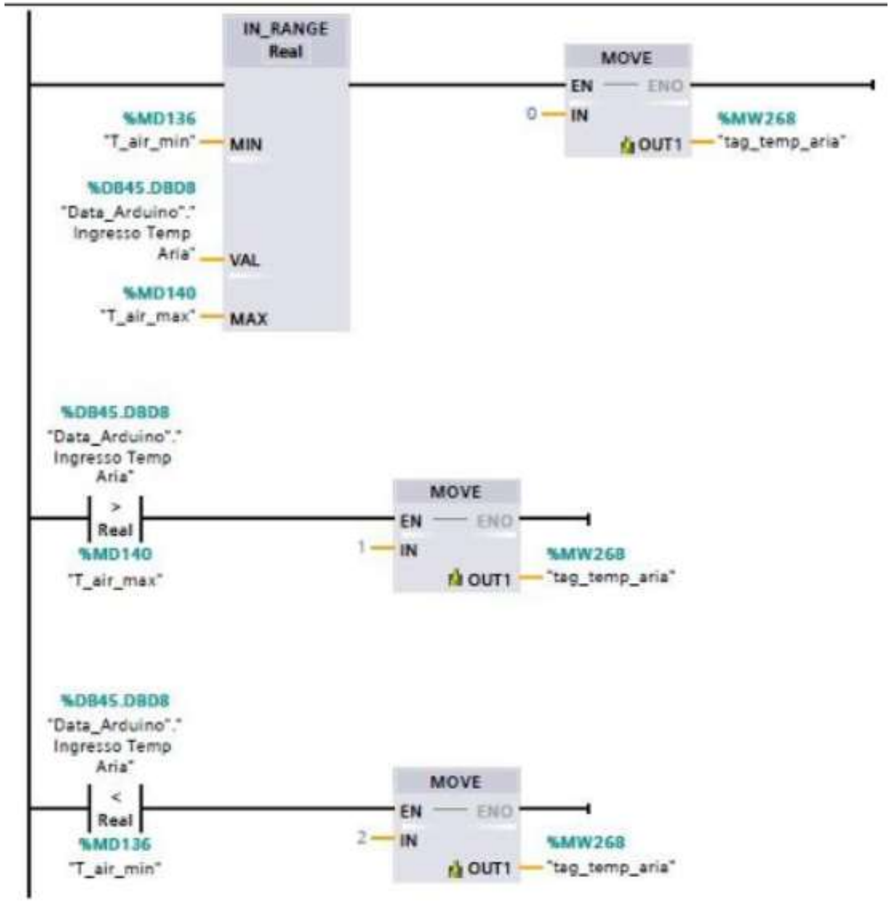


Figure 46 Network 22: Graphic creation of temperature status

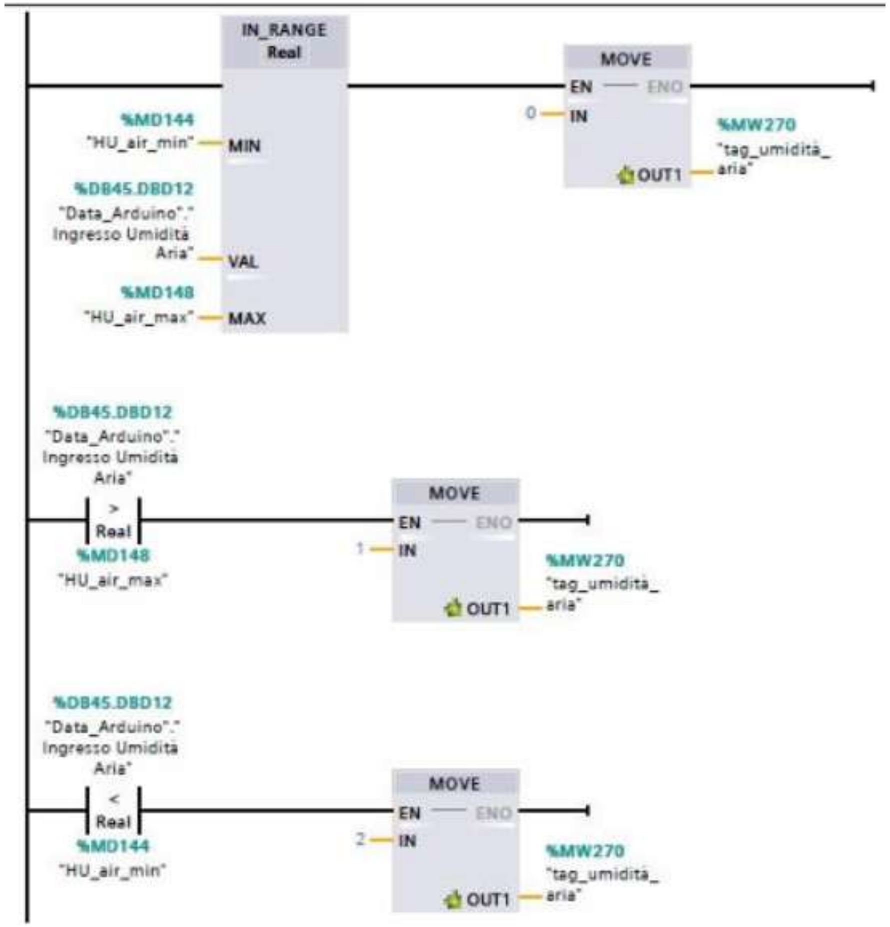


Figure 47 Network 23: graphic Creation Moisture State

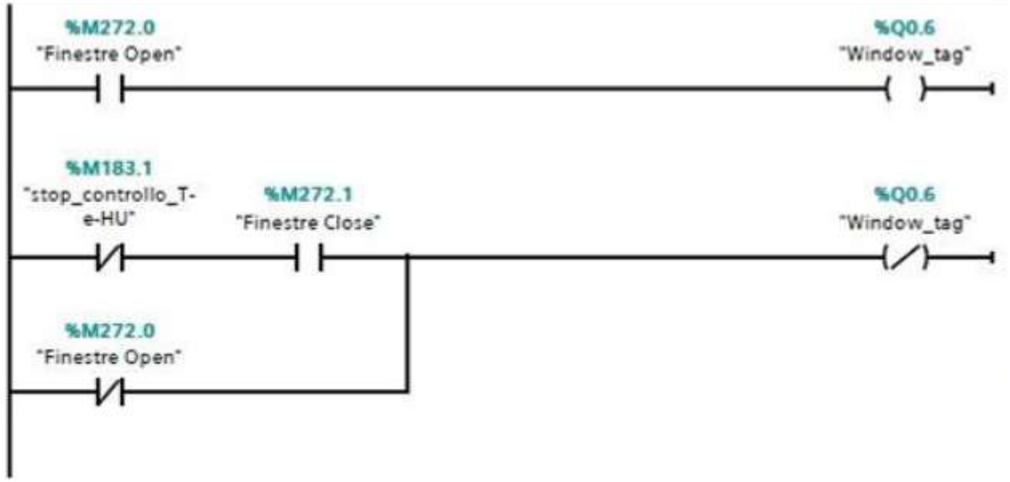


Figure 48 Network 24: window and Output Graphics

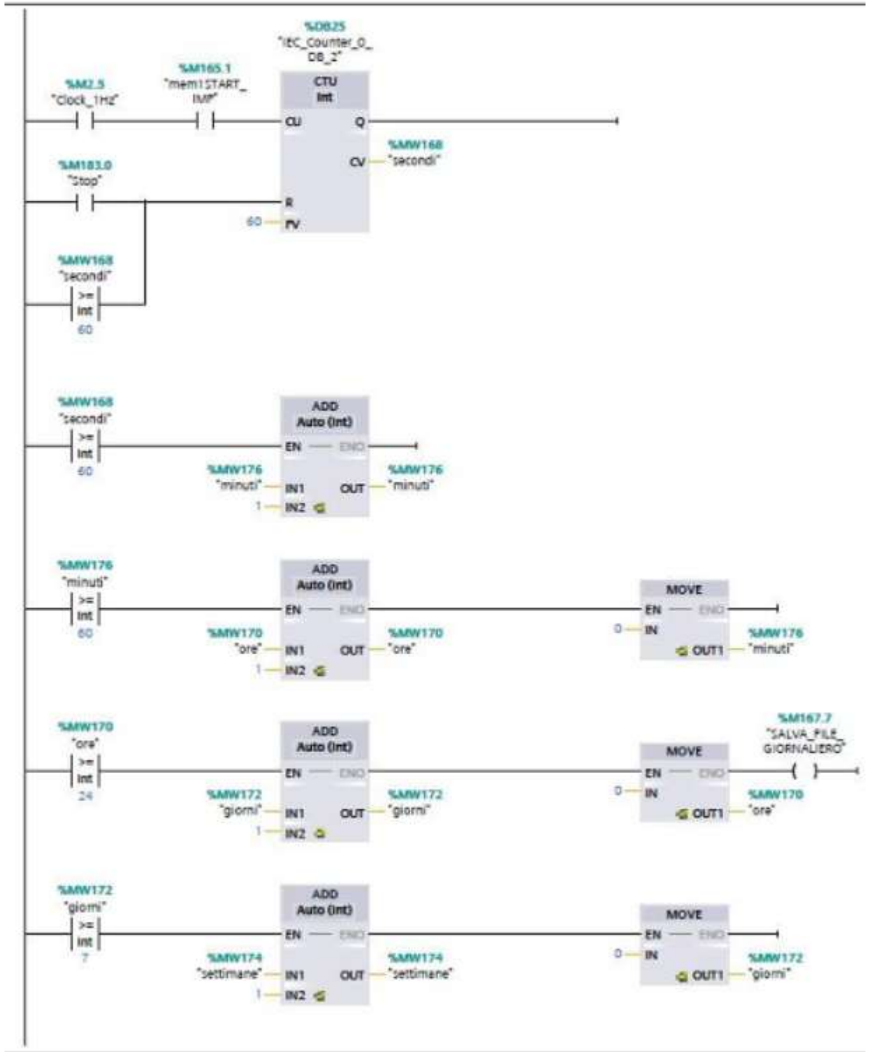


Figure 49 Network 25: plant operating time

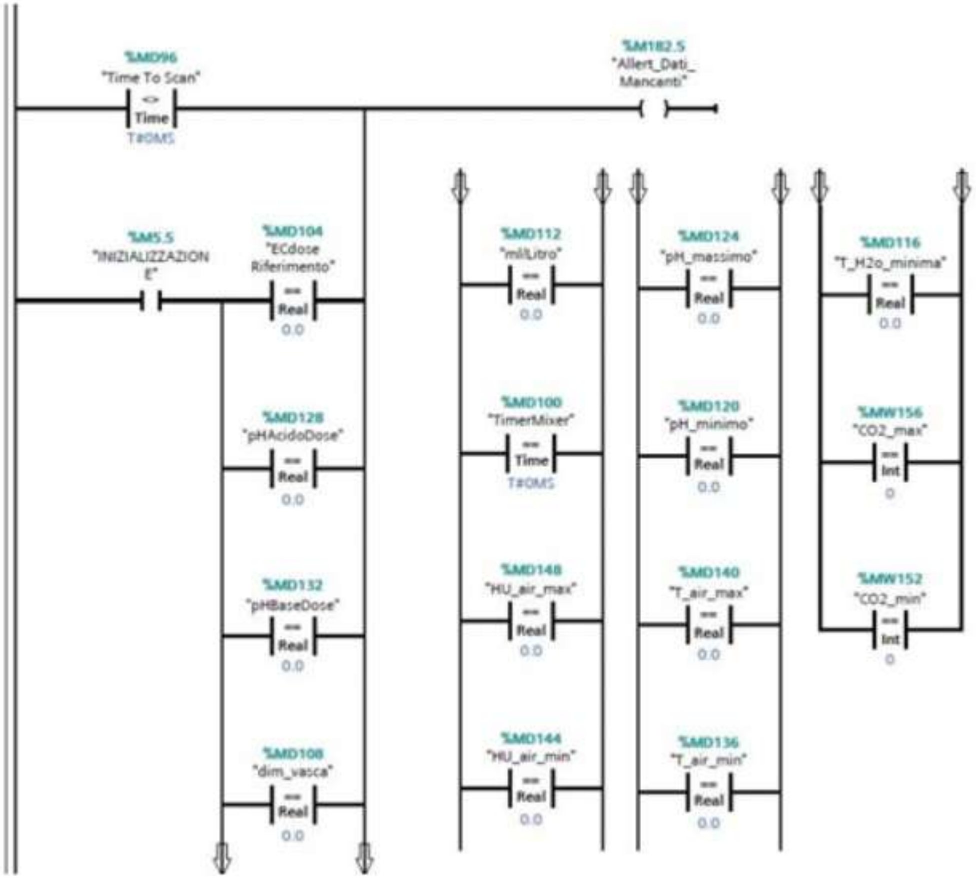


Figure 50 Network 26: missing data warning

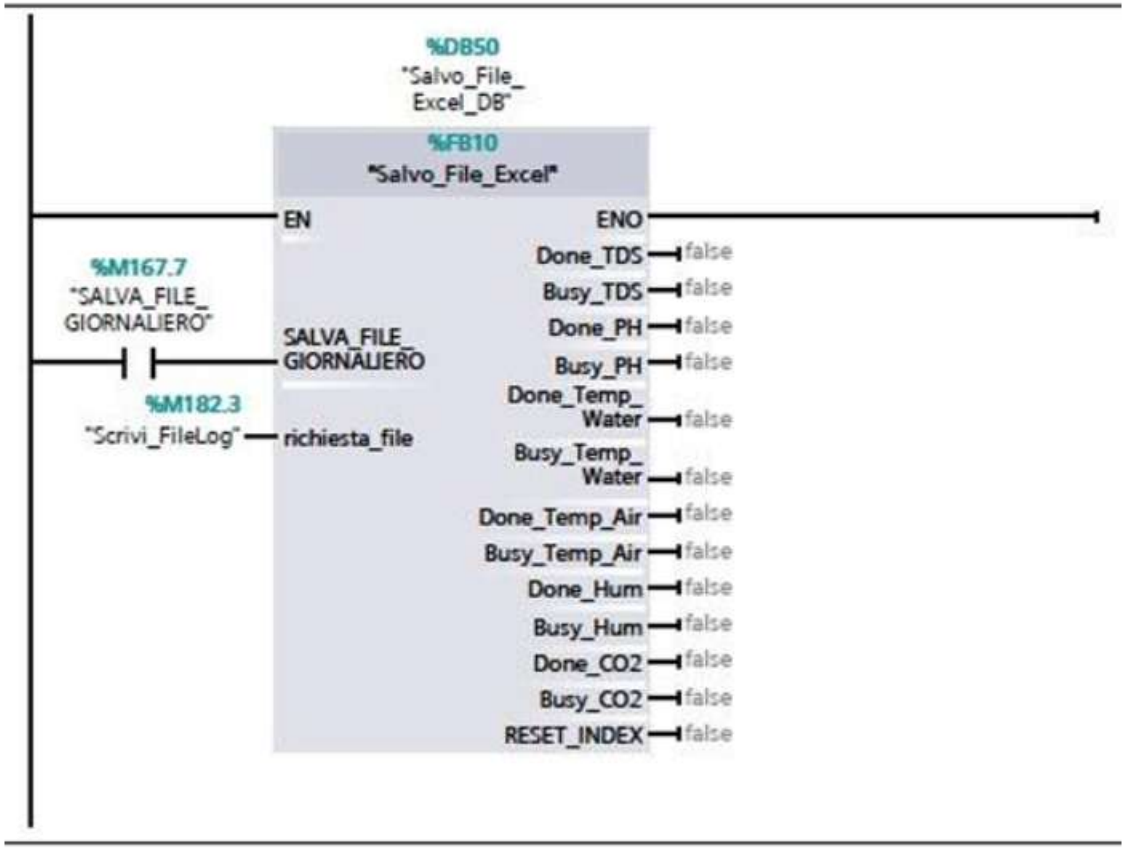


Figure 51 Network 27: saving vector files

The functions used in the Main are listed and explained below.

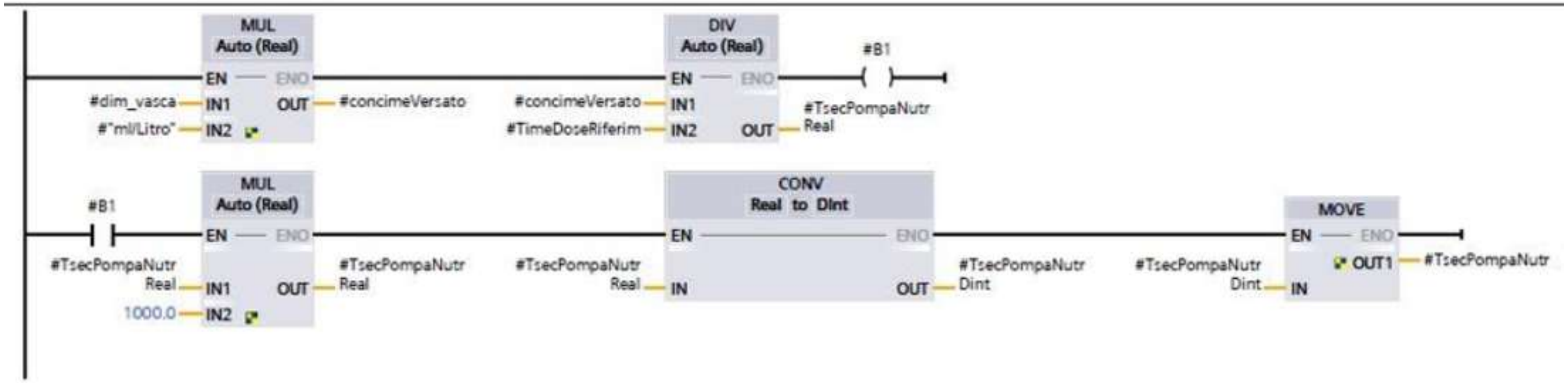


Figure 52 FB7: manure pouring at start-up

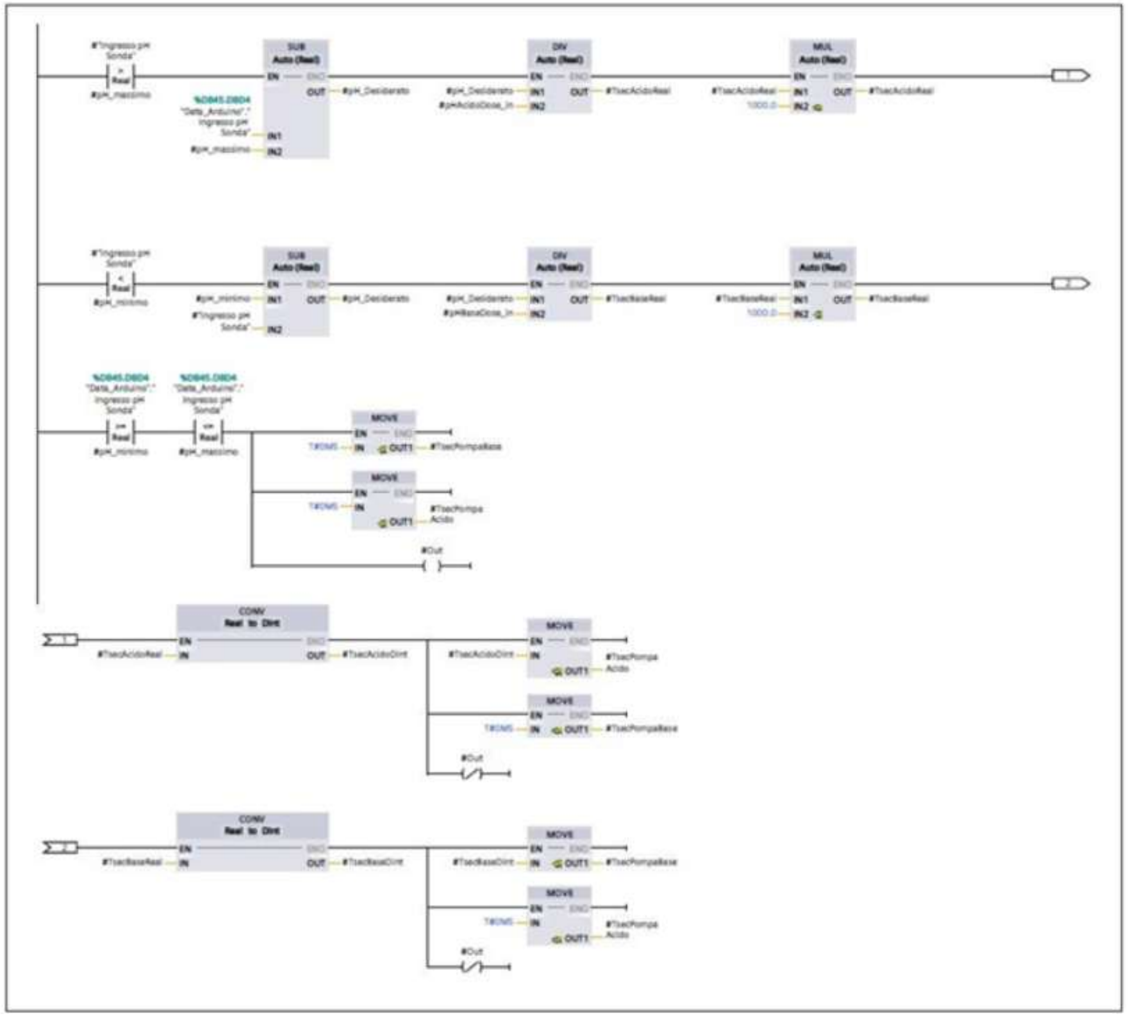
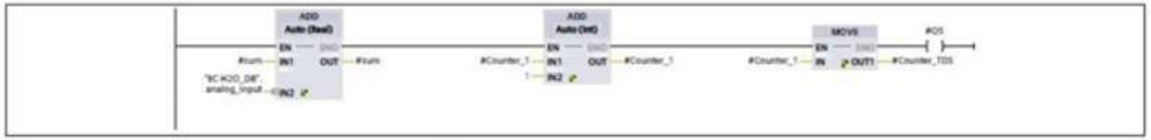
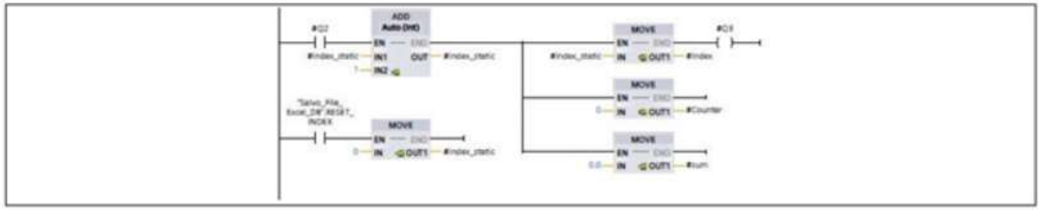


Figure 53 FB8: PH control at startup



Network 2: se contatore =5 calcola media e chiamala ECArray e sblocca riga 3



Network 4: confronto valori EC con target e scrittura output

Network 5:

Figure 54 FB2: continuous Total Dissolved Solids (TDS) Monitoring

Network 2: se counter = 5 fai la media e scrivi il risultato in Th2oArray e sblocca riga successiva

Network 3: calcola indicex per il futuro vettore, resetta sum e counter per la prossima conta e scrive output "Index" e "A2"

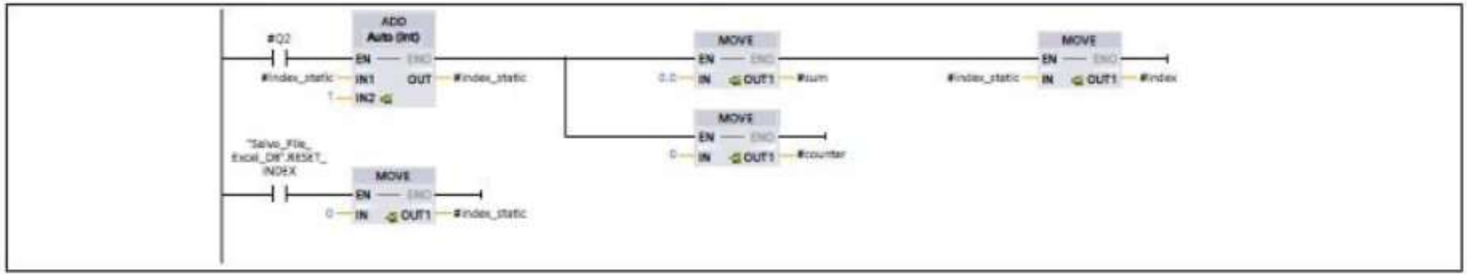


Figure 55 FB4: water temperature control

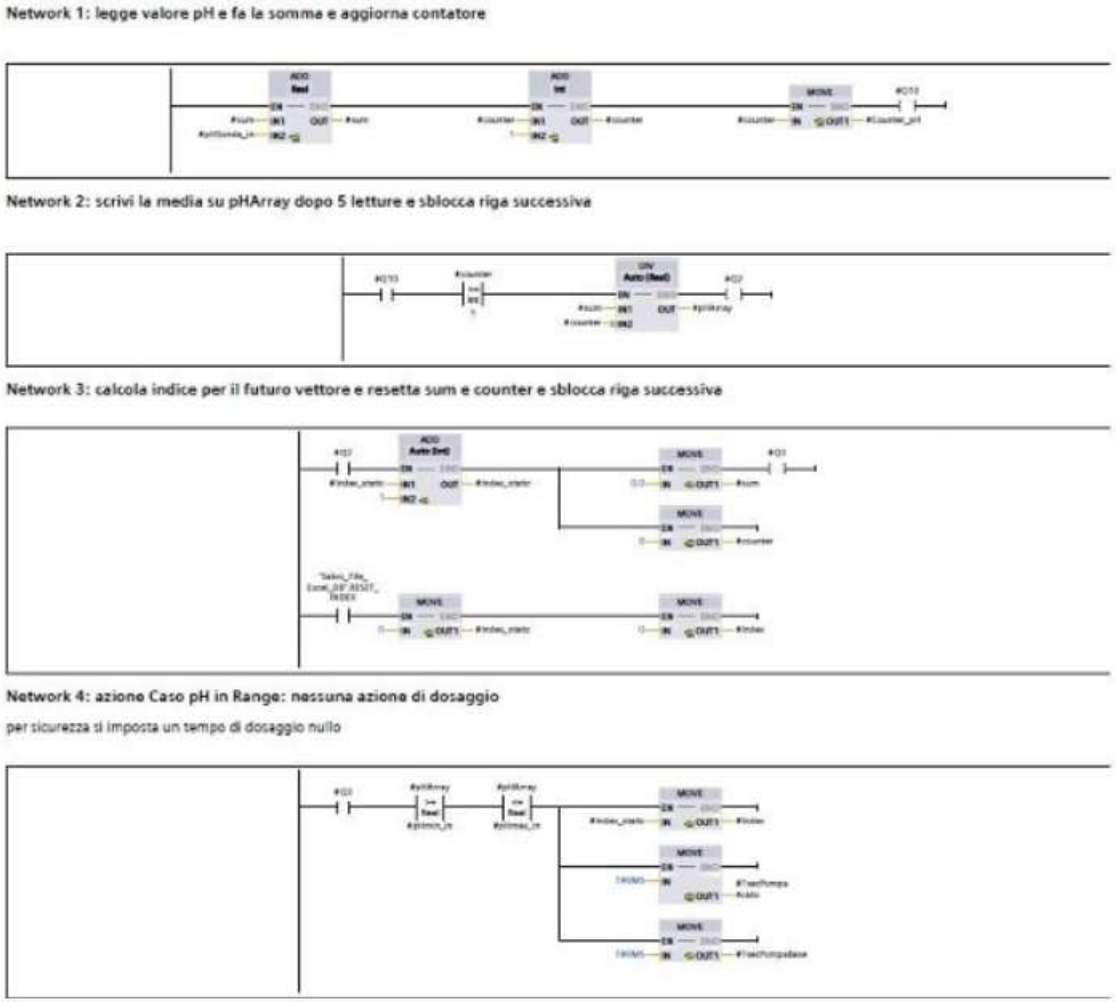
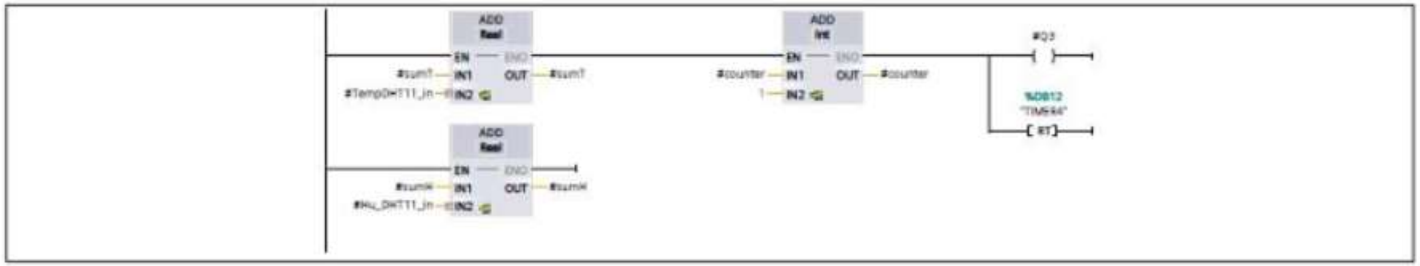
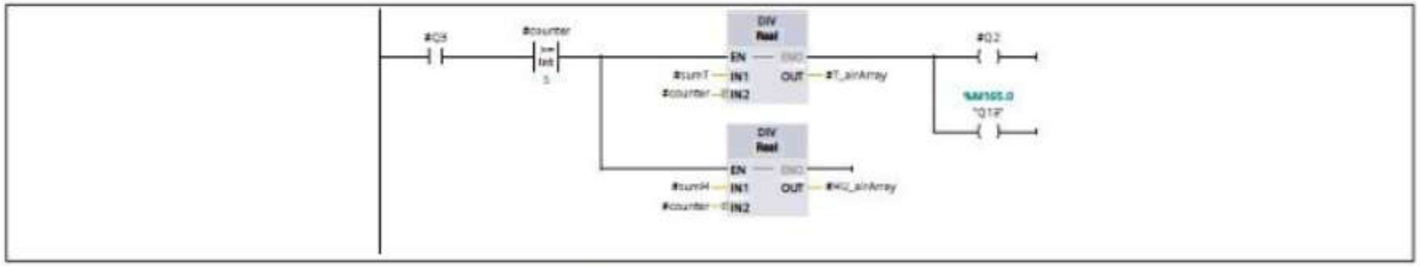


Figure 56 FB4: pH control of nutrient solution

Network 1: ad ogni attivazione si esegue la somma del valore Temp da DHT11 e si aggiorna il contatore Counter



Network 2: se counter = 5 fai la media e scrivi il risultato in T_airArray e sblocca riga successiva



Network 3: calcola indicex per il futuro vettore, resetta sum e counter per la prossima conta e scrive output

3 casi: T>Max, T<min, min<T>Max etc, 9 combinazioni possibili

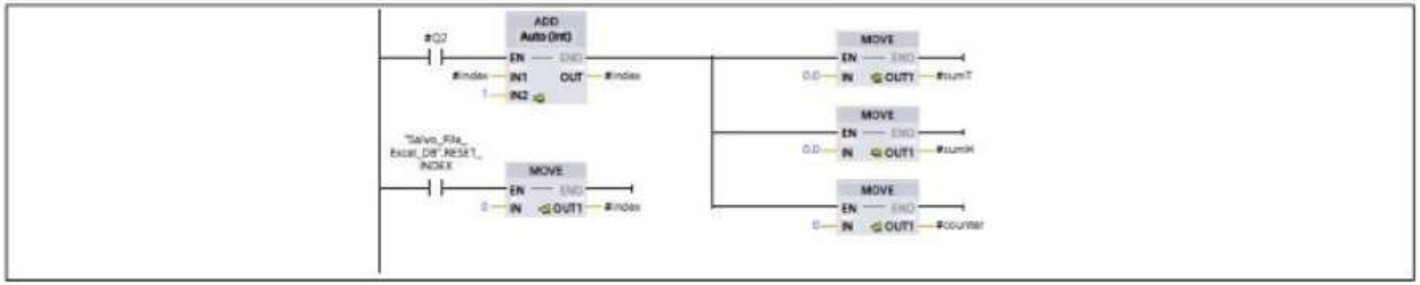
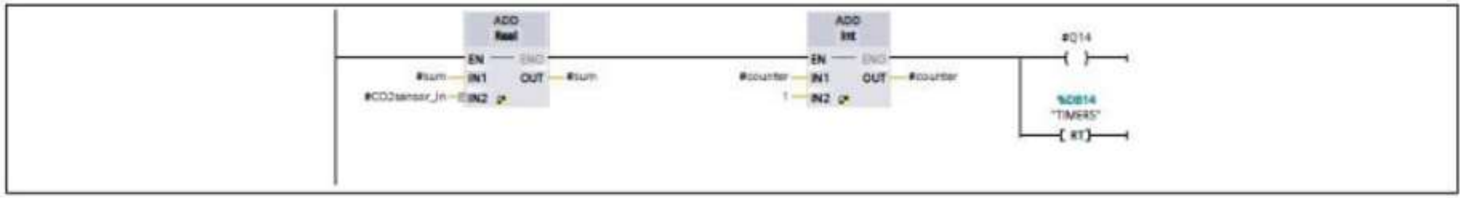
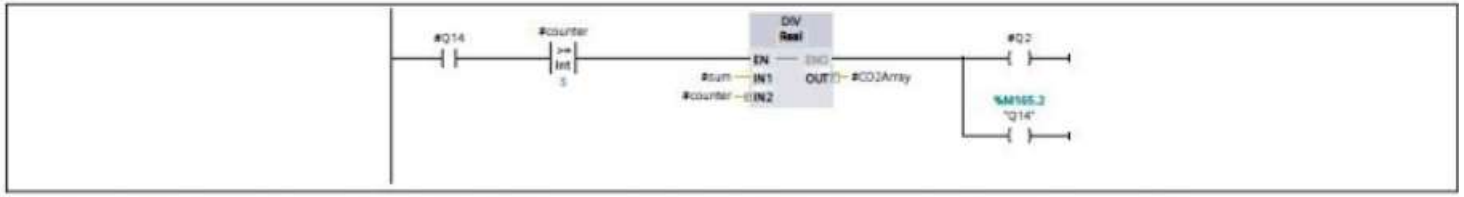


Figure 57 FB5: temperature and humidity control



Network 2: se counter = 10 fai la media e scrivi il risultato in Th2oArray e sblocca riga successiva



Network 3: calcola indicex per il futuro vettore, resetta sum e counter per la prossima conta e sblocca righe successive

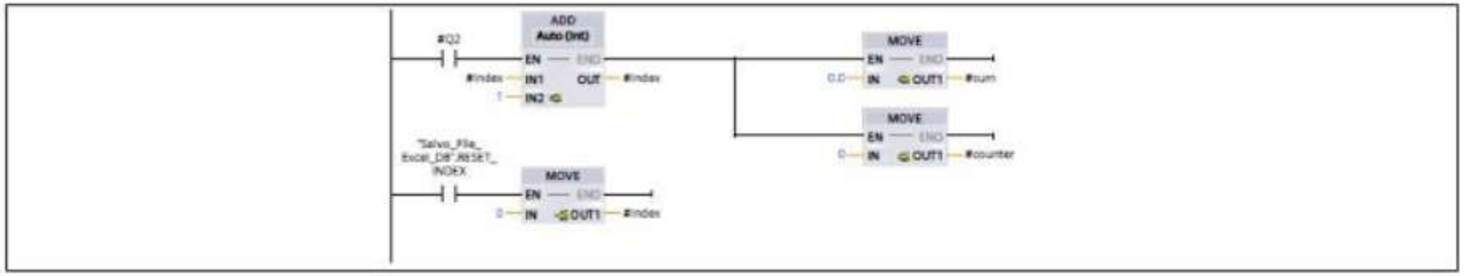


Figure 58 FB6: control of CO2 levels in the air

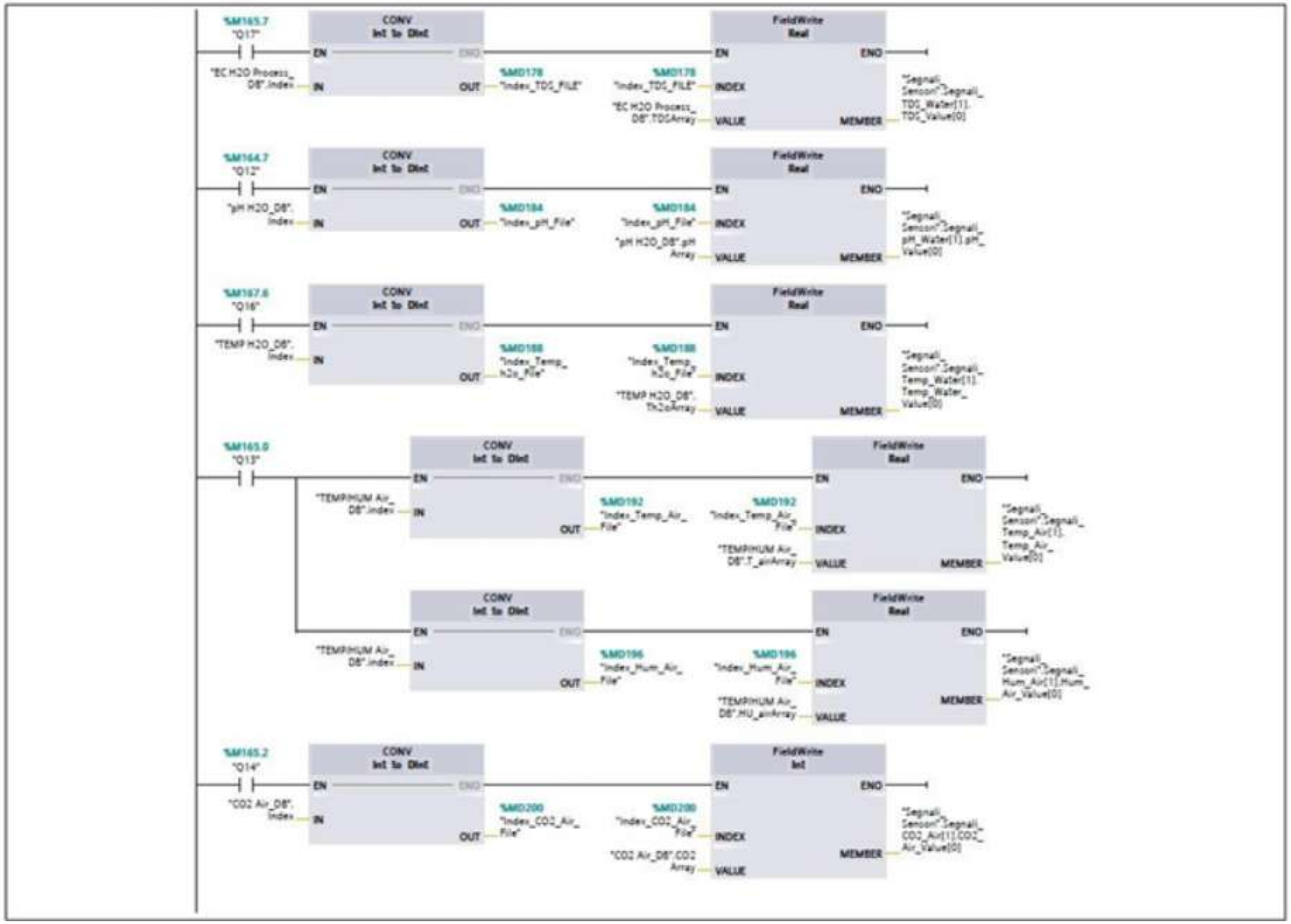


Figure 59 Network 1 FB10: saving vectors to CSV file

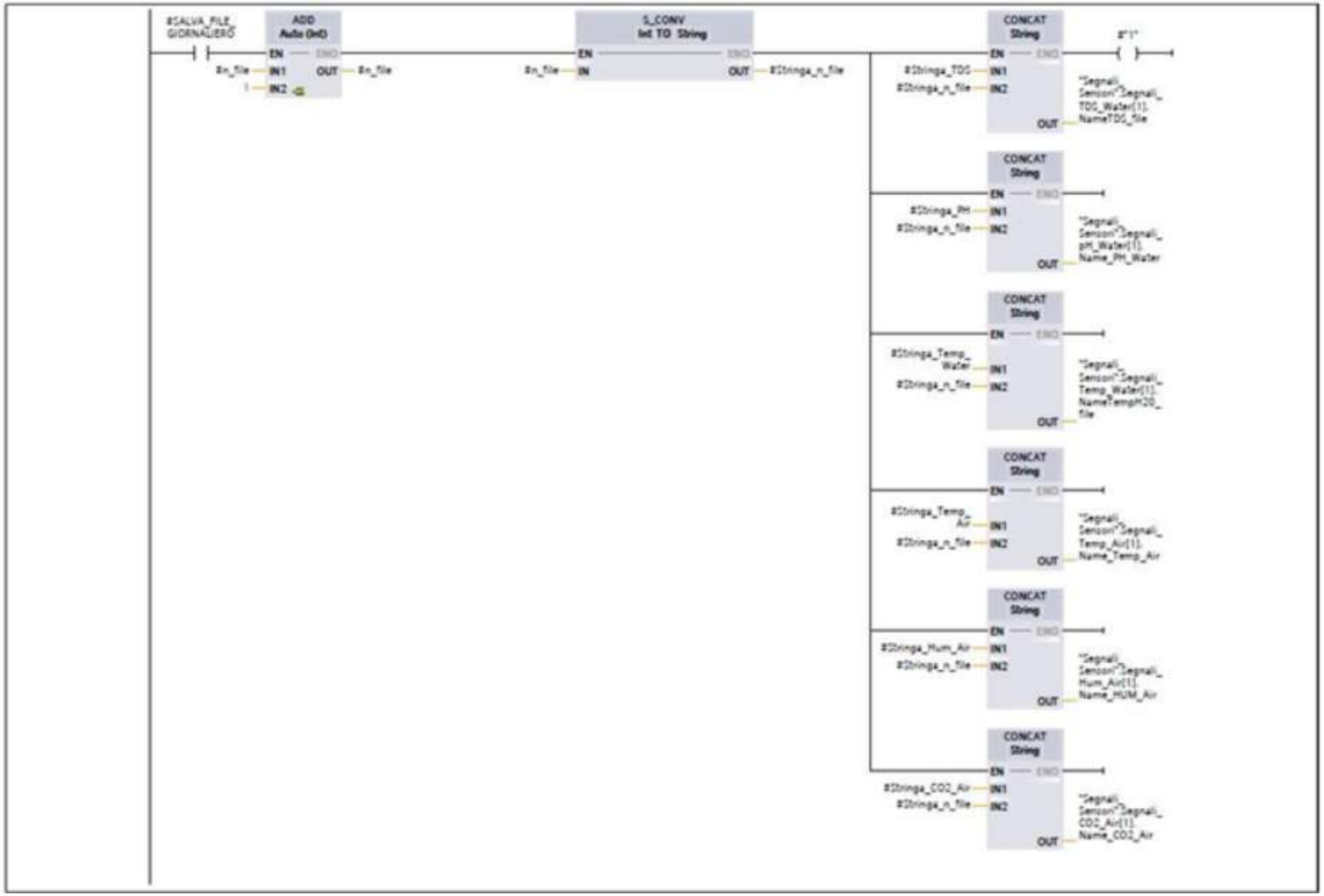


Figure 60 Network 2 FB10

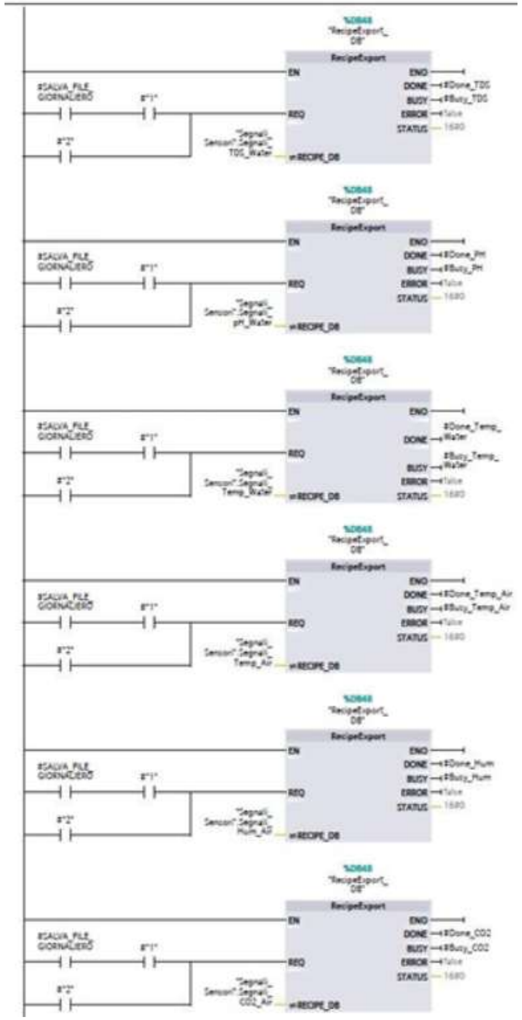


Figure 61 Network 3 FB10

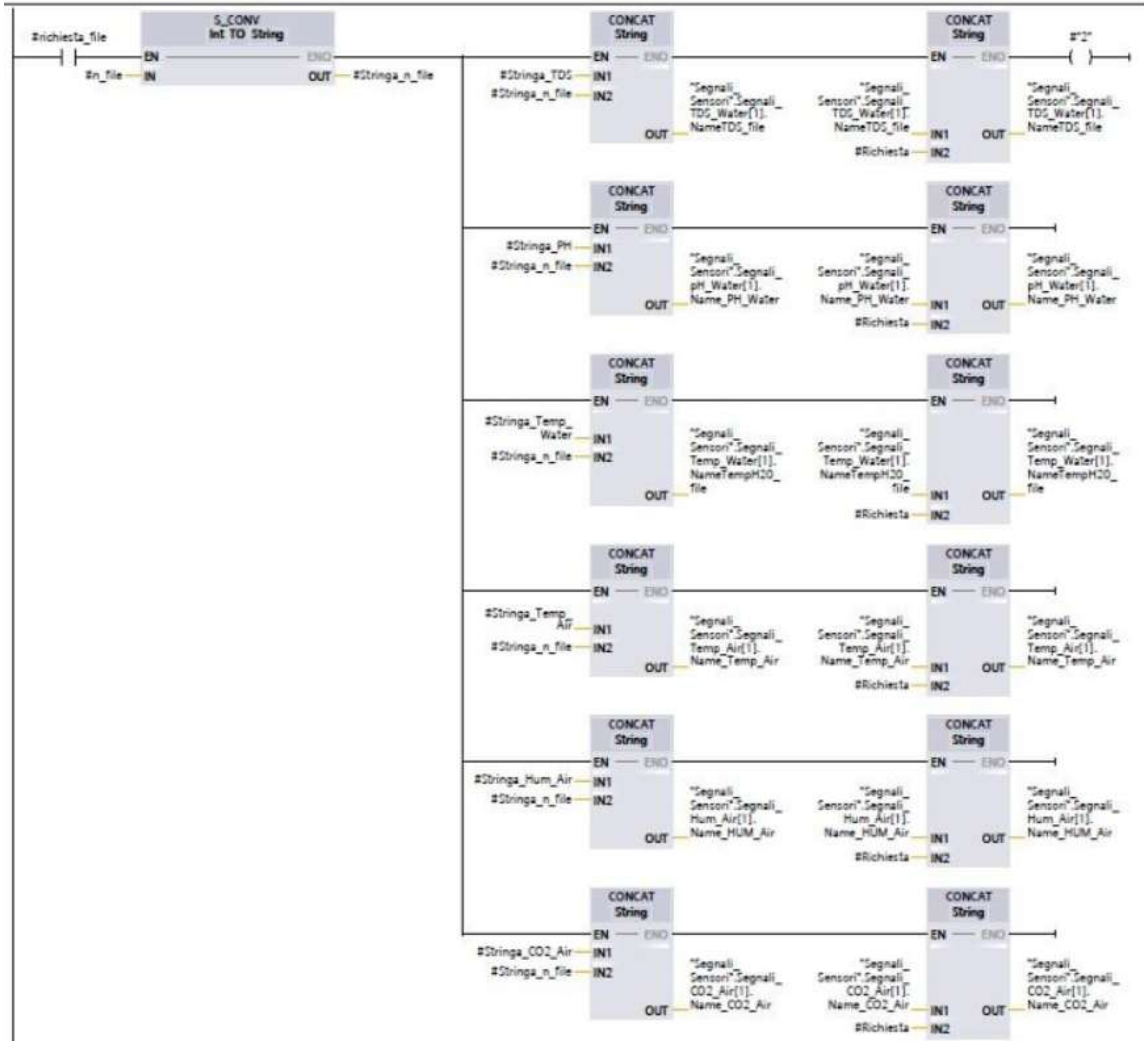


Figure 62 Network 4 FB10

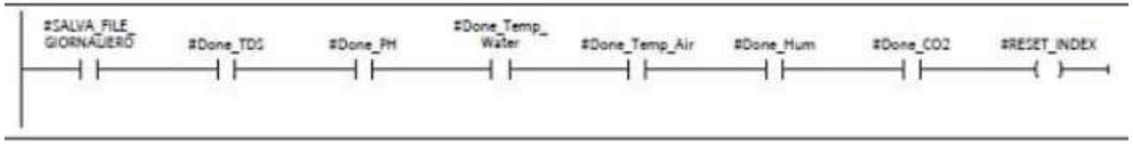


Figure 63 Network 5 FB10