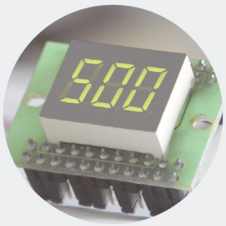
INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
MESTRADO EM ENGENHARIA ELECTROTÉCNICA E DE COMPUTADORES





Temperature Control Using an Air Handling Unit Installed with Carel pCO5+ Controller

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DO PORTO

TEMPERATURE CONTROLLER USING AN AIR HANDLING UNIT INSTALLED WITH A CAREL PCO5+ CONTROLLER

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Department of Electrical Engineering
Master's in Electrical and Computer Science Engineering

Area of specialization in Automation and Systems

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Course of the Master's in electrical and Computer Engineering

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To all, my most sincere thank you!

SUMMARY

This dissertation reports the project work developed in the Thesis/Dissertation course during the 2nd year of the Master of Electrical and Computer Engineering in the field of Automation and Systems, Department of Electrical Engineering (DEE) at Instituto Superior de Engenharia do Porto (ISEP).

The installation of an Air Handling Unit (AHU) in a work place or a hospital plays an important role in the treatment and maintaining the purity of air. The temperature control is focused in this dissertation. The AHU maintains the temperature of the room or office at a set temperature. The heating and cooling function are done automatically by taking in the reference temperature of the room also depending on the outdoor climate.

The main purpose of the AHU is to ensure comfort to the patients, staffs and the employees. In case of the hospitals, the main function of AHU is air cleanliness in hygiene applications. It also includes supplying a sufficient amount of oxygen and removing the carbon dioxide and maintaining a comfortable room climate. They help protect patients and staff from infections.

This dissertation will focus on the study of wide range of technologies which will work on the AHU with the Carel electronic controller whose main function is to control the temperature of an office. The unit was installed at Farfetch, Barco, Portugal. The study includes the working of selection criteria of the supply and return fans, inverters, recovery unit, probes, dampers and the controller.

KEYWORDS

Air Handling Unit, Temperature Controller, Carel controller, Farfetch, Building Automation.

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LIST OF SYMBOLS AND ABBREVIATIONS

List of abbreviations

AHU	Air Handling Unit
HVAC	Heating Ventilation and Air Condition
PID	Proportional + Integral + Derivative
MIMO	Multiple Input Multiple Output
OAE	Outdoor-Air/Economizer
TAB	Testing, Adjusting and Balancing
MERV	Minimum Efficiency Reporting Value
SPSA	Simultaneous Perturbation Stochastic Approximation
PLC	Programmable Logic Circuits
VAV	Variable Air Volume
NN	Neural Network
CHW	Chilled Water
HHW	Hot Water
WBH	Whole Building Diagnostician
FDD	Fault Detection and Diagnosis

List of Symbols

m^3/h	Metre Cube per Hour
Kg/s	Kilogram per Second
V	Volts
mA	Milliamps
kW	Kilowatts

GLOSSARY OF TERMS

Term	Designation
Air Handling Unit	Air Handling Unit is a part of HVAC that regulates and supplies air.
Psychrometry	The study of physical and thermodynamic properties of vapours.
Programmable Logic Circuits	PLCs are industrial control devices that controls the state of output devices based on the state of inputs devices by making decisions through custom programming.
Inverters	Devices that control the speed of motors through frequency.
Dampers	Mechanical devices that restricts the flow of air through the AHU.

INTRODUCTION

1 INTRODUCTION

Temperature control is the process of measuring and adjusting the flow of heat energy in or out of a space to achieve its set point with respect to the change in temperature of space. Air-Conditioners, HVAC, Air Handling Units, refrigerators, space-heaters, etc., are a few devices used in the temperature control [1].

For the temperature control, the following needs to be enabled

1. The probes used for measuring the temperature of the room, outside air and the supply air.
2. The type of control used (Proportional + Integral). The type of control is the same for heating and cooling.
3. The control parameters for summer, winter and the corresponding neutral zones.
4. The cooling and heating temperature set point limits.

The heating and cooling coils have a minimum opening settable parameter. Therefore, if the control probe value does not deviate from the set point by more than the neutral zone and the resulting request is not enough to reach the minimum opening, the valves doesn't open.

The control usually performs cooling in summer and heating in winter. If auto heat/cool mode is set, it is possible to perform heating in summer and cooling in winter depending on the current set point.

The temperature rises proportionally, based on which the valves open. The valves do not open inside the neutral zone around the set point, which means heating or cooling operation is not performed in the neutral zone. It is represented in Figure 1.

**for simplicity purpose, the graphs refer to proportional control only.*

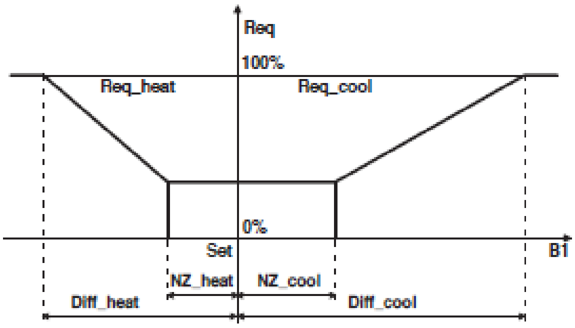


Figure 1 – Temperature control [1]

The percentage of request for opening to cool (req_cool) and request for opening to heat (req_heat) depends on the temperature of the area under consideration. If the temperature of the area exceeds the set point, the controller sends a signal to open the cooling valve proportional to the rise in temperature. If the temperature reduces below the set point, the controller sends a signal to open the heating valve proportional to the reduction in temperature. Cooling differential (Diff_cool) and heating differential (Diff_heat) is the temperature at which the cooling or heating valve opens 100%. It is represented in Figure 2.

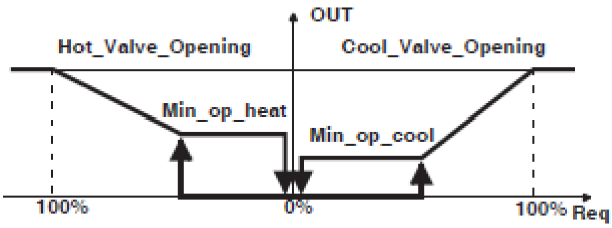


Figure 2 – Valve opening [1]

In reality, the valves don't close 0%. If the valve close 0%, automatically the other valve tends to open. Hence a small percentage of the valve is open. For example, if the minimum opening of cooling valve (min_op_cool) is 30%, the valve is open for 30% until the temperature becomes stable and to maintain the temperature. The same principle is applied to the heating valve.

1.1 Framework and motivation

The work carried out, described throughout this document, is a part for the course of Thesis/Dissertation of the 2nd year of the Masters' in Electrical and Computer Science Engineering in the specialization of Automation and Systems.

The internship was proposed by the company EVAC, that works on the manufacture of Air Handling Units. The topic of temperature control was a field of study where I had little knowledge, however the automation was interesting with enough potential for the future which is a motivation to develop a project in this sense. The work when programmed, forms a management system where the temperature of the entire building is controlled automatically by the controller.

1.2 Company

Equipamentos De Ventilação E Ar Condicionado (EVAC) is a design and manufacturing of ventilation and air conditioning equipment company founded in 1984. Since 1996, EVAC is present in the markets of Europe, South America and North Africa. The logo of the EVAC is shown in Figure 3.

Figure 3 – EVAC logo [2]

EVAC joins the Eurovent Commission in 1998 for the certifications of Air Handling Units. Since 2001, EVAC has its own quality management system implemented and certified by standard ISO 9001. Since 2002, the automation department was started to the designing, programming and assembling of integrated automation and control systems for the equipments.

EVAC has worked on various projects like the hospitals such as Centro Hospitalar Universitário de Coimbra, educational institutions such as INEGI – Faculdade De Engenharia Da Universidade Do Porto.

EVAC works with CAREL controllers. Carel was founded in 1973 the province of Padova specialising in the manufacturing in steam humidifiers. In 1980-89 creates the first monitoring system for air-conditioning units.

The pCO5+ offers a backward compatibility – pCO5+ is a Pin to Pin compatible with the previous versions of the such as pCO5 and pCO3. Software is fully binary compatible using pCO3/pCO5 emulation BIOS. The connectivity features two integrated serial interfaces, two optional expansion cards and two USB ports. pCO5+ controller model embeds two EVDEVO expansion Valve Drivers with optional Uptracap module for integrated energy saving management. It also offers up to 10 Universal I/O pins for maximum I/O flexibility.

The pCO5+ controller offers specific new functions for improving efficiency in HVAC/R system:

- All Analog input channels can be configured as:
  - Digital input (voltage-free)
  - Analog output (PWM or 0 to 10V)
  - Wide selection of probes for different applications (NTC, PTC, PT100, PT500, PT1000, 0 to 1V, 0 to 5V, 0 to 10V, 0 to 20mA, 4 to 20 mA).
- Integration of EVDEVO driver for control of electronic expansion valve with ultracap technology, guaranteeing steeper electronic expansion valves in the event of power failures.
- Connectivity providing more depending designers with upto 5 serial lines, 3 of which always available and configurable in terms of protocol (CAREL or Modbus®) and type (FieldBus or BMS), and 2 optional, configurable in terms of protocol (Modbus®, BACnet™, CAREL, CANbus, Konnex, LonWorks) and physical support (RS485, Ethernet, Can, Konnex, FTT-10).

The wide range of system solutions include Air-conditioning in commercial buildings, automotive industry, data centre, die casting, hypermarket, plastic industry and residential. The unit control applications include Air Handling Units (AHU), chiller/heat pump units, dryers, rooftop, computer room air conditioners and shelter. The schematic controller is shown in Figure 4.

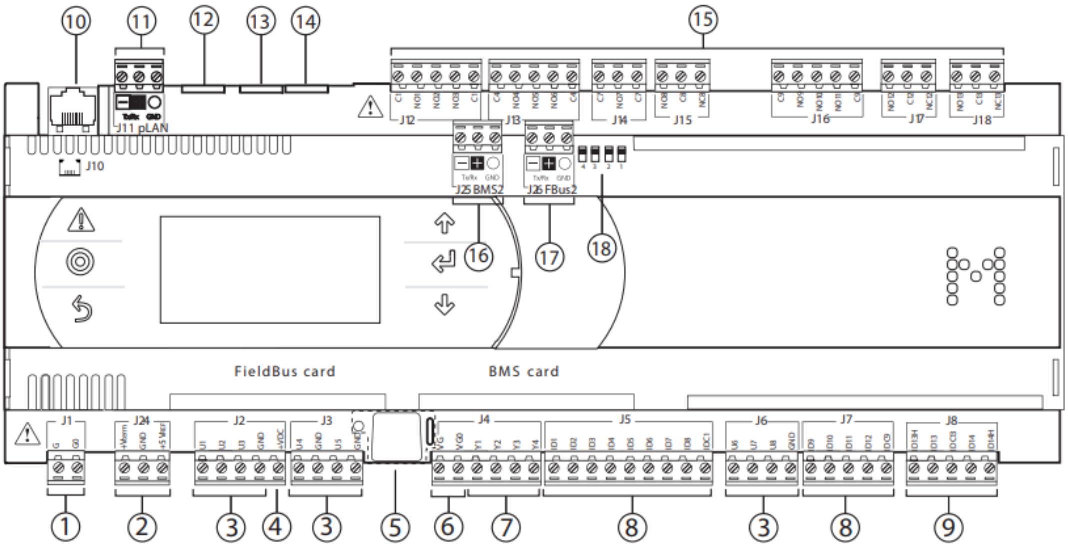


Figure 4 – Schematic of Carel pCO5+ Controller [1]

Ref	Description
1	Power Connector
2	+Vterm: Power to additional terminal; +5 Vref: Power to ratiometric probes
3	Universal inputs/outputs
4	+Vdc: Power to active probes
5	Button for setting pLAN address, secondary display, LEDs
6	VG: Voltage (24Vac) to optically isolates analogue output; VG0: Power to optically isolated analogue output 0 Vac/Vdc
7	Analogue outputs
8	ID: digital inputs at voltage (24Vac)
9	ID: digital inputs at voltage (24Vac); IDH: digital inputs at voltage (230Vac)
10	pLAN telephone connector for terminal/downloading application program
11	pLAN plug-in connector
12, 13, 14	Reserved
15	Relay digital outputs
16	BMS2 connector
17	Fieldbus2 connector
18	Fieldbus/BMS selector microswitch

Table 1 – Schematic description of Carel pCO5+ controller

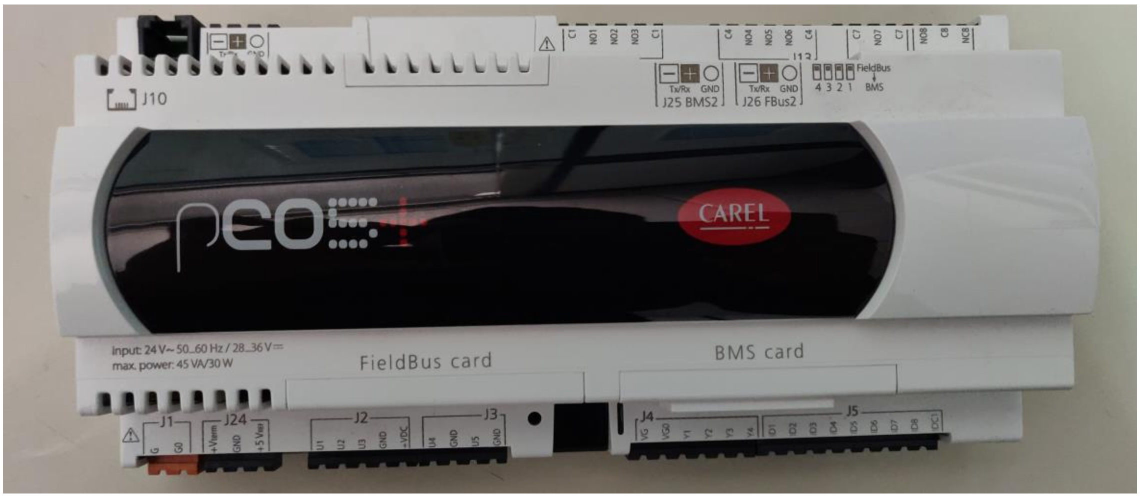


Figure 5 – Carel pCO5+ controller

1.3 Objectives

The development of this dissertation work has its objective of the study and implementation of an Air Handling Unit (AHU) and installing at UTA-RP 50 plus 50 unit at Farfetch, Barco. This unit controls the temperature of the work place at a set temperature of 23°C. The study is aimed at understanding the construction and working of an AHU, drawing the electrical schematics, understanding the control procedure, programming the Carel PLC controller and testing of the unit at factory and site.

1.4 Schedule

The schedule of the project developed in this curricular stage was planned according to the table in Annex A. In this schedule it is possible observe the time spent at each stage in the realization of this project. As developed in a business environment, some changes may have occurred in relation to the planning, however, all stages were successfully completed.

1.5 Structure of report

This section represents the general structure of this dissertation, which is divided into five chapters.

In Chapter 1, a brief contextualization is presented to the proposed work and to the company where the curricular internship was developed, as well as to the work, scheduling and organization.

In Chapter 2, presents the state-of-the-art of Air Handling Units (AHU): their history, the applications and the way they are structured.

In Chapter 3, the system to be implemented is presented: discusses the construction of the unit, development of schematic, the programming of the controller, working, testing and results are discussed.

In Chapter 4, the conclusion and suggestions of future work is discussed.

STATE OF THE ART

2 STATE OF THE ART

In this chapter, the brief definition and history of the Air Handling Units (AHU), the areas in which it is applied. A study was also done on the different control methods used in the controlling of Air Handling Units. Based on these studies, key points were identified to justify the choices made during the development of this project.

The process of removing heat and moisture from the occupied space to improve the comfort of occupants. The HVAC performs four basic roles – control airborne particles, dust and micro-organisms, maintain room pressure, maintain space moisture, maintain space temperature.

The airborne particles, dust and micro-organisms is controlled through air filters. Since the HVAC has one of the main applications in medical facilities like hospitals, medical storage facilities, it is necessary to maintain the room pressure by maintaining a positive pressure, to reduce the chance of airborne contamination [3]. The pressure is maintained by mechanically providing cleaner air to the space. The space moisture or the relative humidity of the room is controlled by cooling air to dew point temperatures or by using dehumidifier. Humidity can affect the stability of drugs and is important to effectively mould the tablets. Maintaining the space temperature is an important function of the HVAC since the temperature can affect the production directly or indirectly by developing the growth of microbial impurities of workers.

2.1 Air Handling Units (AHUs)

An Air Handling unit (AHU) is a device that regulates and circulates air as a part of HVAC. The function of an AHU is to transfer heating or cooling loop into a space to be conditioned by forcing the airflow of the outside air and treating the air with either water or gas for cooling or heating. Industries, which require large areas to be conditioned, uses AHU and HVAC. The Air Handling Units usually connect to a network of duct ventilation system that distributes the treated air to the space to be conditioned throughout the building. It also has a separate duct system for the return air, which are either sent out or a part of it will be reused by removing the carbon di oxide content and mixing it with the fresh air. Temperature sensors are used to determine the temperature at various points of the unit.

Air blowers are usually driven by AC electric motor to force the air inside or outside the unit. The Air blowers are driven by a variable frequency drive to allow a wide range of air flow rates. The speed of the air flow depends on the air filters. If the filters are filled with dust, the blower fans run at higher speed. Multiple blowers may be used in large Air Handling Units for supply and return air.

Heating or cooling elements used to change the supply air temperature. Temperature control can be done by either direct or indirect methods. Direct method involves gas-fired fuel-burning heaters or a refrigeration evaporator placed directly in the air stream. Indirect methods involve using of heating or cooling coil.

Mixing chambers are used to maintain the indoor air quality by mixing the return air and the fresh air. A damper is used to regulate the ratio between the return air and fresh air. Mixing the right amount of return air and fresh air can be used to yield the desired temperature. A general schematic of an Air Handling Unit used to control the temperature of library is shown in Figure 6.

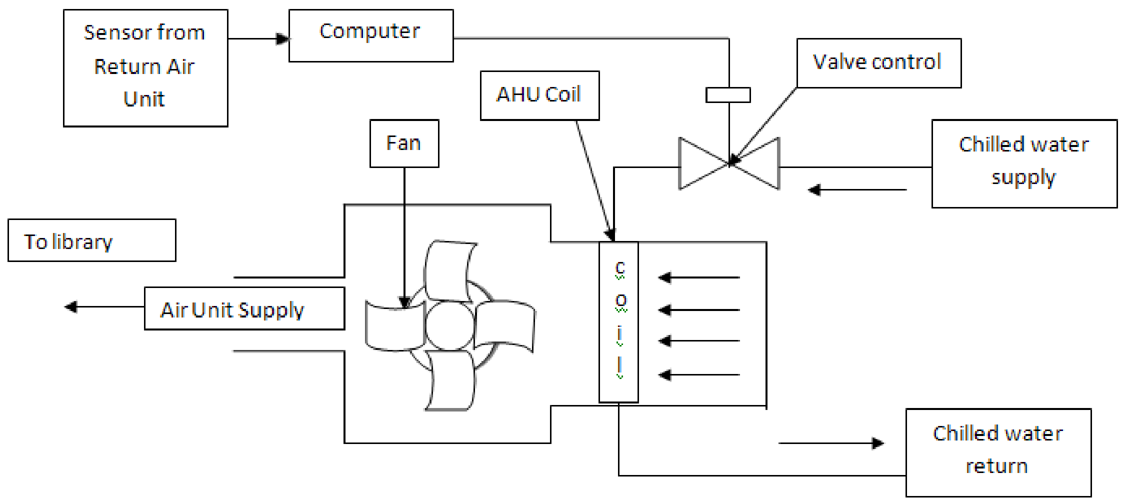


Figure 6 – Schematic of an Air Handling Unit [4]

A heat recovery device is fitted between the supply and extract. The advantage of using a heat recovery system [5] is that the simultaneous recovery of sensible heat and latent heat, energy saving and increased efficiency of the unit without any mechanical parts.

Example of an Air Handling Unit is shown in Figure 7.

Figure 7 – Example of an Air Handling Unit

2.2 Air Conditioning Process

The conservation of mass and energy is used in the study of air conditioning process [6]. The air conditioning process controls the temperature and humidity in spaces such as residential, industrial and commercial services. The process of air conditioning are as follows:

1. Simple heating and cooling process.
2. Cooling with dehumidification.
3. Heating with humidification.
4. Adiabatic mixing of two air streams.

5. Evaporative cooling.

The air conditioning process are represented in Figure 8.

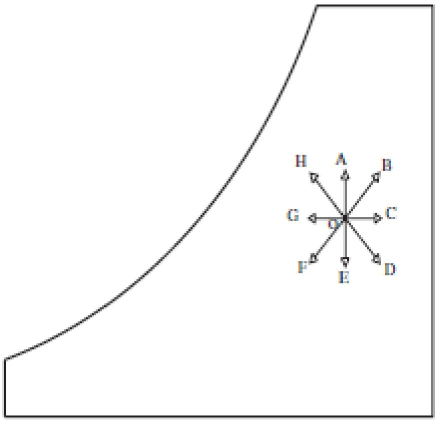


Figure 8 – Fundamental air conditioning process [6]

Process	Direction
Simple heating	O to C
Simple cooling	O to G
Humidification	O to A
Dehumidification	O to E
Evaporative cooling	O to H
Evaporative heating	O to D
Heating and humidification	O to B
Cooling and dehumidication	O to F

Table 2 – Air Conditioning Process

Simple Heating and cooling:

Simple heating refers to heating of the air without adding moisture to the air. With respect to the cooling, simple cooling refers to the cooling of air without condensation. The Humidity Ratio (W) is a constant in both simple heating and cooling, since the air is heated without adding moisture to the air. The schematic and psychrometric of a simple heating process is shown in Figure 9 and the schematic and psychrometric of a simple cooling process is shown in Figure 10.

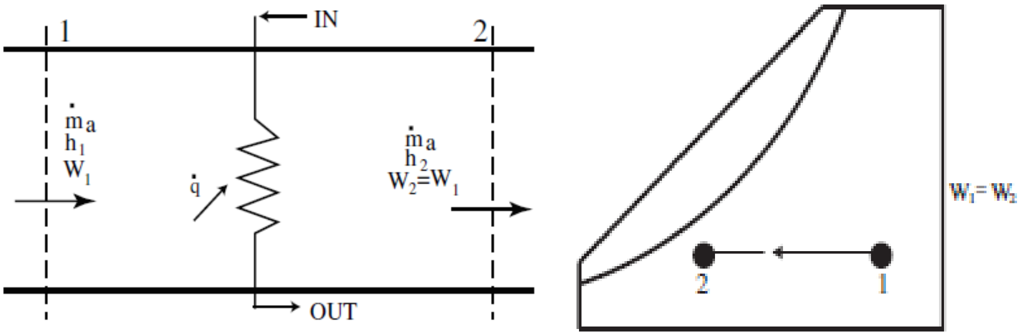


Figure 9 – Schematic and Psychrometric of simple cooling process [6]

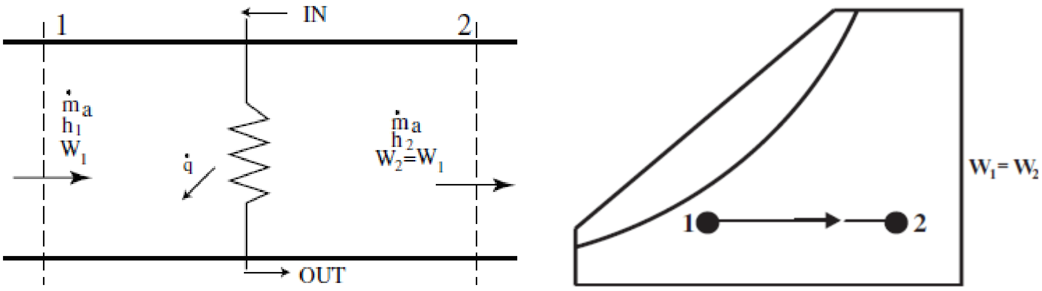


Figure 10 – Schematic and Psychrometric of simple heating process [6]

Cooling with dehumidification:

During cooling, the dew point temperature of the air entering the cooling coil is greater than that of the surface temperature of the cooling coil. The cooling coil will condense the water vapour from the air and the condensate is drained out. This condition lowers the specific humidity of the air that leaves the unit. Three types of heat exchangers in this process

1. Water cooling.
2. Direct Expansion DX coil.
3. Air washer.

In direct expansion, the refrigerant evaporates directly inside the coil's tubes. In air washer, chilled water sprays contacts conditions air directly.

The temperature of chilled water entering the cooling coil T_{we} determines whether the process is a sensible cooling or cooling with dehumidification process. If the cooling coil temperature is less than that of the dew point of the air entering the air washer or when the temperature makes the outer surface of the water-cooling coil, then it is a cooling with dehumidification process.

The sensible heat ratio of the cooling with dehumidifying process SHRc is the ratio of the sensible heat removed during the cooling and dehumidifying process (q_{cs}) to the cooling capacity of the air washer (q_{cc}).

$$SHRc = qcs/qcc.$$

The relative humidity of moist air leaving the water cooling or DX coil depends on the outer surface of the coil including the pipe and fins. The schematic and psychrometric of cooling with dehumidification is shown in Figure 11.

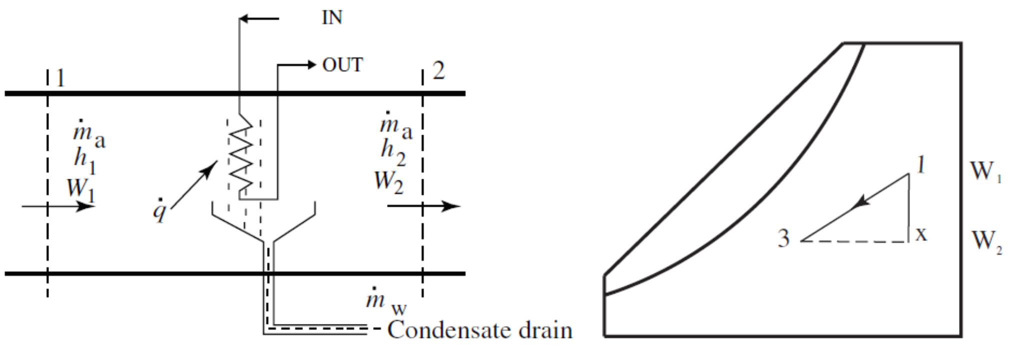


Figure 11 – Schematic and Psychrometric of cooling with dehumidifying process [6]

Heating with humidification:

In locations where the outdoor relative humidity during the winter season is low, it is essential to humidify the supply air in facilities such as hospitals or commercial buildings to maintain the relative humidity. In this process, the air is first heated by heating coils or gas and then it is humidified by adding moisture before it is supplied to the space. The schematic and psychrometric of heating with humidification is shown in Figure 12.

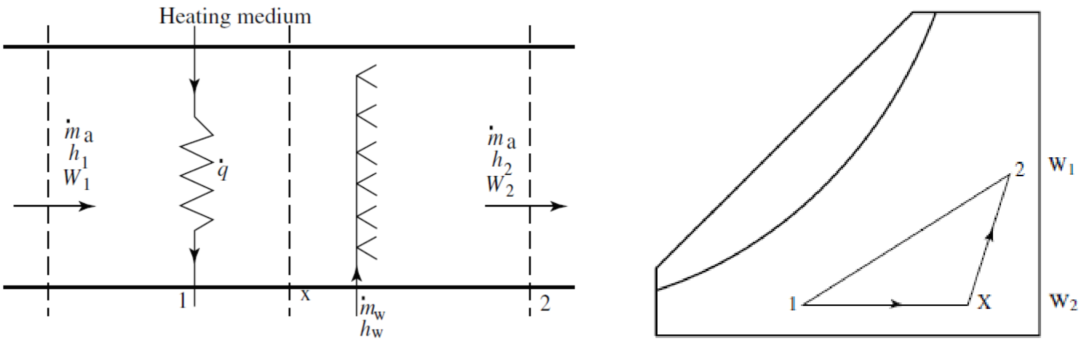


Figure 12 – Schematic and Psychrometric of heating with humidifying process [6]

Adiabatic Mixing of Two Air Streams:

In large buildings such as process plants, office spaces and commercial facilities, the return air would be mixed with a certain amount of fresh air for the ventilation before it enters the air conditioning unit.

Evaporative cooling:

The evaporative cooling based on the principle that when the water evaporates, the latent heat of vaporization is absorbed from the water and the surrounding air which cools both the air and the water during this process. In hot and dry climates, the conventional cooling system which has high initial, operating and maintenance cost can be replaced by the evaporative coolers.

The AHU is well insulated, the heat transfer between the mixing chamber and the ambient air is small, it is usually neglected. The schematic and psychrometric of adiabatic mixing of two streams is shown in Figure 13.

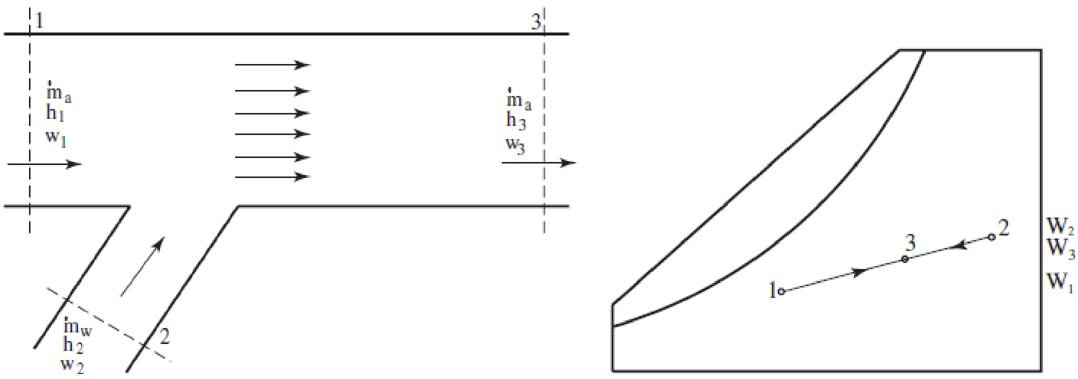


Figure 13 – Schematic and Psychrometric of Adiabatic mixing of two streams process [6]

2.3 System Controls

The HVAC system controls are necessary to regulate the supply air temperature, return air temperature, air flow rate, supply and return humidity and air quality. The control system is also used to provide automatic operation, maintaining a precise controlled condition, providing maximum efficiency and economy of operation with safety. The control methods in the HVAC systems are divided into three main categories [7]

1. Traditional controller method.
2. Advanced controller method.
3. Intelligent controller method.

2.3.1 Traditional Controller Method

The traditional control methods include On-Off controls and PID control. The advantage of using the traditional controllers is the structure is simple structure and the low initial cost [7]. The function of an On-off control is to provide two plant outputs, maximum (on) or zero (off). The disadvantage of the On-Off control is that the On-Off control is not accurate enough and does not have quality. It also proves to have high cost due to high maintenance. The action of an On-Off controller is shown in Figure 14.

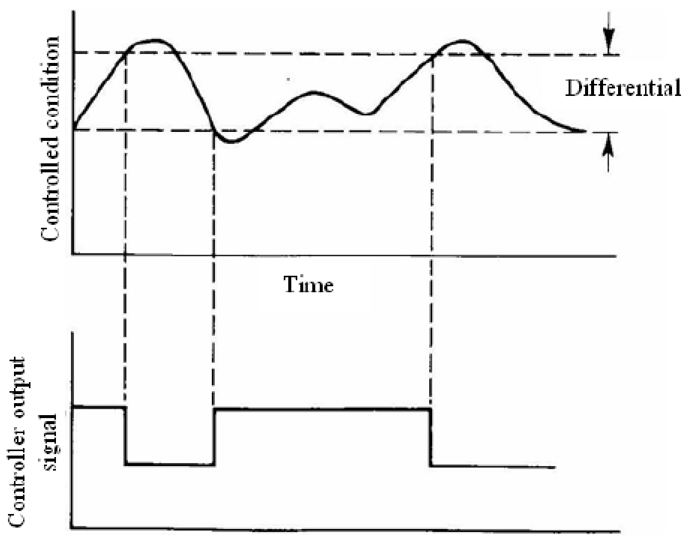


Figure 14 – Action of an On-Off controller [7]

PID is a simple in implementation and is being commonly used in HVAC application. Several types of the controllers such as P, PI and PID are also used in the control of HVAC systems. The Action of a PID controller is shown is Figure 15.

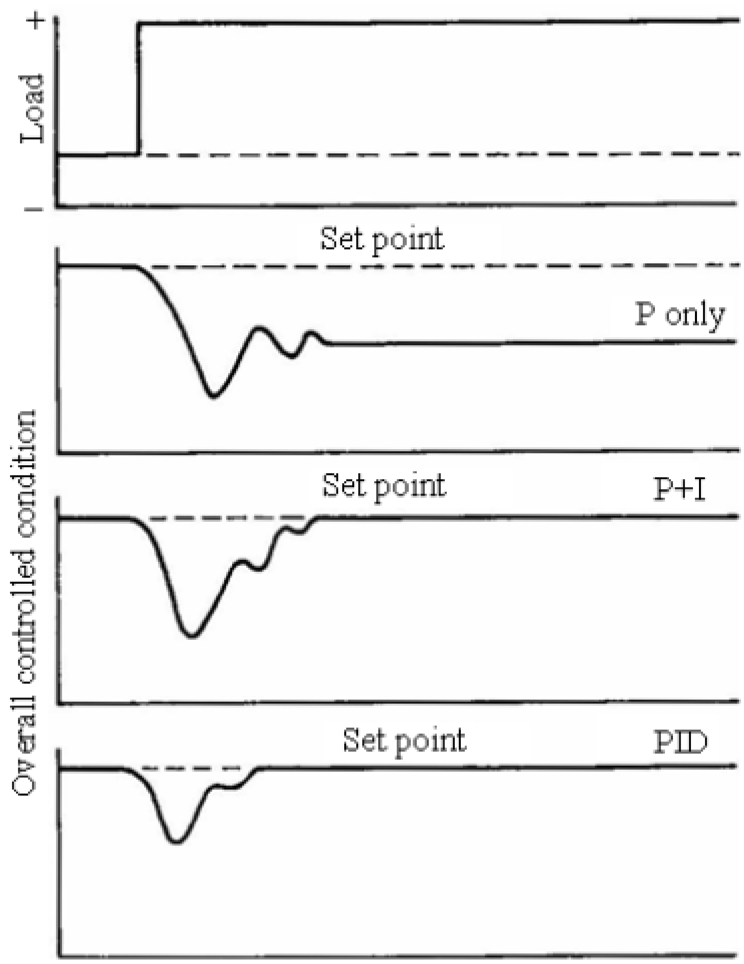


Figure 15 – Action of a PID controller [7]

2.3.2 Advanced Controller Method

The advanced controller modes are categorized into three different groups

1. Auto-tuning PID
2. Modern and Nonlinear controllers
3. Optimal controllers

Auto tuning PID is a type of PID controller that automatically determines the PID control parameters without human interference since the tuning procedure of a PID controller can be a time-consuming, expensive and difficult task. Auto tuning PID algorithm uses two algorithms – model-based algorithms and empirical rule-based algorithms. Model based algorithms are the type of algorithms where the parameters of the PID controllers are related to the parameters of a transfer function model.

Empirical rule-based algorithm is the type in which the parameters of the PID controller are determined by a set of heuristic rules.

The HVAC is a non-linear system for which a number of non-linear controllers are designed and utilized since the 80’s. Serrano and Reyes presented a non-linear disturbance rejection state feedback controller for an HVAC system that is a direct nonlinear method.

Optimal controllers are used in the determination of minimum operating cost of the system to achieve the desired comfort level for the space. In conventional control strategies, it was found that the optimal control strategy had the potential to save energy up to 12-30%.

2.3.3 Intelligent Controller Method

Human comfort is subjective and change with person to person. Neural networks and fuzzy logic-based controllers are used in intelligent controllers. The HVAC systems are Multiple Input Multiple Output (MIMO), nonlinear and time varying systems. Fuzzy logic is trained to describe the subjective human comfort dependent variables.

Neural network intelligent control work on two different methods, the neural network based predictive controller where the neural network is exploited for the system model used in regulating the non-linear system. The neural network based predictive controller is also named as identification technique. The neural network based predictive controller is shown in Figure 16.

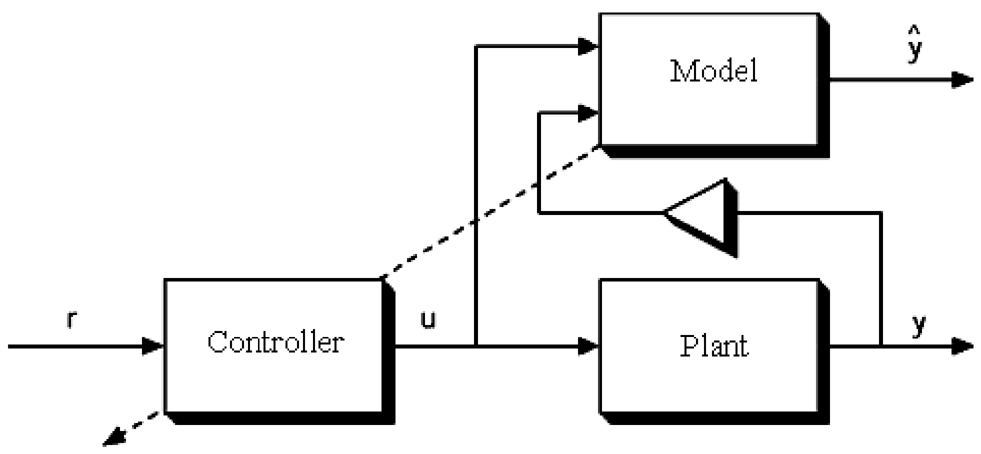


Figure 16 – Neural network based predictive controller [7]

There are two types of identification technique used: forward system identification and inverse system identification. In the forward system identification, neural networks are placed in parallel with the system and the error between the system output and the network output is used to train the networks. The forward system identification is shown in Figure 17. In the inverse system identification, a synthetic training signal is introduced to the system and the system input is introduced as an input to the network. The error is used to train the network by comparing the network output to the training signal. The inverse system identification is shown in Figure 18.

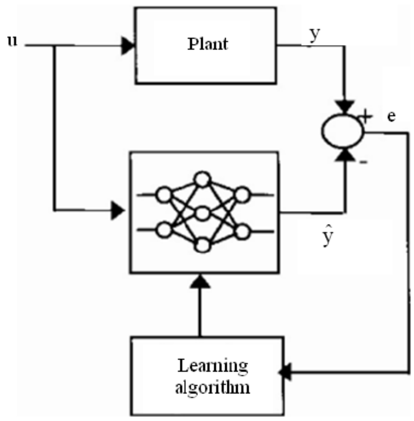


Figure 17 – Forward system identification [7]

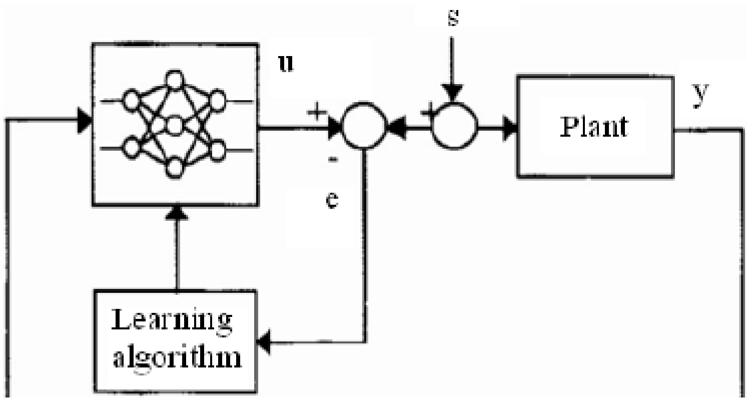


Figure 18 – Direct inverse system identification [7]

In a Direct Neural Network Controller, the controller is trained, and it does need any training of the plant model. It is an output feedback controller with a neural network at the core of the controller. The problem with the direct neural network controller is that the choice of the training scenario must be selected appropriately. The schematic of the Direct neural network is shown in Figure 19.

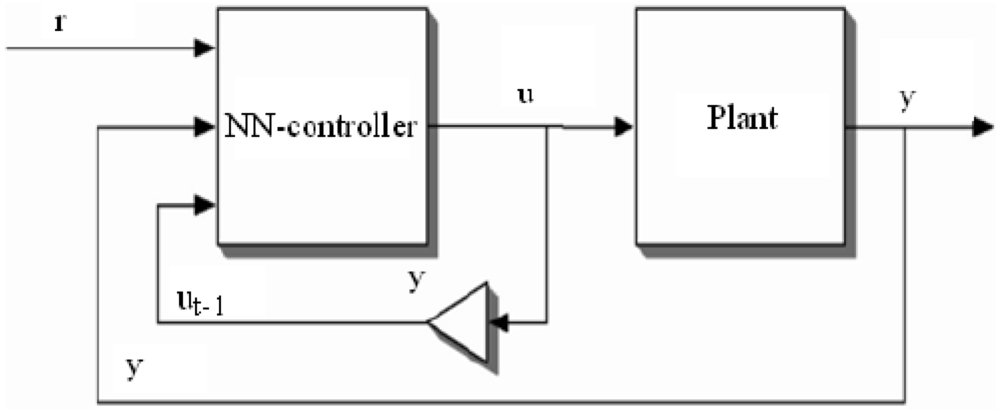


Figure 19 – Direct neural network controller [7]

In this work, a Proportional + Integral controller was used owing to its accuracy over a Proportional controller, where a near stable settling point is reached near the set point. The value of the controller output *u(t)* is fed into the system as the manipulated variable input.

$$u(t)= K + K_c e(t) + K_c/\tau_I \int e(t)dt$$

The term K is a constant or a null value which is set to the value of u(t) when the controller is switched from manual mode to automatic mode to give a bumpless transfer if the error is zero and the when the controller is turned on. The tuning values of a PI controller are controller gain K_c, which is a multiplier on the proportional error and integral term. When the value is higher, the controller responds aggressively to the errors away from the set point. The other tuning value of the PI controller is the reset time or the integral time constant, τ_I. The integral action can be adjusted independently by the integral time constant.

$$e(t) = SP – PV$$

The difference between the set value (SP) and the process variable (PV) gives the error e(t). The set value is the target value and process variable is the measured value. In the proportional term, when the error e(t) increases or decreases, the constant changes proportionally. The integral term considers the history of error and calculates how far the measured variable has been from the set point over time.

2.4 Air Filters

An air filter is usually made from a pleated paper or cloth enclosed in a cardboard frame. The basic function of the air filter is to clean the air and circulate it to the conditioning space. The filters filter the impurities and carbon dioxide contents from the air that includes dust, pollen, fibres, hair, bacteria and microorganisms. A filter is represented in Figure 20. The filters are classified on the basis of the level of efficiency by the filters' Minimum Efficiency Reporting Value (MERV rating) [8]. Standard MERV values range from 1 to 16, higher MERV values indicating better filtration.

1. MERV 1-4: Common standard filters that provide a basic level of filtration. It is also called as coarse air filters. The coarse filters are divided into three categories – Viscous and reusable, Dry and reusable and Dry and disposable. Viscous and reusable are filters such as corrugated wire mesh and screen strips, coated with oil that acts an adhesive to increase the removal of dirt. They can be cleaned and reused by washing the filter with detergents.

   Dry and reusable are such as synthetic fibres that can be cleaned or washed to reuse of the filters. Dry and disposable are filters that are discarded as soon as the pressure drop is reached. The face velocity of panel filter is between 300-600 fpm and the pressure drop is 75 Pa.
2. MERV 6-8: Provides good filtration and are commonly used in residential settings. They are manufactured by pleated cloth or paper to provide more surfaces for capturing particles. These types of filters are low-efficiency filters. They are used to remove dust particles between 3µm and 10µm. Low-efficiency filters are pleated filters or bags. The size of the panel filters is as same as size of the framework. The pleated mat is used to extend the surface area of the filter. The face velocity of the low-efficiency is 500 fpm and the pressure drop are 150 Pa. Pleated filters often extended their filter area by 2 to 8 times their surface area. Thus, the velocity penetrating the filter is reduced to 250 fpm.
3. MERV 9-12: Relatively better quality than the MERV 6-8 types of filters and can capture small particles of 1 micron or larger. These types of filters are mid-range or medium efficiency filters. MERV 9-12 are used to remove dusts of size 1µm to 3µm such as coal dusts, bacteria and welding fumes.

4. MERV 13-16: These are the best standard available filters in the market. They can remove very small particles of 0.3 microns or larger. These types of filters are high-efficiency filters. MERV 13-16 removes particles of the order of 0.3µm to 1µm such as bacteria, viruses, cooking oil fumes and tobacco smoke.

The filters are connected to a pressure switch which opens a contact when the filters indicate that the filters are filled with dust and it requires to be changed.

Figure 20 – Filters

2.5 Programmable Logic Controllers (PLC)

A Programmable Logic Controller (PLC) [9] is a digital computer generally used in automation. The use of PLCs for electromechanical process are designed for multiple inputs and outputs operations. The data from the sensors is obtained and commands the actuators.

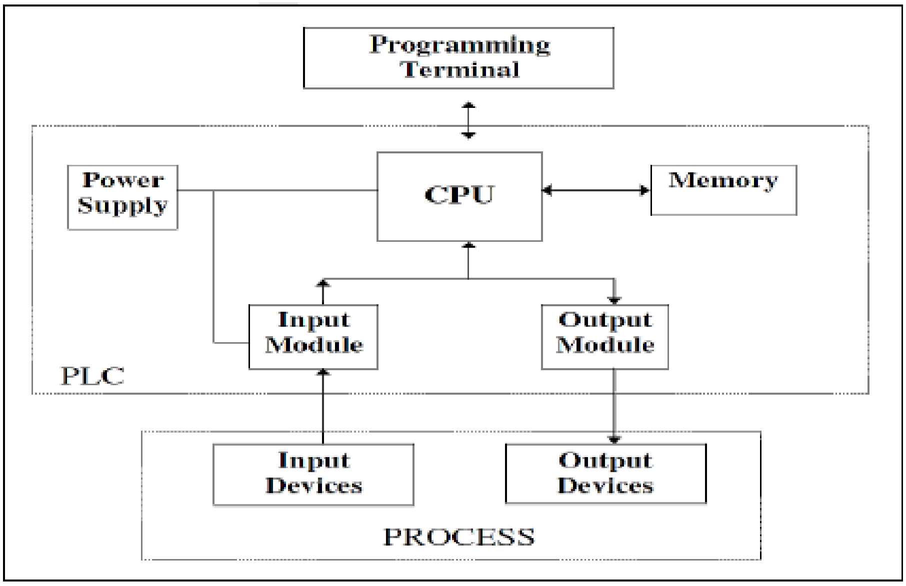


Figure 21 – Block diagram of PLC [10]

The PLC program is uploaded to the controller. The function of the input module is to convert the signals from the sensors into the signals that can be processed by the PLC and passed on to the control unit where the required operation is processed. The output module converts the processed signal from the PLC to operate the plant actuators. The block diagram of the PLC is represented in Figure 21. Working power for the input module and the PLC is given through a power supply, usually 24V. The CPU contains the memory for storing different types of program and data.

The PLCs are a cost-effective way of controlling complex control systems. It is flexible and can be reapplied to control other systems easily. The computational abilities allow the sophisticated control using less operating time. The trouble shooting is done easier compared to the other control systems such as relay control systems, digital logic control systems, etc. The interfacing with the computer is an easy process.

The PLC program is executed as a part of a repetitive process referred to as a scan [11]. A PLC scan starts with the CPU reading the status of inputs. The status of physical input signal is copied to an area of memory accessible to the processor. The time taken by the processor of the PLC to evaluate the instructions and update the I/O image table with the status of outputs. This represents the response of the PLC. If the scan time takes too long, the response of the PLC to process conditions would be sluggish. The scan sequence of the PLC is represented in figure 22.

The input scan, the current status of every signal from input module is stored in the input memory table. The CPU enters the user program execution, or program scan. The involves preliminary the first program instruction, then moving on to the second instruction and carrying out its execution sequence. The output modules are not updated continuously during the program scan. The output table is transferred to the output modules during the scan that comes after the execution.

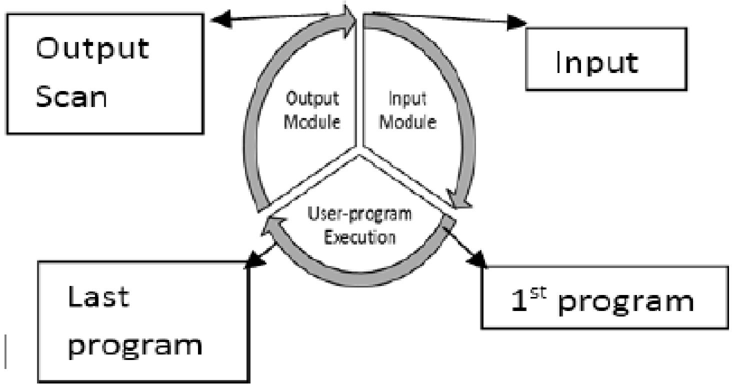


Figure 22 – PLC Scan sequence [11]

For building automation, a Direct Digital Control (DDC)creates more impact than the PLC due to its application specilization and cost advantage. A DDC is similar to a small PLC. It has capabilities of handling a limited number of digital and analog I/Os. Among few vendors across the world such as ABB, Siemens, OMRON, Rockwell automation, Carel is a leading manufacturer of electronic controllers and probes. Carel pCO5+ controller is a microprocessor based, programmable electronic controller. These controllers can be easily with BMS. Compared with the previous version, pCO5+ have a second BMS serial port on the connector J25 and one extra Fieldbus port on connector J26. The advantage of using a Carel controller is that the program is preprogrammed and can be uploaded directly to the controller and can be modified in the controller directly.

2.6 Temperature Probes

Temperature probes are used to determine the temperature of the air flow at different points namely the supply, return and external. There are different types of probes such as Negative Temperature Coefficient (NTC), Positive Temperature Coefficient (PTC), Pt100, Pt1000. The temperature probes are connected to the controller, provides a resistance value, which is then converted to a temperature by the controller. The probes will have different types of caps, index of protection, cable length, operating ranges and mechanical dimensions.

An NTC probe [12] is made of sintered semiconductor material that comprises a mix of several other metal oxides. These materials possess charge carriers that allow current to flow through the probe making changes in the resistance proportional to the change in temperature. NTC probes have high resistances at low temperatures. When the temperature increases, the resistance of the probe deceases. The NTC works on the inverse resistance principle. The NTC probes are non-linear in nature, thus the output requires linearization. The effective temperature range in a standard NTC probe is between -50°C to 250°C. An NTC probe is represented in Figure 23.

Figure 23 – Temperature probe (NTC)

An PTC probe [13] works opposite to an NTC probe. In a PTC probe, the resistance increases with increase in temperate and when the temperature decreases, the resistance also decreases.

Pt100 works on the principle of measuring the resistance of a platinum element. The 100 in Pt100 represents 100 ohms at 0°C and 138.4 ohms at 100°C. Pt1000 have a resistance of 1000 ohms at 0°C. The relationship between the temperature and resistance graph is approximately linear. The linearization equation [14] is represented by,

$$R_t = R_0 * (1 + A* t + B*t^2 + C*(t-100) * t^3)$$

R_0 is a 100Ω resistance at 0°C.

$A = 3.9083 \times 10^{-3}$

$B = -5.775 \times 10^{-7}$

$C = 0$ for $T > 0°C$, or $C = -4.23225 \times 10^{-12}$ for $T < 0°C$

Though there are different types of temperature probes available, in this work, an NTC temperature probe manufactured by Carel is used. These Carel [15] probes are used together with Carel electronic controllers. The operating range of this temperature probe is between -50°C to 105°C.

Storage Conditions	-50°C to 105°C.
Operating Range	-50°C to 105°C.
Connections	Stripped ends, dimensions: 5±1 mm
Sensor	NTC 10kΩ ± 1% at 25°C Beta 3435
Dissipation factor (in air)	Ca./ approx. 7mW/°C
Thermal constant over time (in air)	Ca./ approx. 10s
Cable	Two wire with double sheath, AWG22, tinned copper with electrical resistance ≤ 63Ω/km – insulation: TPE specific for immersion in water on outer sheath, PP/Co inside on wires, OD 3.5 mm max.
Sensitive element index of protection	IP67
Sensitive element housing	AISI 316 steel diameter 4 mm, L=30mm
Classification according to protection against electric (sensitive element & cable)	Basic insulation for 250 Vac
Category of resistance to heat and fire	Flame retardant

Table 3 – Specification of Temperature Probe (NTC)

2.7 Flow Transmitter

The DPT flow sensor is designed for air handling units to measure the air flow of the supply and return air. The flow transmitters are sensors with an electrical transmission output for the remote indication of flow rate. The flow sensor has a display unit, which can be used as an on-site for flow as a transmitter to regulate the air flow on a selected passageway. The flow sensor is appropriate for non-aggressive air and gas. The output signal of the transmitter is 0-10 Vdc. The operating range of the transmitter is between 0 to 5000 Pa. The measuring element in the flow transmitter is a Micro Electric Mechanical Systems (MEMS). The application of the flow transmitter in an Air Handing Unit is to monitor the air flow across the centrifugal fans and to monitor in-duct air flow. The DPT transmitter used in this work is represented in the figure 24.

Figure 24 – DPT Flow transmitter [16]

Autozero calibration is a form of automatic zeroing circuit built into the Programmable Circuit Board (PCB) [16]. This function electronically adjusts the transmitter zero at a predetermined time interval. This function eliminates all the output drift signals due to thermal, electronic or mechanical effects.

The technical details of the flow transmitter used in this project is shown in the table. The manufacture of the transmitter is HK instruments and the model is HK instruments DPT flow 5000.

Accuracy (from applied pressure)	Pressure < 125 Pa = 1.5% + ± 2 Pa Pressure > 125 Pa = 1.5% + ± 1 Pa
Zero Point Calibration	Automatic with autozero element or by push button
Measuring units	Pressure: Pa, kPa, mbar, inchWC, mmWC, psi. Flow: m^3/s, m^3/hr, cfm, l/s, m/s, ft/min.
Supply voltage	24 Vac
Power consumption	< 1 W

Output signals for pressure and air flow	0-10 Vdc
Operating temperature	-10-50°C
Response time	1-20s

Table 4 – Specification of DPT Flow5000

2.8 *Fans and Inverters*

Fans are used as an air pumps that creates a pressure difference and causes airflow. The fans are generally placed in the supply and return ducts of the Air Handling Unit. The function of the fans is to forces the air into or from the room. The air handlers employ a motor driven by an AC induction electric motor. the impeller imparting to it both static and kinetic energy, which vary in proportion, depending on the fan type. All fans produce pressure by altering the velocity vector of the flow. The fans used to circulate the air to sections of the buildings in this project are centrifugal fans. The selection of the fan will depend on the air volume and the static pressure required of the system. A fan produces pressure or flow because the rotating blades of the impeller impart kinetic energy to the air by changing its velocity. The fans are coupled with a motor. The motor works with the help of a programmed inverter.

The motors used in the Air Handling Unit depends on its application. The common type of motors used are AC motors. The fan coupled with the motor is represented in the Figure 25.

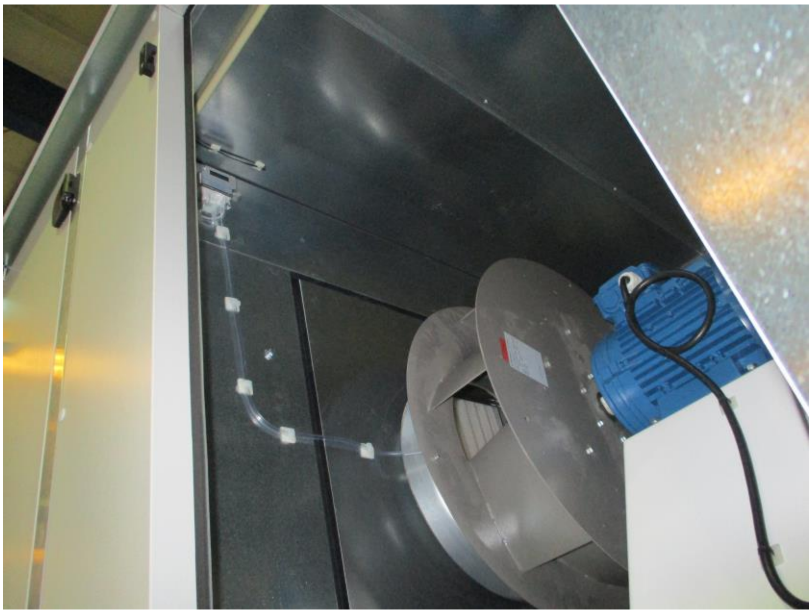


Figure 25 – Fan coupled with a Motor

Inverters are devices used for varying the speed of a driven equipment to exactly match the process requirements. Frequency inverters makes it possible to match the speed of the motor to the load or process requirement which also ensures avoidance of losses which may otherwise occur by using other conventional methods. By using an inverter, a stepless control of motor speed in tune with load requirements encountered by fans or pumps is possible. Retro fitting these frequency inverters onto existing installations can be done and therefore a very viable proposition exists of making existing installations of fans and pumps more energy efficient. The frequency inverter used in this project is a CFW 500 manufactured by Weg. The datasheet of the inverter is attached in the annex. The inverter used in this project is represented in Figure 26.

Figure 26 – Electronically commutated Inverter

2.9 Dampers

The damper is a mechanical device regulate the flow of air in and out of the Air Handling unit. Dampers are specifically a valve or a plate that can regulate the air flow through an Air Handling Unit duct. Automatic dampers are used to regulate the airflow constantly and are operated electric or pneumatic motors, which is controlled by a thermostat or a Building Management System (BMS). Automatic dampers can also be controlled by a solenoid. There are two types of dampers used – modulating damper and On-Off damper.

Modulating damper actuator will position, or throttle, the damper or valve as commanded by the controller to achieve a desired position or flow with a 24 Vac to 230 Vac contacts. The modulating control signals works with 0-10 Vdc. The response of the actuator indicates the damper position. When the damper is fully closed, the output voltage gives a response of 0 Vdc and when fully open, it gives a response of 10 Vdc. If the damper is open 50%, the output response is % Vdc. The damper used for this project is a LM 24A-SR as the damper size up to 1 m^2. The technical datasheet of the LM 24A-SR is attached in the annex. A modulating damper is represented in Figure 27.

Figure 27 – Modulating Damper Actuator [17]

On-Off damper or an Open/Close damper produces a two-position response. When the damper is open, it is 100% open and when the damper is closed, it is 0% open. The damper used for this project a LM 24A-TP as the damper size up to 1 m^2. The technical datasheet of the LM 24A-TP is attached in the annex. An On-Off damper actuator is represented in Figure 28.

Figure 28 – On-Off Damper Actuator [18]

2.10 Testing and Commissioning

Testing, Adjusting and Balancing (TAB) [8] is a procedure that determines the quantitative performance, studying the flow rate and air flow pattern and adjusting as per the design specified and adjusting the flows in proportion within the design system based on the design requirements. TAB is a systematic procedure that are performed after the equipment is completely installed and serviced [19]. TAB procedure involves quantifying and reporting of adjusting of equipment, measurement of electrical requirements, record data to verify the performance of components, verifying settings and operation of automatic controls, measure and test of sound and vibration on critical systems.

Commissioning [20] is systematic, documented and collaborative process that includes inspection, testing and training conducted to confirm that it functions according to its design objectives or specifications. Commissioning ensures reduced energy use, improved air quality management and occupants' health, safety and comfort. The other benefits of commissioning include better operation, maintenance and reliability, low energy and operating costs and complete and useful documentation.

A test procedure guideline has been prepared for the general checks and testing operations [21].

Guidelines for general checks

1. Confirm the unit is built according to the drawing.

2. Confirm that all the connections have been properly given.
3. Check if the power supply is isolated, has the correct source, voltage and circuit breaker sizing.
4. Confirm that the electrical terminations are connected properly.
5. Check the air filters, pressure switches, temperature probes and flow transmitters are fixed properly and connected.
6. Check the coils are not damaged.
7. Check if the fans are free to rotate.

Guidelines for testing operation

1. Confirm that the CHW and HHW valves are working properly.
2. Verify the operation at full air flow, pressure differential across coils.
3. Check if the fans rotate in the correct direction. Measure the current of the fans.
4. Check the manual testing of the alarms for filter switches, control valve positions, and other necessary alarms.
5. Operate the test in AUTO mode to verify that the units do not have any alarms and verify that it can satisfy the set points.

Automated proactive methods [22] have been used for commissioning of Air Handling Units. Application of the generic, automated, proactive commissioning process requires development of methods for each of four fundamental processes it comprises fault detection and diagnosis based on passive observations, proactive fault detection and diagnostics, fault evaluation and decisions regarding if and what corrective actions to take, including automatically implementation some of the selected actions.

The air-side fault detection has been automated in a software tool known as the Outdoor-Air/Economizer (OAE) diagnostic module of the Whole Building Diagnostician (WBD). The OAE continuously monitors the performance of AHUs and can detect over 20 different basic operation problems or faults. It, however, does not detect problems on the water-side of the AHU.

Automated FDD processes generally rely on analytical or physical redundancies to isolate a fault during diagnosis. Most HVAC systems in commercial buildings lack physical redundancy, because HVAC systems are considered non-critical. An AFDD process can use proactive diagnostic processes to create analytical redundancy to help isolate the causes of faults.

Although proactive diagnostics help in isolating faults and deepening diagnosis, they are intrusive. Some building owners and operators may consider this disruptive to normal operation of building systems. They may not, however, if such proactive tests can be conducted quickly enough so that acceptable control of the building systems is maintained. Entirely proactive commissioning procedures could provide ‘‘continuous’’ commissioning if they were periodically triggered e.g., once a day, week, or month. These procedures might be scheduled to occur during unoccupied hours to reduce their intrusion on normal operations.

Another Fault Detection and Diagnosis (FDD) [23] process is divided into two steps, the first being testing in accordance with the desired setpoints. When the difference between the actual value and the selected set point exceeds a selected threshold value, an alarm marked with a time stamp is updated into the log file for fault diagnosis.

The second step deals with the analysis of psychrometric processes of the control strategy from outside air to supply air. The factors that controlled are temperature and humidity.

The commissioning for a new building is carried out in different phases – Pre-design, Design, Construction, Acceptance, Post-Acceptance. The scope of commissioning is developed in the pre-design phase. The design intent document is reviewed by the commissioning authorities.

In the design phase, the project schedule is established, and the authorities work on a commissioning plan. In the construction phase, the document verification and system start-ups are being carried out. The authorities document the tests. In the acceptance phase, the functional performance test is carried out on the unit and the full documentation is provided. In the post-acceptance phase, any small deficiencies are corrected, and a re-test is carried out if necessary.

For an existing building, the commissioning methodologies are periodic re-commissioning, retro commissioning and system modifications [24]. Periodic re-commissioning is a periodic commissioning of a unit in a building that were commissioned when new. The purpose is to diagnose an unresolved problem. Retro commissioning is similar to that of a periodic re-commissioning procedure, but it occurs when the unit was not commissioned when installing. System modifications are some modifications that need to be made as the operational requirements change over time. A new commissioning procedure will ensure that the modifications will be in accordance with the present requirement. [25]

2.11 Existing Technologies

2.11.1 Supply Air Temperature Control of AHU with a Cascade Control Strategy and a SPSA Based Neural Controller. [26]

In centralized heating, Air Handling units are traditionally controlled by a single loop Proportional-Integral-Derivative (PID) controller. Though the control structure is simple, the performance was not found to be satisfactory. Hence, a cascade control strategy was proposed for the control of temperature. Instead of fixed PID controller, a neural network was used outside the outer control loop. This approach not only avoided the tedious tuning procedure for inner and outer PID loop parameters, but also made the whole control system be adaptive and robust. The structure of the control scheme is shown in Figure 29. A special multilayer training network was used to train the neural network online – Simultaneous Perturbation Stochastic Approximation (SPSA). SPSA guaranteed the weight convergence of the neural network and stability of the control system. A novel cascade system was implemented to improve the supply air temperature control of the AHU.

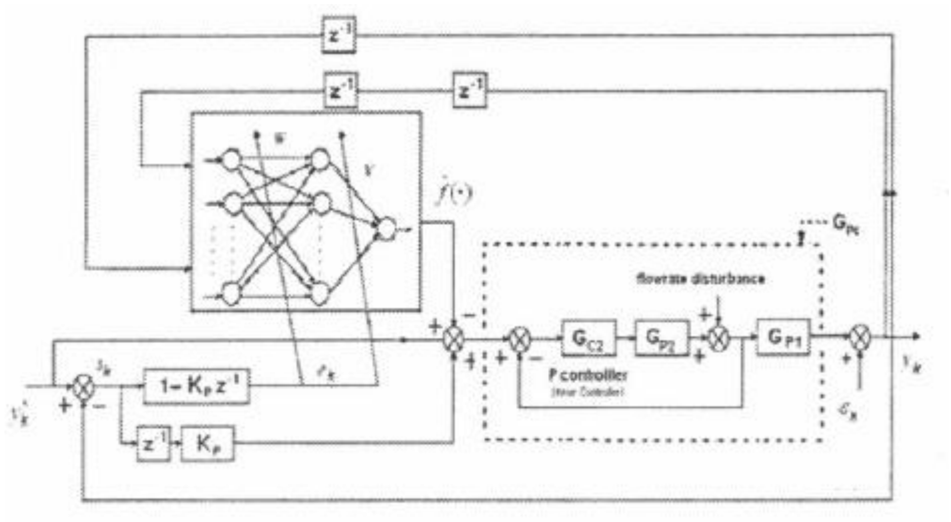


Figure 29 – Structure of the control scheme

The results of the AHU for a single loop PID controller is shown in Figure 30 and the result for Cascade control with PI inner loop controller and PID outer loop controller is shown in Figure 31.

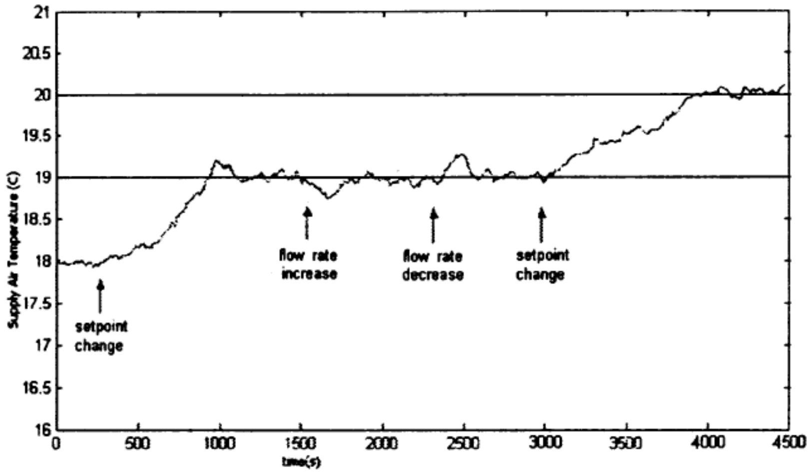


Figure 30 – Supply air temperature control performance of AHU (single loop PID control)

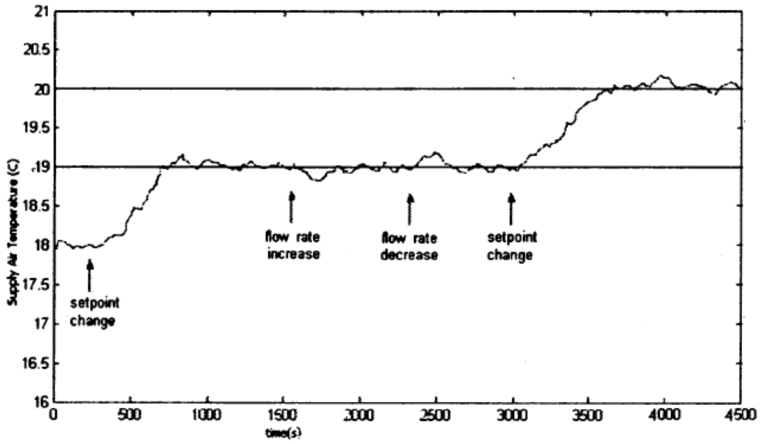


Figure 31 – Supply air temperature control performance of AHU (Cascade control with PI inner loop controller and PID outer loop controller)

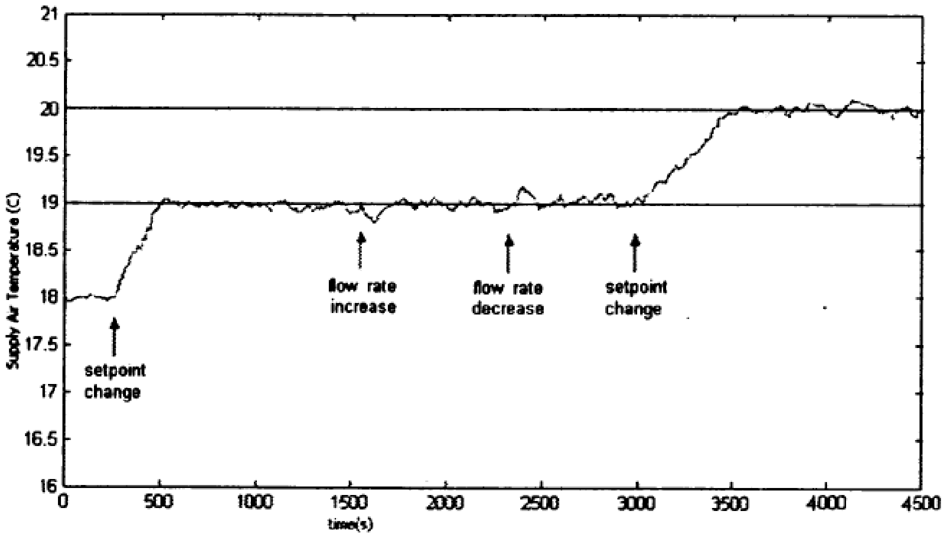


Figure 32 – Supply air temperature control performance of AHU (Cascade control with PI inner loop controller and NN outer loop controller)

Both the off-coil temperature and chilled water flow rate were measured. The chilled water temperature was controlled around 8°C and supply air pressure was controlled to be constant by keeping the supply fan running at a constant speed. The test results showed that the proposed neural network assisted cascade control system improved the temperature control performance of AHU for both temperature set-point changing and chilled water flow rate disturbances. The result was shown in Figure 32.

2.11.2 AHU Control Strategies in the VAV System. [27]

This paper mainly introduces Air Handling Unit control in the Variable Air Volume (VAV) air condition system. Combined with engineering experiences, it introduces some experiences of supply air temperature control of AHU and makes a comparison with the constant static pressure control strategy, the optimized static pressure control strategy, and the total air volume control strategy, to give some recommendations for the VAV system control.

This paper focuses on the similarities and differences between Variable Air Volume air conditioning system and Constant Air Volume air conditioning system. In a CAV system, it is needed to control fan start or stop, air damper or return air damper open and close, water coil valve position, humidifier start and stop, need to take in account the filter alarm, fault alarm, anti-freeze protection, season conversion, etc. But in a VAV system, the parameter used to control damper position should be the supply air temperature instead of the return air temperature.

The location of the supply air temperature sensor needs to be installed as far as possible from heating or cooling unit (3~5m). This is to give the distance for the full mixture of air. A suitable working range will contribute to a better control accuracy. A higher P value and lower I value would help in achieving an ideal transient process. This makes the AHU and VAV unit more stable and faster.

AHU supply air volume control is the core of VAV system, which determines the stability and the energy conservation of the system. Fan's speed is controlled by frequency converters. It uses either 4-20mA or 0-10V signals and converts it into corresponding output signal of current frequency.

There are different control strategies advocated by different manufacturers

- Constant Static Pressure Control
- Optimized Static Pressure Control
- Total air volume Control Strategy

Constant static pressure control strategy uses feedback control mechanism. It has least energy conservation with about 40-50%. The main advantage about this strategy is that it is a simple control strategy.

Optimized static pressure control strategy uses feedback control mechanism and has an energy conservation of about 50-60%. Optimized static pressure control is the most energy conservation strategy. The main disadvantage of this strategy is that it is a complicated control. The requirements for this is a On line control, VAVBOX damper position feedback.

Total air volume control strategy uses feedforward control mechanism. It has an energy conservation of about 45-55%. The main advantage of this unit being it has a fast control response. The disadvantage of this unit is that it has a complicated control. Total air volume control strategy requires On line control, Pressure-independent VAVBOX and air flow measurements.

2.11.3 A New Energy-saving Air Handling Unit for Clean Operating Room. [28]

The existing air handling units for clean room were introduced and a new energy–saving air handling unit in which air temperature and humidity was conditioned separately and two stage dehumidifiers are set is presented, the structure of the new type air handling unit is given and characteristics are provided; a project example was

calculated and discussed in the paper; compared with the traditional air handling unit, the new type of air handling unit for clean operating room has significant effect on energy saving and can satisfy the different situations of constant temperature and humidity control
requirements.

It is highly essential that operating rooms in hospitals have the right temperature and humidity. This can be ensured by having the right air conditioning equipment. Packaged direct expansion air conditioning unit has a compact construction, but the control does not apply to very large volume areas. Another widely used equipment is Modular Air Handling Units, using the cooler to cool and dehumidify air. Heater in traditional modular air handling units always used to reheat air in summer. This leads to high energy consumption and high running costs.

Setbacks in the methods can be overcome if temperature and humidity can be conditioned separately. In the new method it can adapt to different situations of constant temperature and humidity control requirements and has the advantages of low energy consumption, flexible operation and easy control.

The existing AHUs can be divided into two types according to the different process of return air. Type 1 uses return air is used only once. Air must be reheated in summer making waste of both heating and cooling. A schematic of an existing clean air conditioning system (type 1) is shown in Figure 33. The cooling and dehumidifying process is processed by the same cooling coil, air needs to be cooled enough to move the moisture content. It is also not possible to supply the air at low temperature to the conditioned space, it must be reheated thus resulting in high consumption of energy. Evaporative temperature of the chiller unit reduces when moisture load from the room becomes high. This reduces the efficiency of the chiller making the whole system uneconomic.

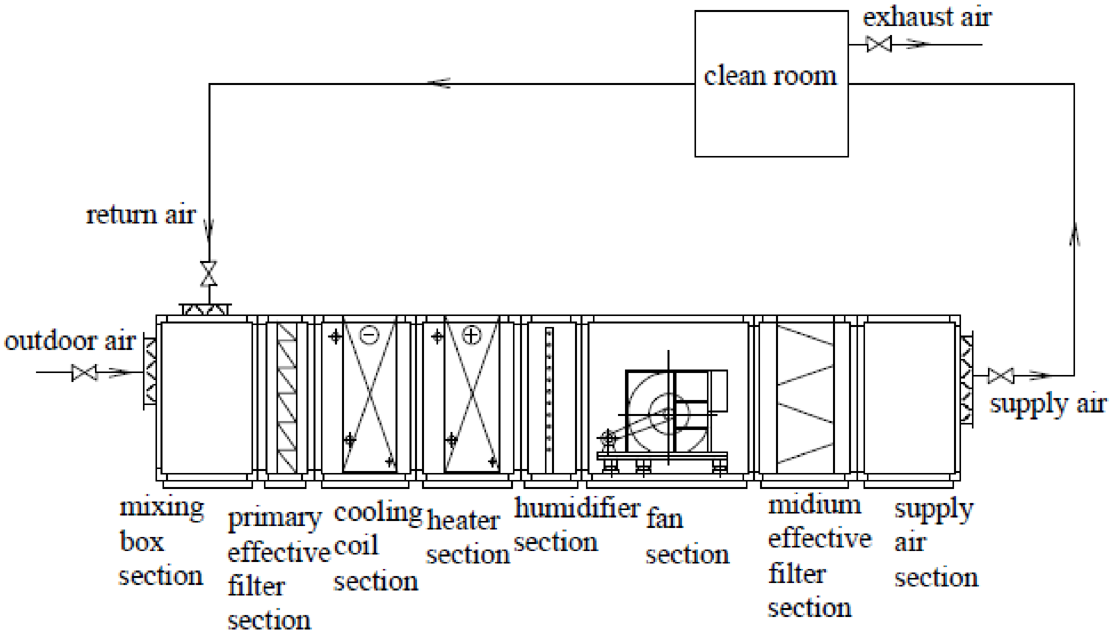


Figure 33 – A schematic of an existing clean air conditioning system (type 1)

In type 2, the return air is used twice in the unit to avoid the reheat problem. Air entering the secondary mixing box section is called the “due point air”. The volume of air that flows through the cooling coil is less than that of type 1, so the air needs to be cooled to a lower temperature to move the moisture. In some situations, with the high percentage of fresh air, minimum fresh air volume may be more than the calculated dew point air volume. The control becomes complex when the cooling or moisture load changes. The ideal way is to regulate the primary and secondary return air ratio, but it is difficult to achieve. In practical cases, the primary and secondary return air percentage is fixed. When there is a load change, it is controlled by adjusting the dew point temperature. A schematic of an existing clean air conditioning system (type 2) is shown in Figure 34.

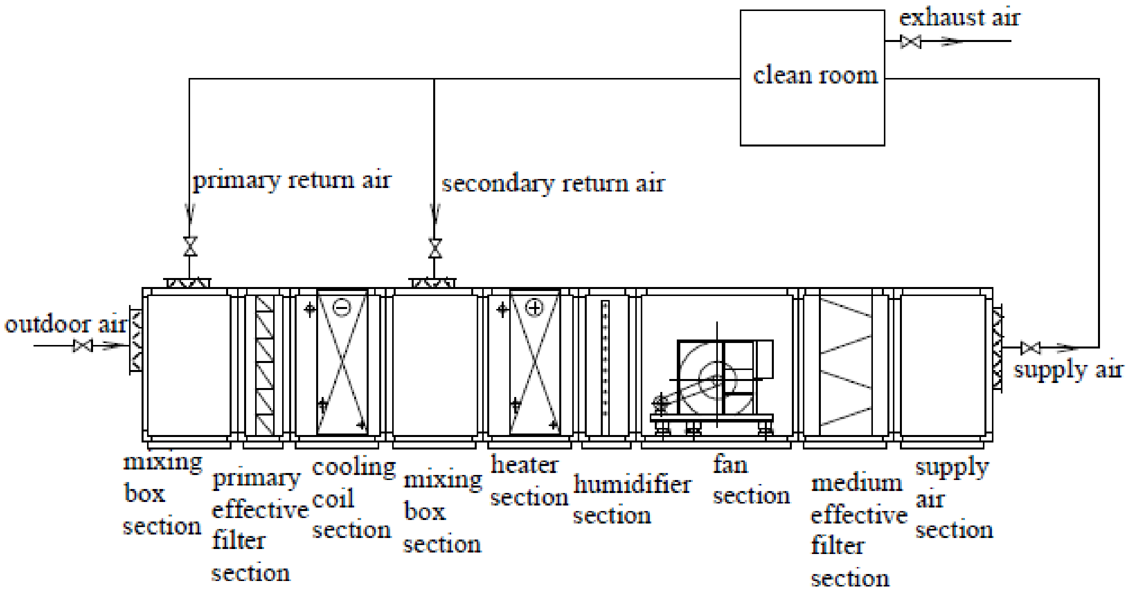


Figure 34 – A schematic of an existing clean air conditioning system (type 2)

The new design is similar to that of type 2, but the dehumidifier conditions only the fresh air. A schematic of a clean air conditioning system equipped with new AHU is shown in Figure 35. Two coils are used chilled water coil and direct expansion coil. The fresh air enters through the inlet section to the primary filter and to the dehumidifier section. The fresh air is then cooled by the chilled water coil, some moisture of the air is moved, in the secondary dehumidifier coil flows refrigerant, more moisture is removed. The conditioned fresh outdoor air enters the mixing box section, mixes the return air, the mixed air is driven by the fan, blows to the next sections, cooling coil section is followed by the fan section, the mixed air is cooled by the chilled water. The heater section followed by the cooling coil section is mainly used in winter to heat air, medium effective filter section is used to purify air again, and air is transported from supply air section to conditioned space by ducts.

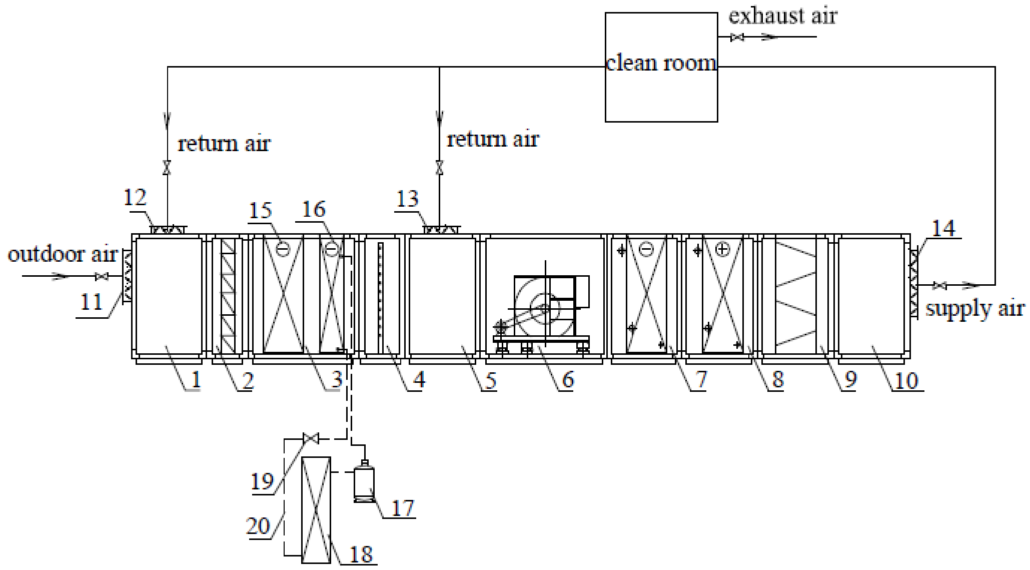


Figure 35 – A clean air conditioning system equipped with new AHU

This case study was taken from a hospital located in Gaungzhou city, China. The hospital consisted of 5 clean operating rooms, one Grade 1, one Grade 2 and three Grade 3 operating rooms. The air handling process of different systems were found and is shown in Figure 36. The psychrometric chart for the indoor point N and outdoor point W, a line is drawn with an angle scale 10717, supply air point must be on some position of the line. It was found that the supply air flow rate is 9000 m^3/h, indoor air density is 1.18 Kg/m^3, supply mass flow rate is 2.95 Ks/s under the density.

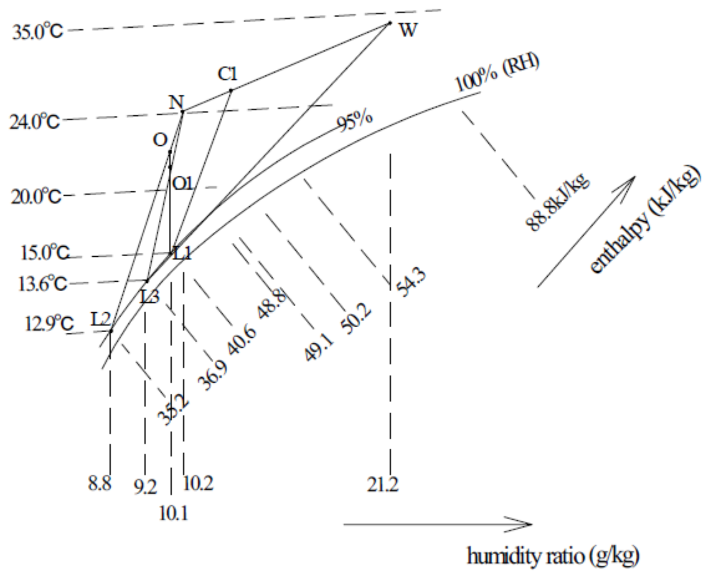


Figure 36 – Air handling process of different systems

2.11.4 Control Strategy Research for the Combined Air Handling Unit [29]

The interaction of temperature and humidity causes low control performance and high energy cost for combined AHU (air handling unit). In this thesis a new control strategy combined with decouple and fuzzy theory was studied to improve the comprehensive performance of the combined ABU. Firstly, based on the first principle the dynamics of temperature and humidity were built and transformed into different TFs (transfer function). Then the moisture content was introduced as intermediate variable and feed-forward compensator was designed, the interaction between temperature control and humidity control was decoupled. Finally, a fuzzy controller was designed to adjust the PID parameters adaptively with different operation conditions. The results of case study show that the proposed method is quite effective to the combined AHU, the overshoot and transient time is obviously smaller than conventional control method.

When the room temperature is lower than the set point, the opening degree of the steam is increased proportionally which increases the room temperature and vice-versa.

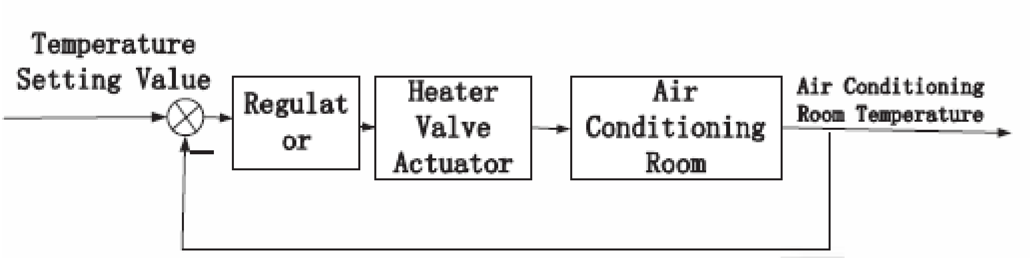


Figure 37 – Temperature control loop

Based on the above method, the relative humidity can also be controlled by regulating the cold-water valve or the humidifying valve. The schematic of a temperature control loop in Figure 37. The schematic of the humidity control loop is shown in Figure 38.

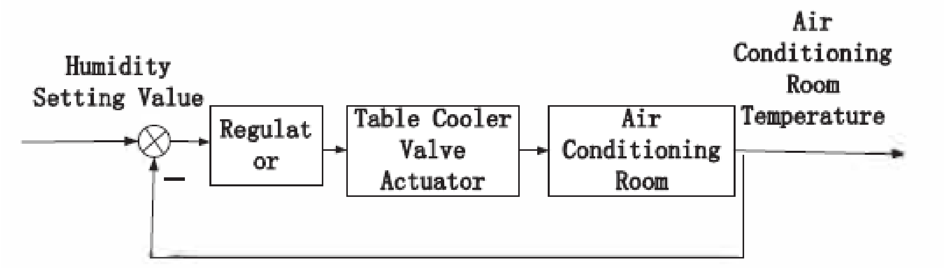


Figure 38 – Humidity control loop

PID controllers are widely used to control system outputs, especially for systems with accurate mathematical models. The key issue is the accurate and efficient tuning of parameters. The traditional PID parameter tuning methods are not suitable for these difficult calculations. Because the air conditioning system has some similar characteristics, a hybrid control method should be introduced into its controller. A fuzzy PID controller was designed to set PID controller parameters by fuzzy reasoning. This controller not only has the merits of high control accuracy and small static error from the traditional PID controller, but also has the merits of high adaptability and strong robustness and stability from the fuzzy controller. The schematic of the Fuzzy PID model is shown in Figure 39.

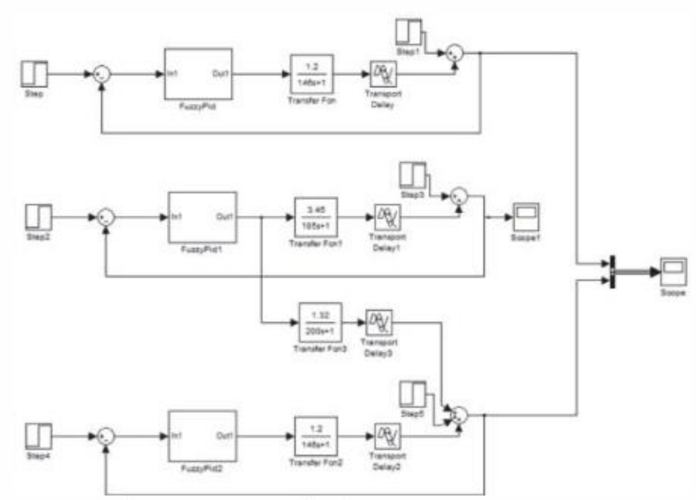


Figure 39 – Model of Fuzzy PID control

The fuzzy PID was established and simulated before and after decoupling. Comparing the two response curves, it was found that the overshoot of the system response scales down. The simulation of the room temperature is shown in Figure 40. Similarly, moisture content for the room was also simulated and was found that it was the same since the heating did not have any effect on the moisture. The simulation of the room humidity is shown in Figure 41.

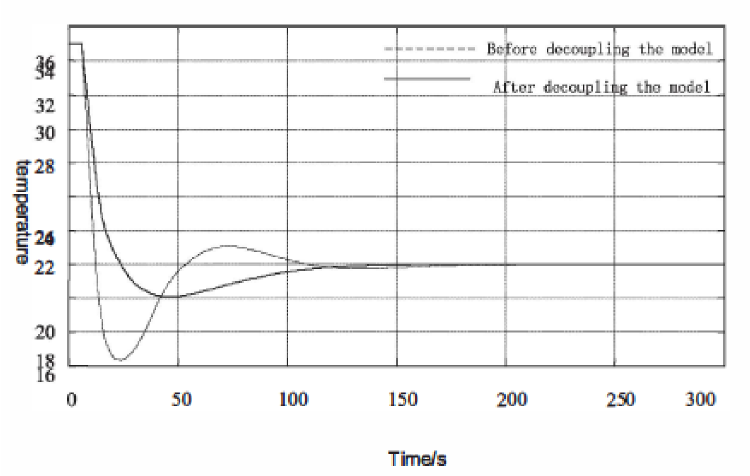


Figure 40 – The simulation of room temperature

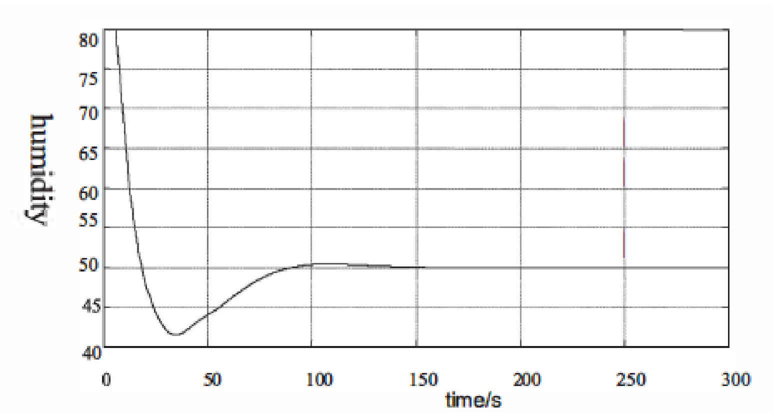


Figure 41 – The simulation of room humidity

PROJECT OF AIR HANDLING UNIT

3 PROJECT OF AIR HANDLING UNIT

In this chapter, the construction of the unit, schematics for the unit, the programming of the unit, the working of the unit, testing and results of the unit are discussed.

3.1 Unit Construction

The UTA-RP 50 plus 50 is a two-fan unit. The fans each used for supply and recovery. The unit uses two dampers at the inlet and outlet to restrict the flow of air in and out to the atmosphere. Filters are used at inlet and return to reduce the amount of carbon dioxide and dust impurities. Pressure switches are used at the filters to determine the purity of the filter, which is represented by G4. The damper for inlet is where the air is supplied to the room through the unit. The Figure 42 represents the inlet and outlet section with the damper.

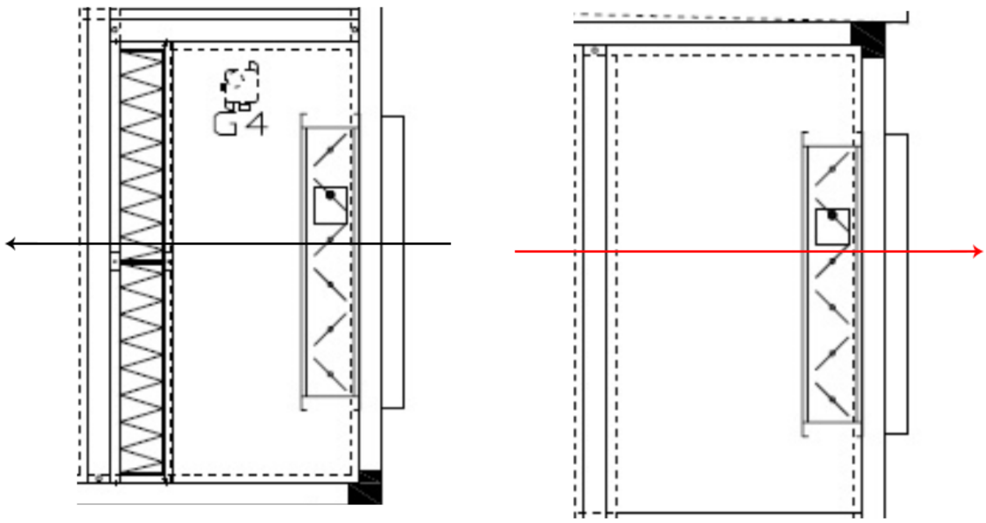


Figure 42 – The inlet and outlet duct of UTA-RP 50

Another damper is present for mixing the return air and new air. A recovery bypass unit is present. The construction is such that the recovery unit is placed between the inlet and outlet duct. The recovery unit is represented in the Figure 43.

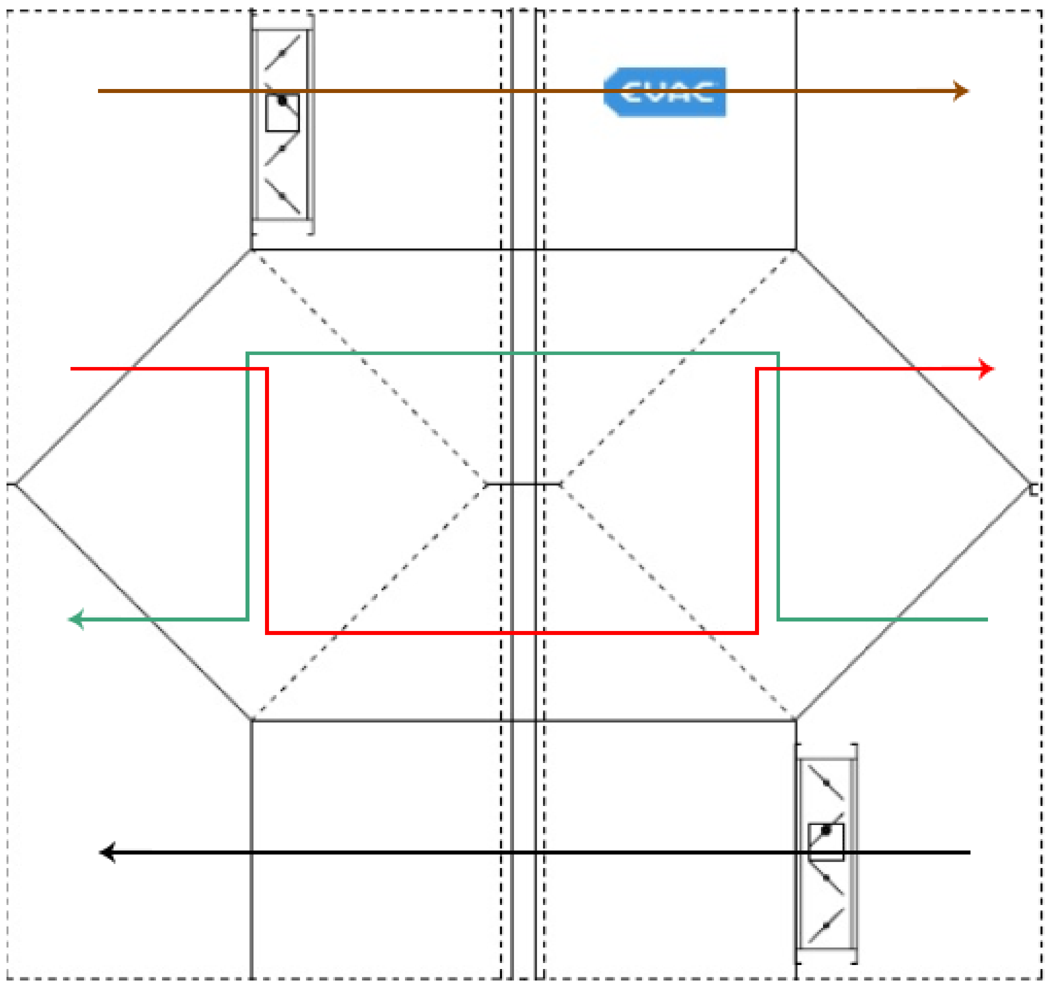


Figure 43 – Recovery unit of UTA-RP 50

Three temperature probes are used to measure the temperature at three different points, namely the air outside, air at supply and air at return. The probe to determine the temperature of the outdoor air is placed on the damper of the inlet duct. The probe for the supply temperature is fixed near the filters to determine the temperature of the air supplied to the room. The reference probe is the return probe, and it is fixed on the return duct.

The supply duct consists of the fans for supply of the air. Filters are present in the supply to remove the dust particles. Pressure switches are present near the filters to determine the purity of the filters. Once the filters collect the dust, the contact opens. The power of the supply engine is 5.5kW. The supply duct is represented in the Figure 44.

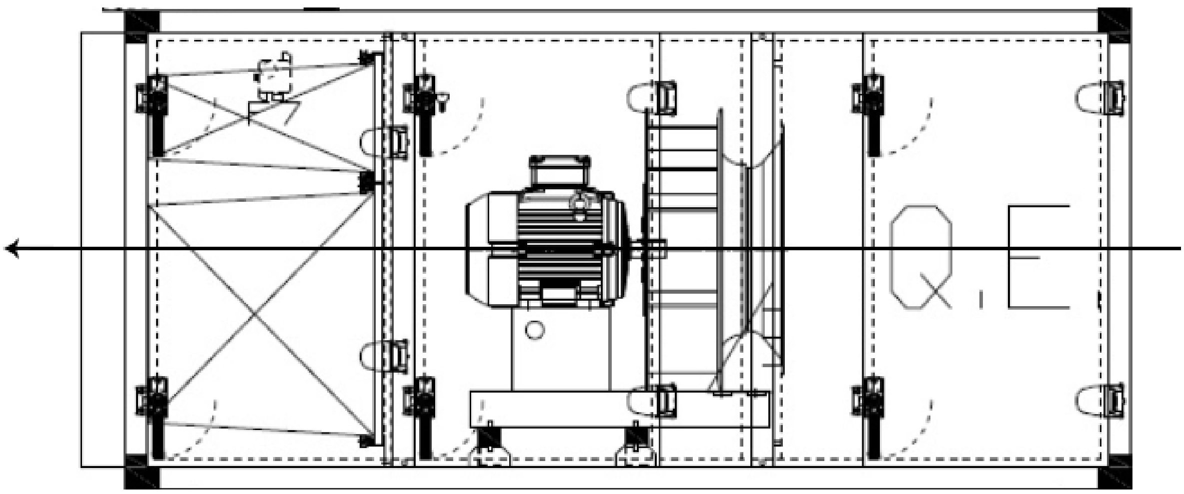


Figure 44 – Supply unit of UTA-RP 50

The return air is supplied out to the atmosphere or a part of the air is returned back to the room by a mixing process through a mixing duct. The return unit is represented in Figure 45.

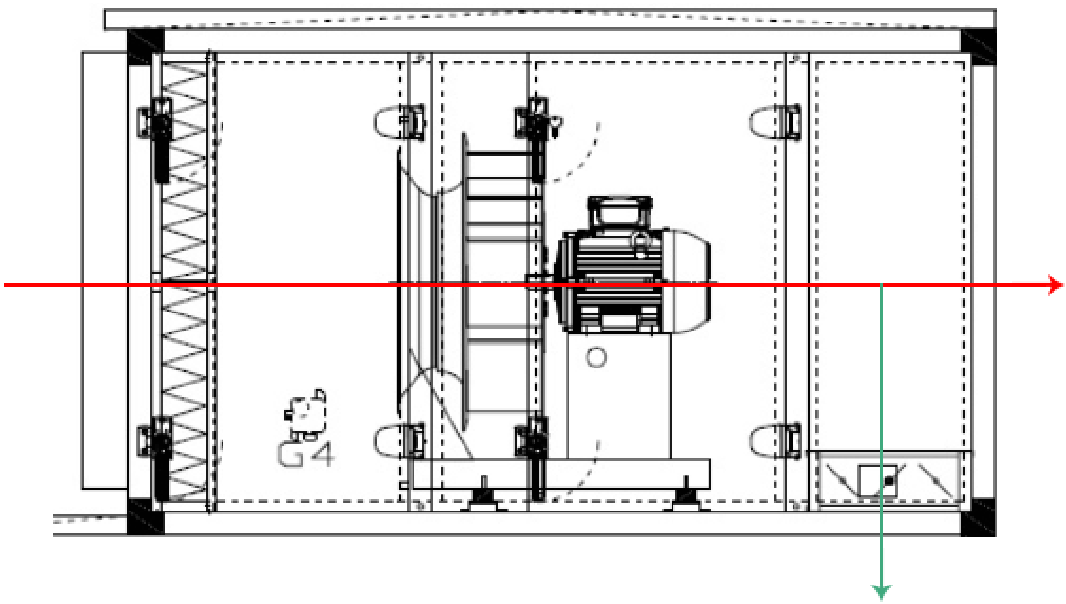


Figure 45 – Return unit of UTA-RP 50

The overall unit of UTA RP 50 plus 50 is represented in the Figure 46.

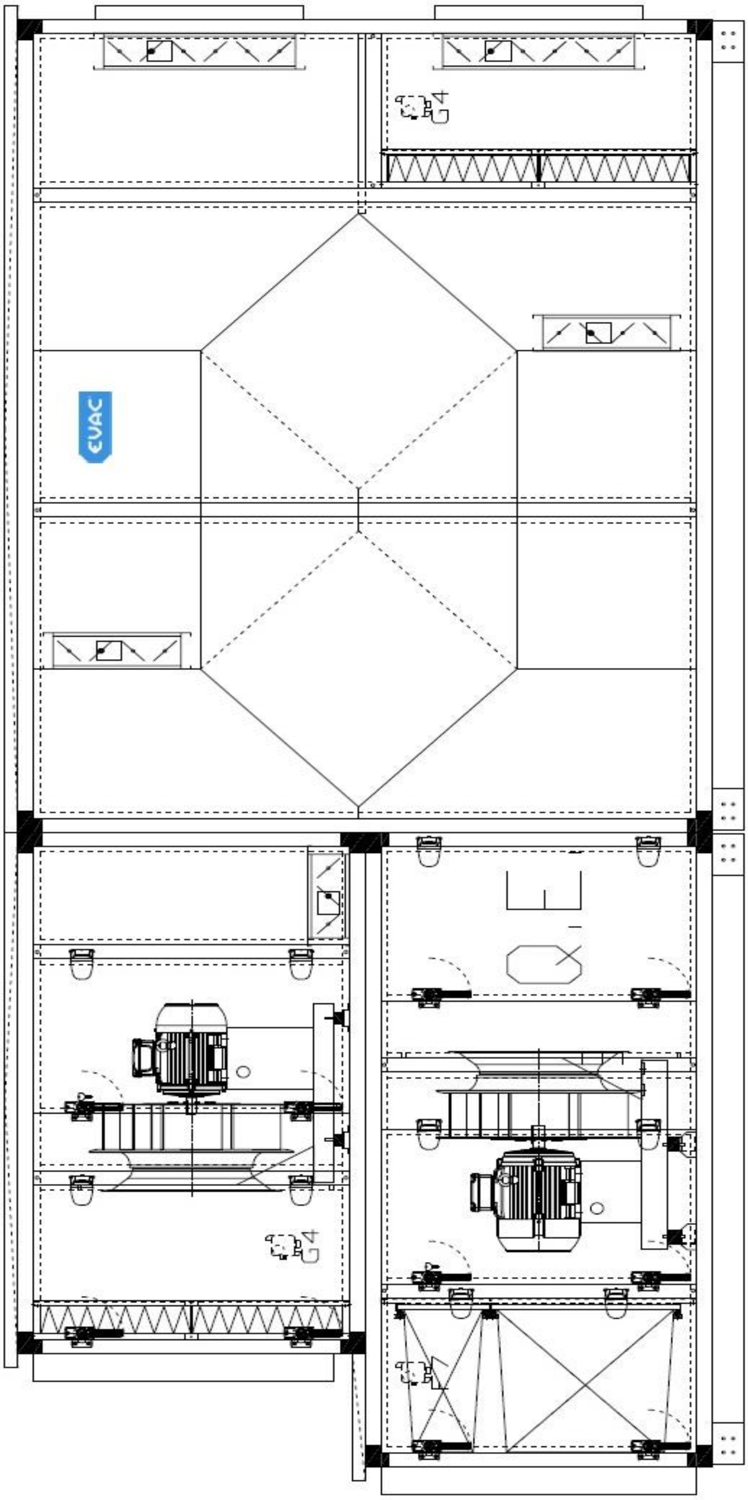


Figure 46 – The overall unit of UTA-RP 50

3.2 Schematic

The schematic is a representation of the elements of a system using abstract, graphic symbols rather than realistic images. A schematic diagram uses symbols to represent the temperature probes, motors, fans, switches, etc. The schematic is divided into electrical specifications, table of terminals, Transformer connections, Supply motor, Return motor, Analog Inputs and Outputs, Digital Inputs and Outputs, communication bus, List of materials. The schematic sheets are presented in the Annexure.

3.2.1 Electrical Specifications

The first sheet of the schematic consists of the basic information regarding the electrical specifications of the units. This sheet gives the information regarding the power for the supply fans and return fans, power supply for the units and auxiliary circuits. The electrical schematics is represented in Figure 47.

Electrical Specifications

	UTA4
SUPPLY MOTOR	5,5kW (~17,1A)
EXTRACTION MOTOR	4kW (~12A)

Figure 47 – Schematic of Electrical specifications of schematics

3.2.2 Terminals

The next sheet is named “Table of terminals”. This sheet of schematic describes the power and signal to the auxiliary devices such as temperature sensors, pressure switch, signals for dampers, etc. from pCO5+. The terminals are represented in Figure 48.

Terminals

PR. TRANSMITTER SUPPLY			PR. TRANSMITTER EXTRACTION			DAMPER - MIXTURE			DAMPER - AIR NEW DAMPER - EXTRACTION			TEMP. SENSOR SUPPLY		TEMP. SENSOR RETURN	
Gnd	Signal	24Vac	24Vac	Sinal P.	Gnd	Gnd	0...10Vdc	24Vac	24Vac	0...10Vdc	Gnd				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Figure 48 – Schematic of Terminals of schematic

3.2.3 Transformer Connections

The next sheet is named "Transformer connections". This sheet of schematic describes the power supply to Bus1 and Bus2. Bus1 represents Electrical Bus1 which is 400V, that supplies power to the supply and return fans. Bus2 represents Electrical Bus2 that is 24V, which supplies power to the pCO5+ and other auxiliary circuits such as temperature sensors, pressure switches, etc. The 24V is obtained by stepping down the 400V through a transformer. It also contains fuses for the safety of the unit and controller. The schematic of the electrical bus is represented in Figure 49.

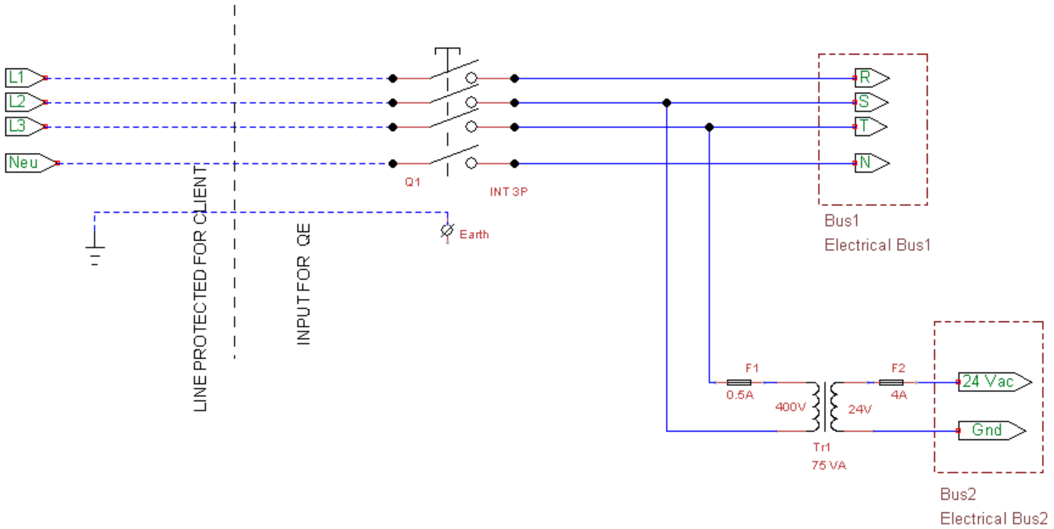


Figure 49 – Schematic of Electrical bus connections

The schematic of the power supply is represented in Figure 50.

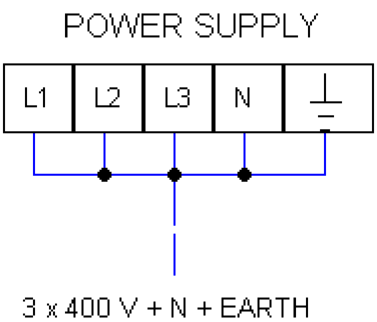


Figure 50 – Schematic of Power supply

3.2.4 Supply Motors

The next sheet is named “Supply Motor” which describes the schematic for the supply inverter which is connected to the supply fan. The error signal from the digital input 5 is connected to the pins 11 and 13 of the inverter. The inverter has a manual switch connected by a relay connected to pin 1 and pin 16, that switches on the inverter with a fixed frequency. The schematic of the return motor and inverter is shown in Figure 51.

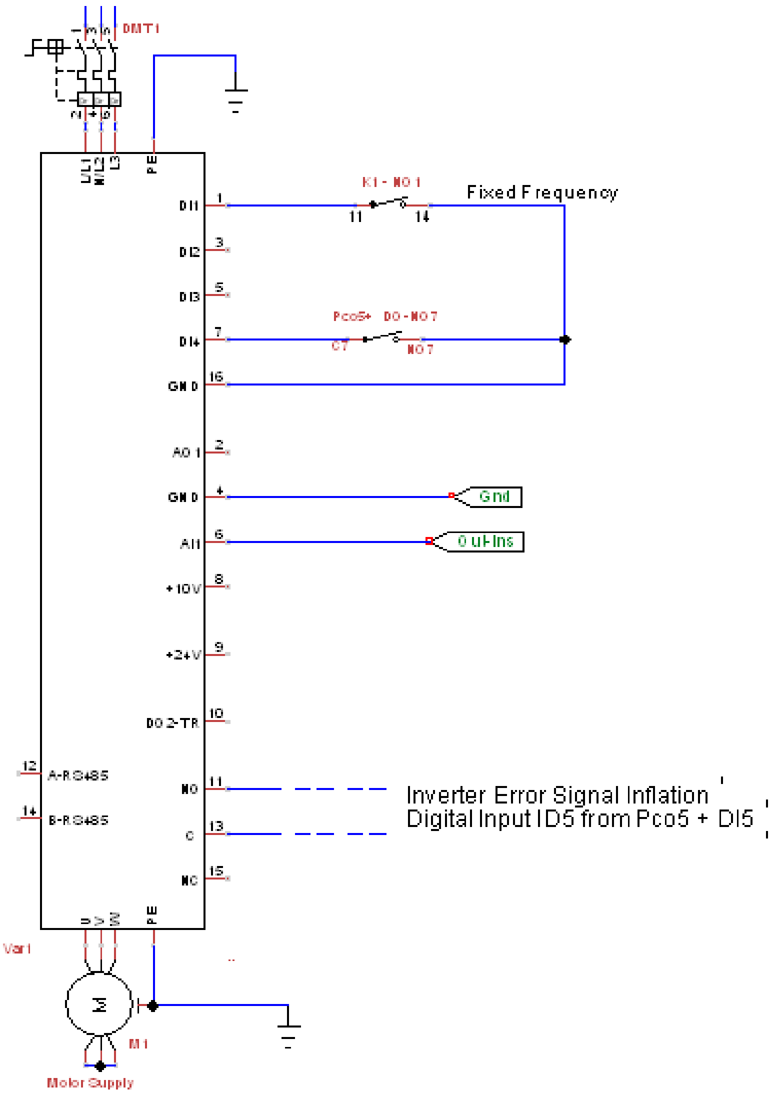


Figure 51 – Schematic of Inverter schematics for Supply

A relay is used in this used to manually switch on the inverter of the supply motor (K1 NO1) and return motor (K1 NO2) with at a fixed frequency. It also has a position switch to select the operation to be Manual, Automatic or Off. The schematic of the position switch and relay is shown in Figure 52.

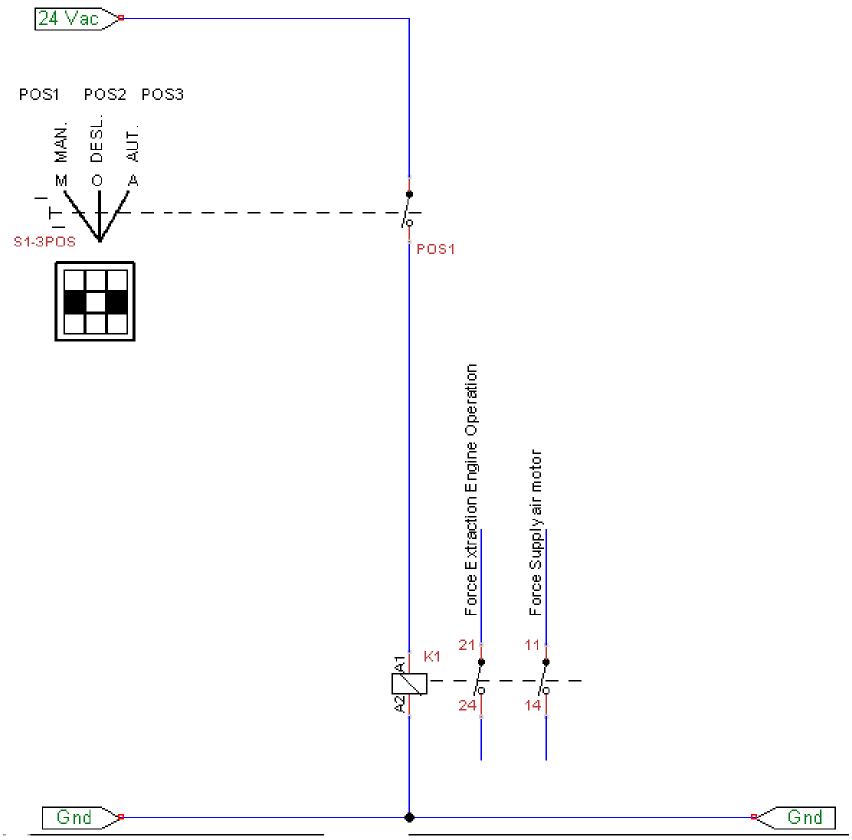


Figure 52 – Schematic Relay and Position switch schematics

3.2.5 Return Motors

The next sheet is named "Return" which describes the schematic for the return inverter which is connected to the return fan. The error signal from the digital input 6 is connected to the pins 11 and 13 of the inverter. Similar to the supply motor inverter, the relay is connected to pin 1 and pin 16, that switches on the inverter at a fixed frequency. The schematic of the return motor and inverter is shown in Figure 53.

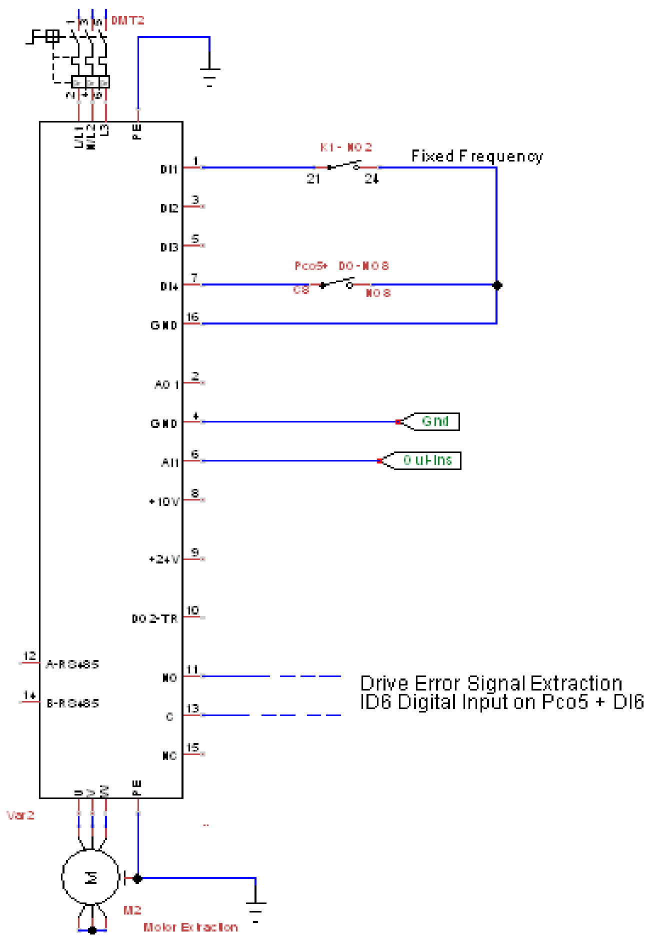


Figure 53 – Schematic of Inverter supply for return

3.2.6 Analog Inputs

The next sheet is named “Input Analog” which describes the Analog inputs from the pCO5+. The ports are universal ports depicted by “U”. This describes the inputs for Flow sensor to terminals U1 and U2 to determine the flow of the air. One of the flow sensors is to determine the flow rate of the supply air and it is fixed on the supply line. Similarly, the other flow sensor determines the flow rate of return air and it is fixed in the return line. The schematic of the flow sensors is shown in Figure 54.

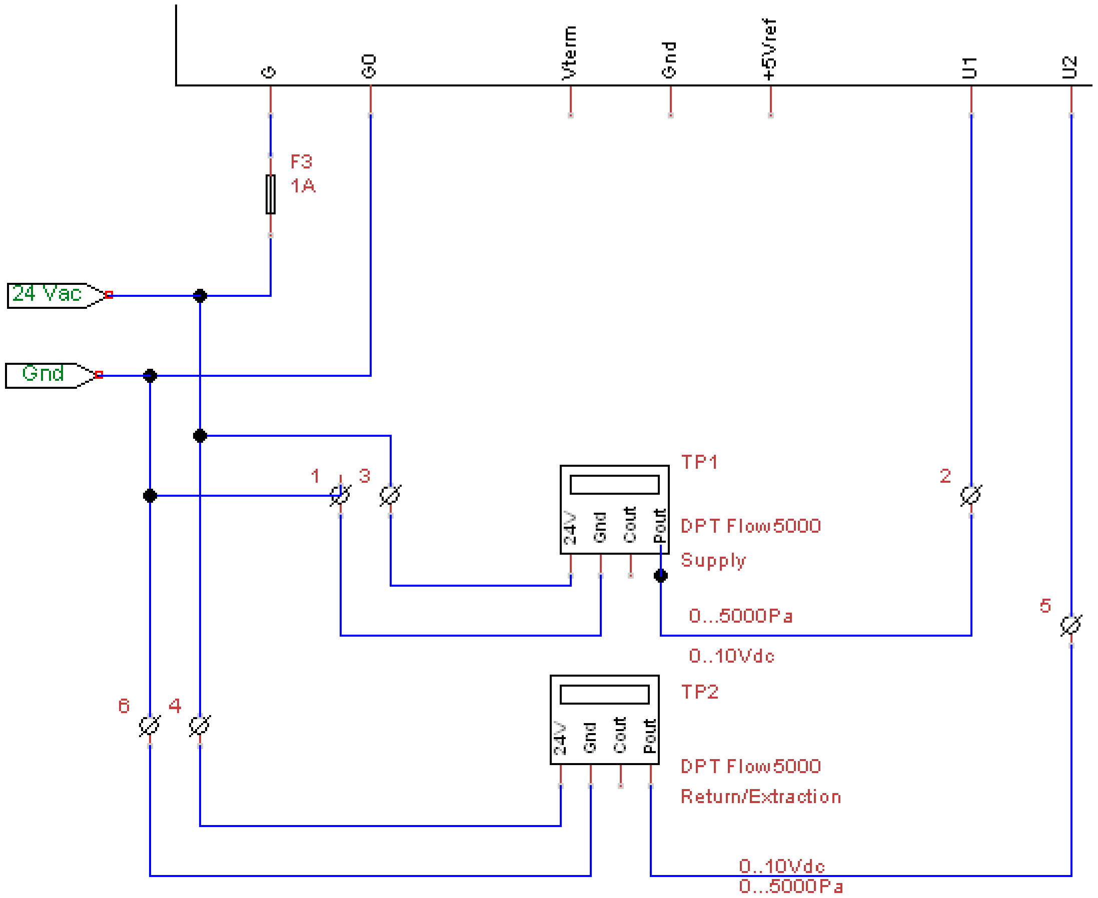


Figure 54 – Schematic of Analog inputs of DPT

Temperature probes are connected to terminals U3, U4 and U5. The temperature sensors determine the supply temperature, return air and the outside fresh air. The schematic of the temperature is shown in the Figure 55.

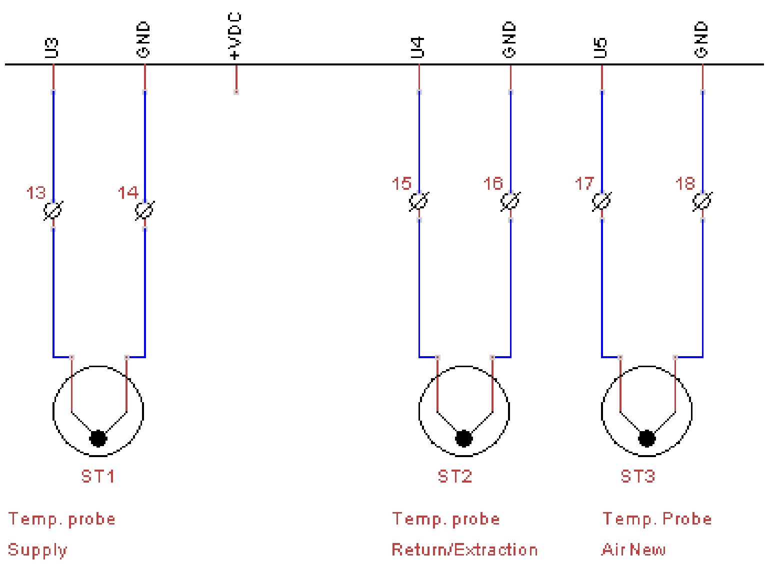


Figure 55 – Schematic of Analog inputs of temperature probes

3.2.7 *Analog Outputs*

The next sheet is named "Output Analog" which describes the Analog outputs from the pCO5+. This describes the outputs for dampers (terminals Y3 and Y4). The dampers 1 and 2 for air new are connected to Y3 and damper 3 for Air mixture damper is connected to Y4. The schematic for the dampers is shown in the Figure 56.

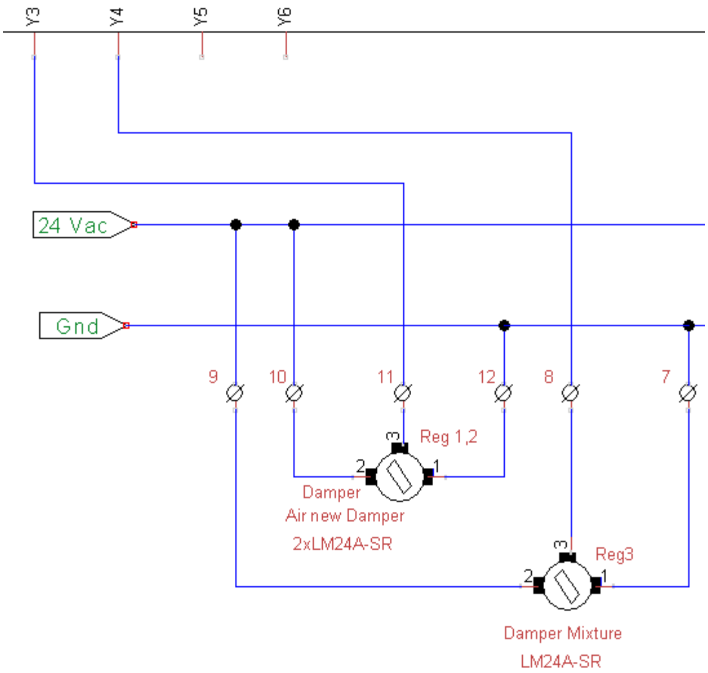


Figure 56 – Schematic of Analog outputs of dampers

The signal for supply inverter (terminal Y1) and signal for return inverter (terminal Y2). The signal for the supply inverter is given to the inverter pin A11 from Y1 and the signal for the return inverter is given to the inverter pin A11 from Y2. The schematic is shown in the Figure 57.

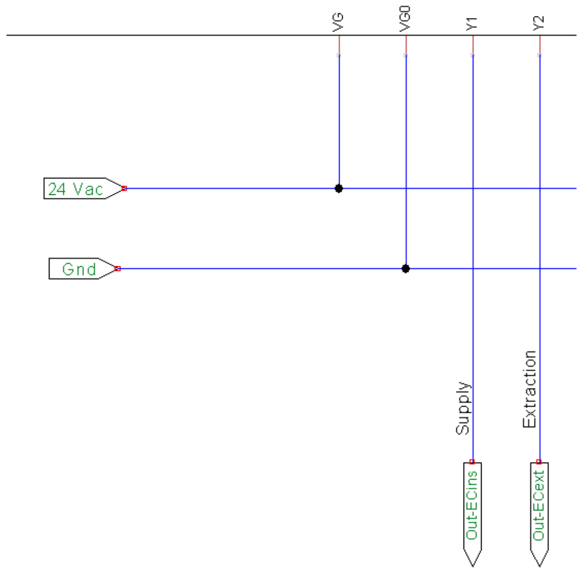


Figure 57 – Schematic of Analog outputs of supply and extraction signal

3.2.8 *Digital Inputs*

The next sheet is named “Digital Inputs” which describes the Digital Inputs from the pCO5+. The input for plain filter alarm air new, filter bag alarm supply, plain filter alarm return, supply inverter alarm, return inverter alarm, fire alarm and remote On-Off to ID1, ID2, ID3, ID5, ID6, ID7 and ID8 respectively. The filters alarm are pressure switches fixed near the filters. The schematic for the digital inputs is shown in the Figure 58.

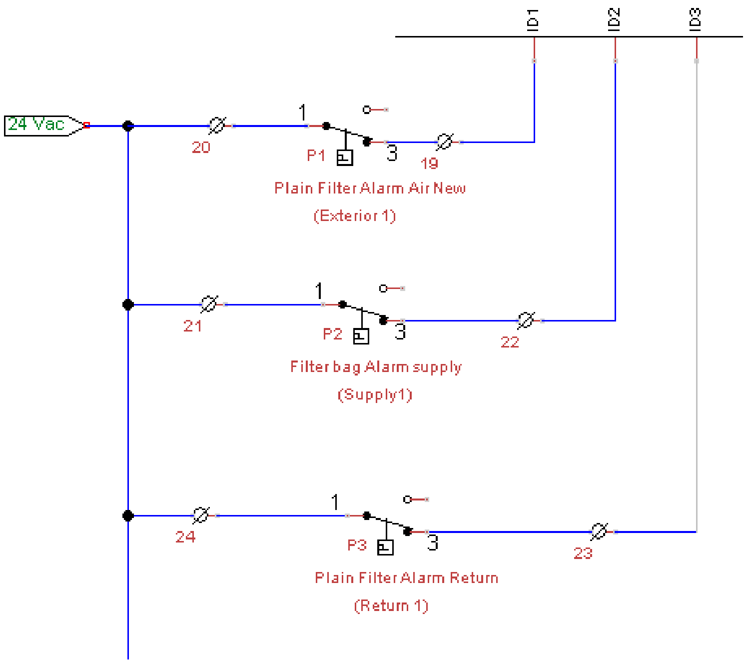


Figure 58 – Schematic of Digital inputs

3.2.9 *Digital Outputs*

The next sheet is named “Digital Output”. This describes the signal alarm running and general connected to terminals NO1 and NO2. The schematic of the digital outputs alarms is represented in Figure 59.

Figure 59 – Schematic of Digital outputs of signals

The damper bypass is connected to NO6. The damper bypass is a digital signal which either opens or closes. The On/Off to the supply motor to the terminal NO7 and On-Off to the extraction motor to the terminal NO8. The schematic of the digital outputs for the bypass damper and On-Off for supply and extraction motor is represented in Figure 60.

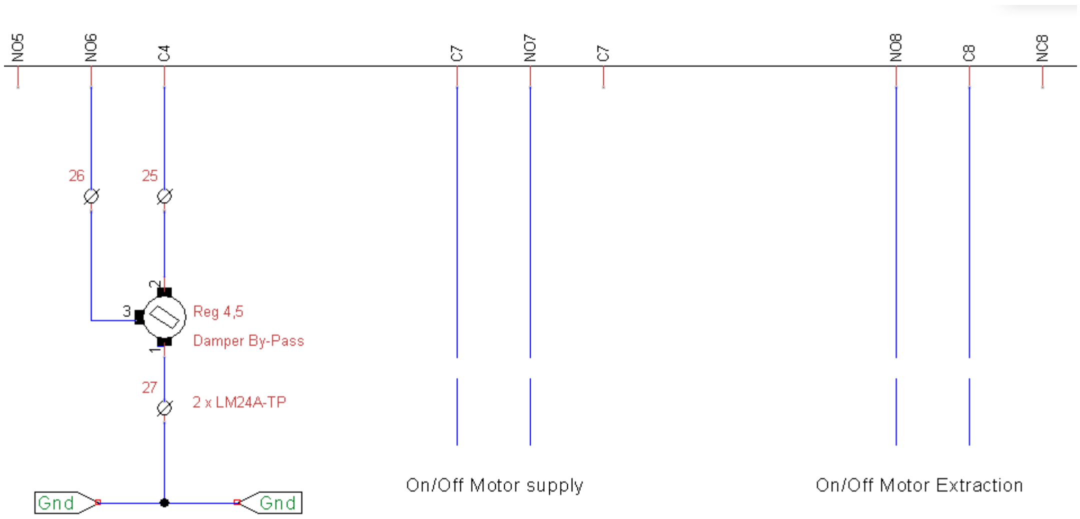


Figure 60 – Schematic of Digital outputs of by-pass dampers and on-off for supply and extraction motor.

3.2.10 Communication Bus

The next sheet is named "Communication Bus" which describes to the communication protocol used in the pCO5+. Communication ModBus/Carel is connected to J25 BMS2. The schematic of the Modbus connection is represented in Figure 61.

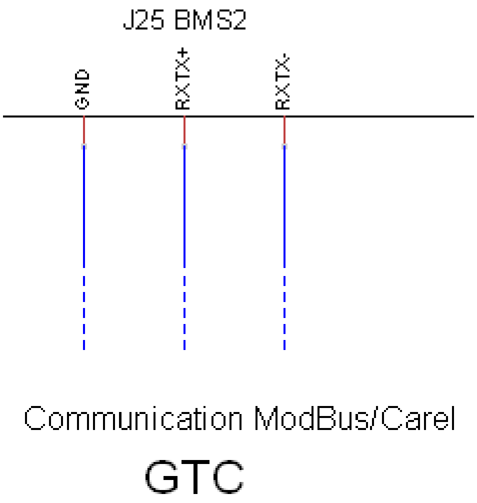


Figure 61 – Schematic of Communication

The PDG1 is connected to the visor through an RJ12 cable. The PGD1 is connected to the door of the Electric Board. The schematic of the pGD connection is represented in Figure 62.

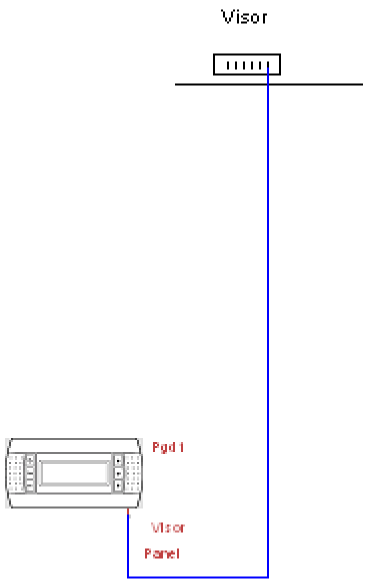


Figure 62 – Schematic of pGD connection

3.3 Implementation

3.3.1 Programming the application

The application that is uploaded to the pCO5+ is a pre-programmed application from the vendor, CAREL. Once the application is uploaded the program is altered according to the requirements of the unit. The program is altered in the pCO5+ through a pGD.

3.3.1.1 Program for Hardware – Software Interface

The HW_SW_CHECK block represents the interface between the software and the hardware. For example, when En is enabled as 1, and when the input is given as 200, it enters the manufacturing section where the inputs/outputs and other parameters are configured in this section. The macroblock writes 10 integer values to the same number of integer variables in permanent memory. If En=1, then outN=InN. The software block of HW_SW_CHECK is represented in Figure 63.

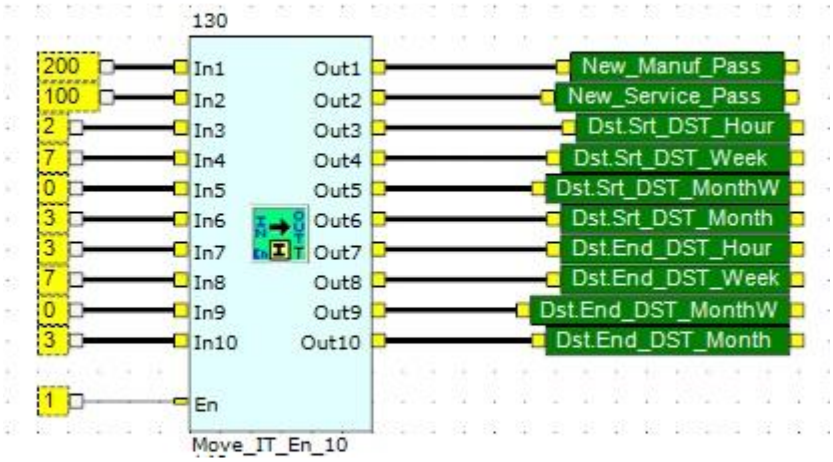


Figure 63 – HW_SW_CHECK

3.3.1.2 Program for Analog Inputs and Outputs

Analog Inputs block (ANALOG_INPUT_MNG) programs the Analog inputs. The Array allocation (Array_Alloc) block creates a list made up of WORD elements. No block is available that creates lists made up of BYTE elements. Macroblocks Array_Read2B and Array_Write2B can be used to save digital values to be converted to integers. The first element is 0 while the last element is Len-1. The list is created in the memory defined by the Mem input. The software block of ARRAY_WRITE is represented in Figure 64.

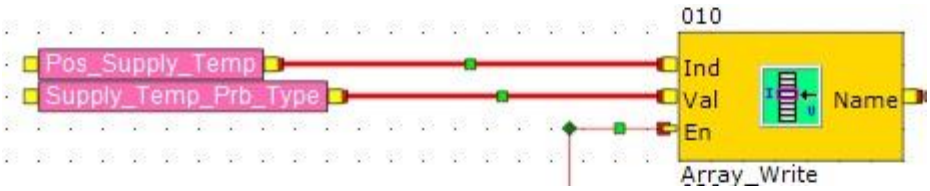


Figure 64 – ARRAY_WRITE

The Analog input configuration (Ain_Conf) block reads the analog input specified by the Ch input and assigns the Val output a value corresponding to the signal provided by the sensor. The Ain_conf atom is used in the software for controllers that require software configuration of the analog inputs. The Ch input specifies the analog input to read. The value of the channel is the number that appears in the description of the terminal. The Type input specifies the type of sensor connected to analog input. Each type of sensor is identified by a number. The software block of Ain_Conf is represented in Figure 65.

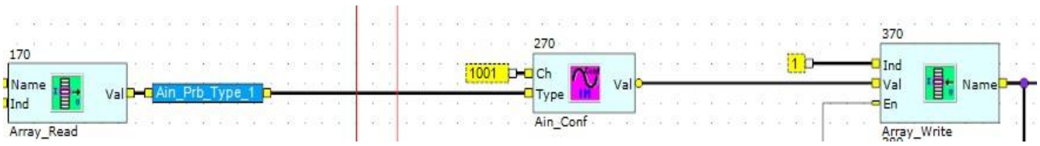


Figure 65 – Ain_Conf

For example, the Supply temperature position (Pos_Supply_Temp) block is compared with a value 10, when it is less than or equal to 10, it is then passed through a AND block with a Supply Temperature Probe Enable (En_Prb_Supply_Temp) and when the value is 1, the supply temperature is displayed in the pCO5+. The software block of Pos_Supply_Temp is represented in Figure 66.

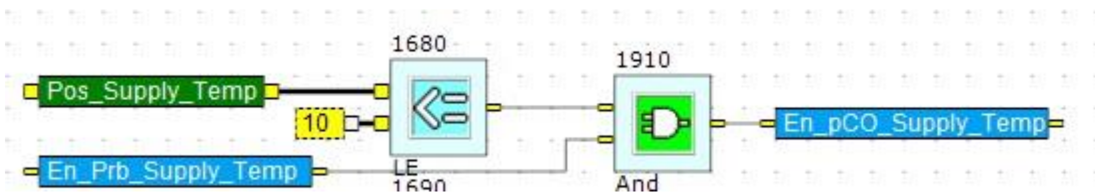


Figure 66 – Pos_Supply_Temp

The Analog Output (Aout_conv) block defines the status of the analog output specified by the Ch input according to the value specified by the Val input. It manages both the common 0/10V outputs and all the variants of the analog outputs in PWM and phase cutting operation. The software block of Aout_conv is represented in Figure 67. For this reason, the Analog Output Configuration (Aout_conf) block can be considered, for the pCOx family of controllers, the evolution and replacement of the Aout atom. The Ch input specifies the number of the analog output to be written. The value is the number that appears in the description of the terminal, for example 3 for terminal Y3, 4 for terminal Y4. The software block of Aout is represented in Figure 68.

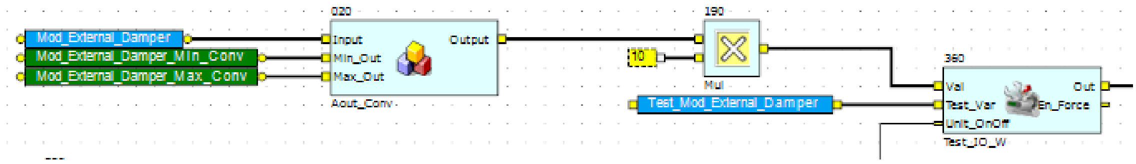


Figure 67 – Aout_conv

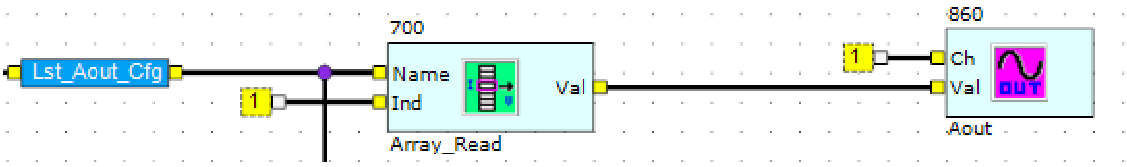


Figure 68 – Aout

3.3.1.3 Program for Fans and Dampers

The signals for the dampers are programmed in this section, the dampers are programmed in the strategy editor environment where the software is programmed for the opening and closing of the dampers. The software block of Damper (Mod_Damper) is represented in Figure 69.

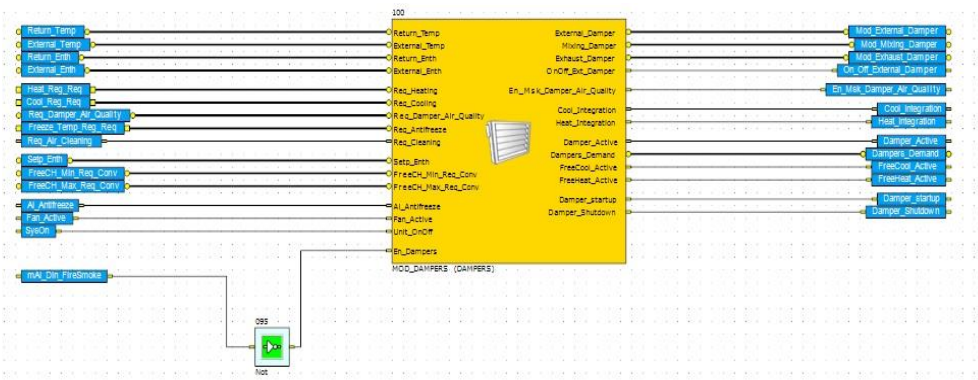


Figure 69 – Mod_damper

3.3.1.4 Program for Digital Inputs and Outputs

Digital inputs programmed in this section. For example, the alarms for filters, smoke and fire, etc., are programmed in this section. The Din atom reads the digital input specified by Ch input and assigns the Val output a value corresponding to its status. In certain conditions and for some digital inputs signals can be managed in frequency, for example, calculating the frequency from the voltage applied to the digital input ID1. The Din atom reads both the digital inputs connected to the controller that those connected to the I/O expansion boards. The software block of Din is represented in Figure 70. The Ch input specifies the number of the digital input to be read. The value is the number that appears in the description of the terminal. The values are stored in Digital Input Array (Din_Array_Write) block. The software block of Din_Array_Write is represented in Figure 71.

Status (**)	**Value returned (*Val*)**
Contact closed	0
Contact open	1

Table 5 – Digital Input logic

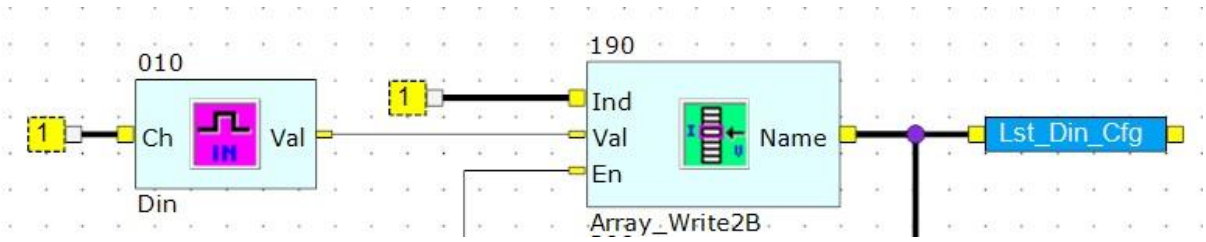


Figure 70 – Din

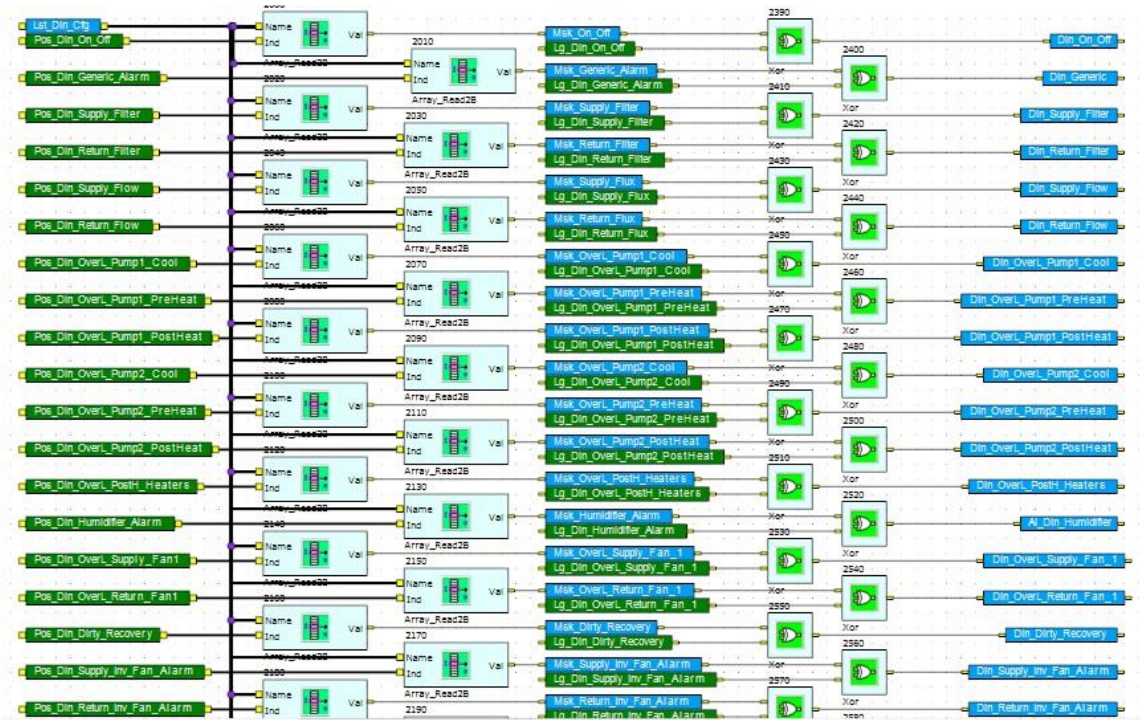


Figure 71 – Din Array_Read

The digital output (Dout) atom defines the status of the digital output specified by the Ch input according to the value specified by the Val input. The Dout atom writes both the digital outputs connected to the controller and those connected to the I/O expansion board. The software block of Dout is represented in Figure 72. The Ch input specifies the number of the digital output to be written. The value is the number that appears in the description of the terminal.

Val	Digital output status (*)
0	deactivated (relay de-energized)
1	activated (relay energized)

Table 6 – Digital Output Logic

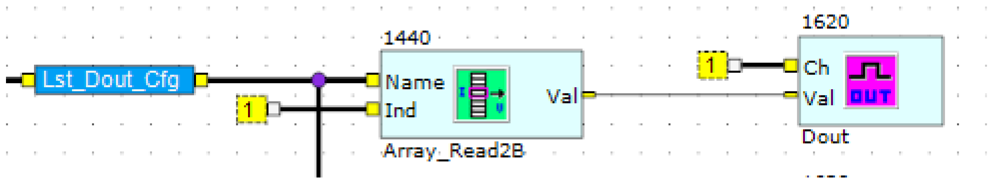


Figure 72 – Dout

3.3.1.5 Program for Thermoregulation

Thermoregulation is the area of the software where the control strategy is programmed. In thermoregulation, the strategy editor environment lets the designer to design the entire control regulation strategy. The regulation strategy can be organized in pages to group specific functions. The regulation strategy can be completed with other strategies called event task. Event tasks are directly activated by pressing a key or indirectly by the main strategy. For example, in cascade, the free cooling/free heating, recovery, cooling, Pre-Heating, Post-Heating, is programmed in this section with the strategy editor environment. In a temperature macroblock, when the block is enabled, the block controls the temperature of the room through the pCO5+. The software block of Temperature Regulation (Mod_Temp_Reg_Air) and humidity regulation (Mod_Humid_Reg_Air) is represented in Figure 73. This block adjusts the temperature of the supply air by measuring the temperature of the outside air and the return air to maintain the set temperature. The temperature is maintained in summer and winter. The humidity of the room is also controlled by the same procedure. When the humidifier is enabled, the supply humidity is adjusted by comparing the humidity outside and the return humidity from the room. However, the humidity function can be disable or enabled as per the requirements of the client. The damper programming block is represented in Figure 74.

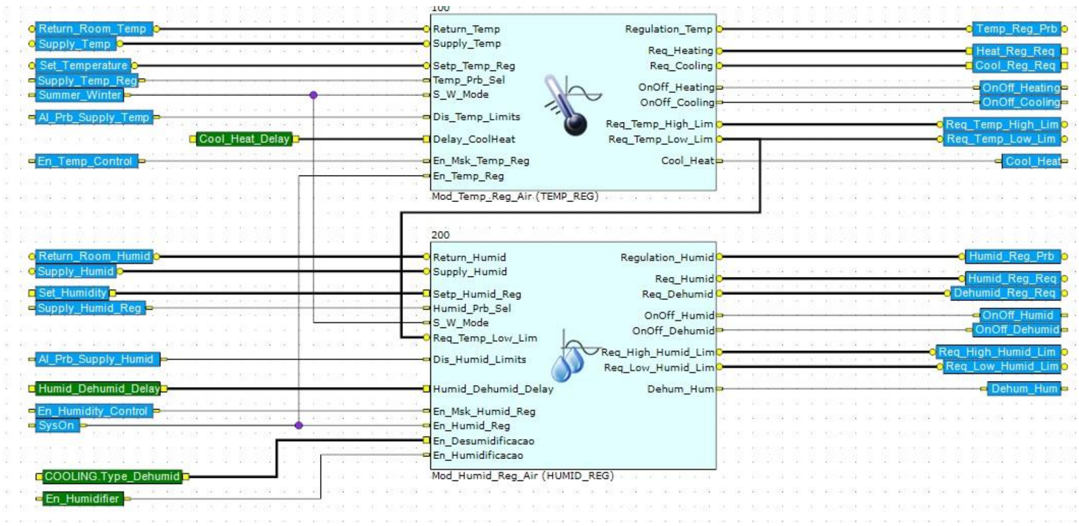


Figure 73 – Mod_Temp_Reg_Air and Mod_Humid_Reg_Air

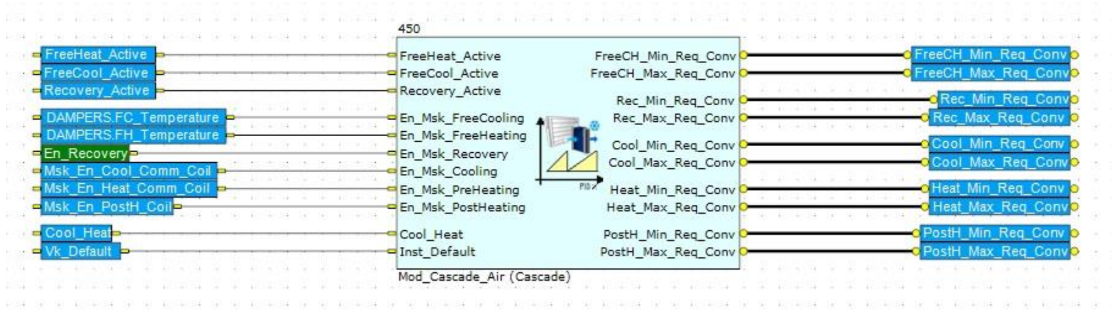


Figure 74 – Mod_Cascade_Air

3.3.2 Uploading the program to the controller

The following steps are used to upload the program of the controller.

3.3.2.1 Determining the COM port

Connect the pCO5+ to the computer and select the COM port once the pCO5+ goes online. The COM port for this unit is COM9. When the system is connected, an old BIOS version exists, so it is essential to change to a newer BIOS version. The COM port and BIOS version is represented in Figure 75.

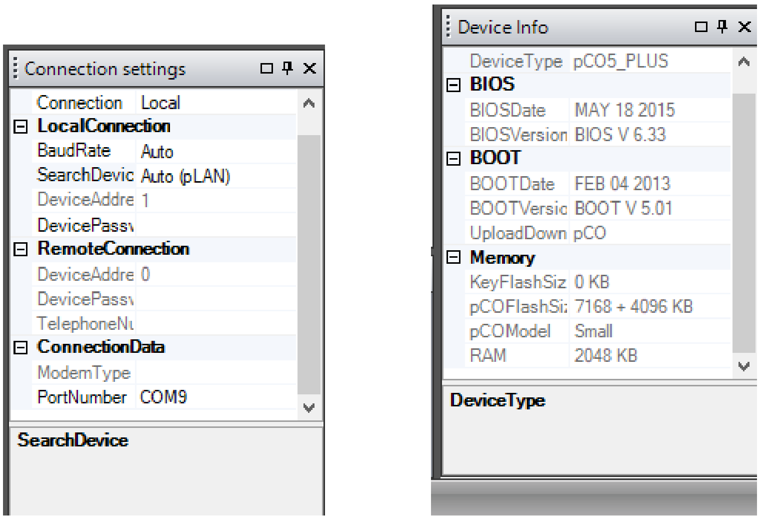


Figure 75 – COM port and BIOS version

3.3.2.2 Uploading the required files to the interface

Add the required newer version of BIOS, the control program, strategy files (.bin) and default settings file (.dev). Once the required files are uploaded, select the required languages from the list of languages available (PT, EN, FR). Select CLIMATIZADOR.bin as the required strategy file and unselect the CLIMATIZADOR.dev and select the uploaded default settings file. The selection of files to be uploaded is represented in Figure 76.

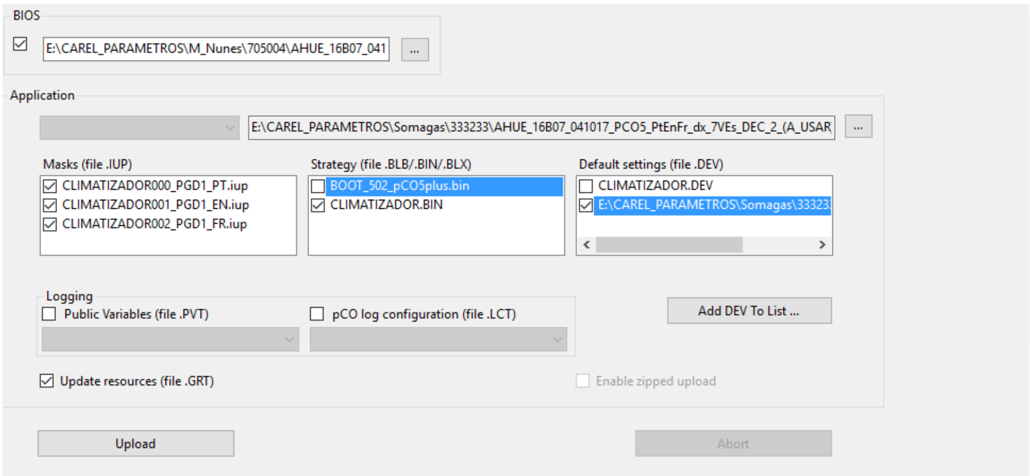


Figure 76 – Uploading of the files

3.3.2.3 Uploading the files to the controller

Click on the upload button and wait till the files are getting uploaded to the controller. Once the upload is completed, a message appears displaying that the upload was successful. Once the upload is successful, close the window and disconnect the controller from the computer. Reconnect the power supply and connect the pGD to the pCO5+ to assign the inputs, outputs and other parameters to the controller pCO5+. The files uploaded to the controller is represented in Figure 77.

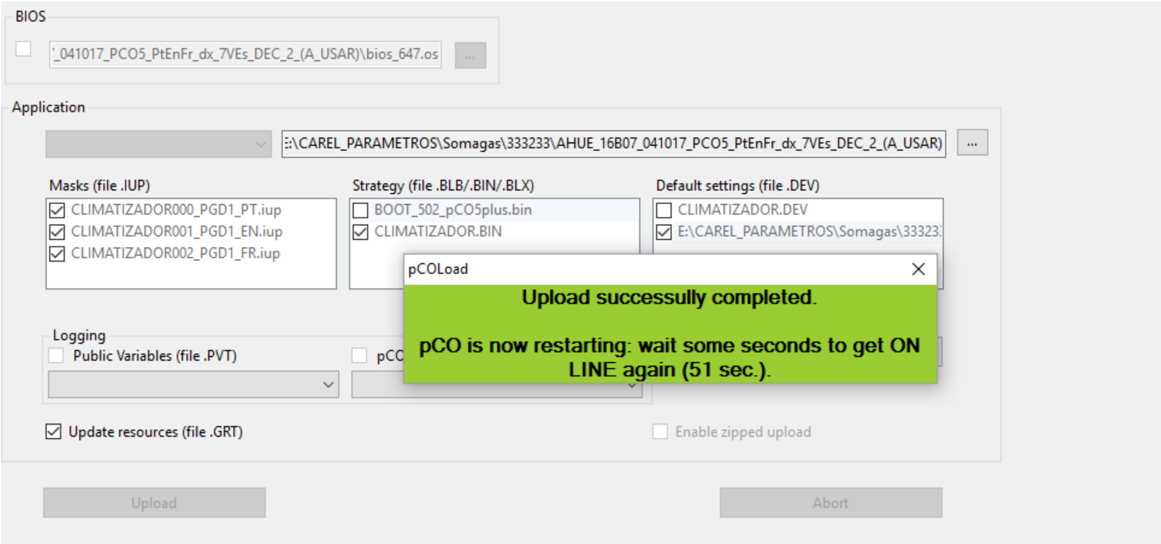


Figure 77 – Uploading of files to the controller

3.3.3 Mapping the Controller

The pCO5+ is configured by connecting the pCO5+ with a handheld or a wall mounted device called pGD. In the configuration part, the Analog inputs/outputs, digital inputs/outputs, mapping the supply and return fans.

3.3.3.1 Mapping of Analog Inputs

The Analog inputs such as temperature probe and pressure transmitter are mapped in this part. The supply temperature probe, extraction temperature probe and air new temperature probe is connected to the universal ports 3, 4 and 5 respectively. The pressure transmitter for supply and return is connected to universal port 1 and 2. It represents position and type of the probe. In case of a probe that uses type 0-10V or 4-20mA type, there is an option to change the minimum and maximum limit. The pGD mapping of Analog inputs is represented in Figure 78.

Figure 78 – Analog Input (Temperature)

3.3.3.2 Mapping of Analog Outputs

The Analog outputs such as signal for the supply and extraction motor. The output voltage is 0-10V. The supply and extraction signals are obtained from the port 1 and 2 respectively. The signals for dampers for air new and air mixture is connected to ports 3 and 4 of the Analog outputs. The minimum and maximum voltage is 0-10V. The pGD mapping of Analog outputs is represented in Figure 79.

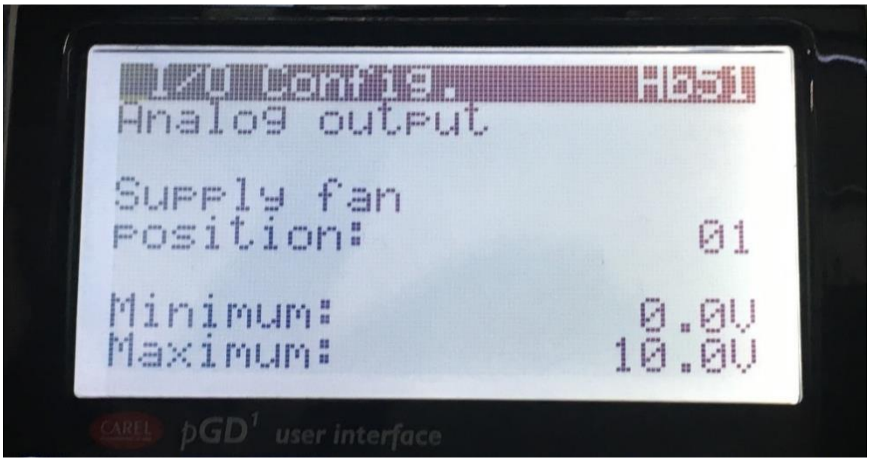


Figure 79 – Analog Output (Supply fan)

3.3.3.3 Mapping of Digital Inputs

The digital inputs such as remote On-Off, filters, inverter alarms and fire alarm are connected to the Digital inputs. The logic of digital inputs is usually Normally Open (NO) or Normally Closed (NC). When a signal is interrupted to a NO contact, it is closes the contact. Similarly, in case of NC contact it is usually closed, and when a signal is interrupted, it opens the contact. The pGD mapping of digital inputs is represented in Figure 80.

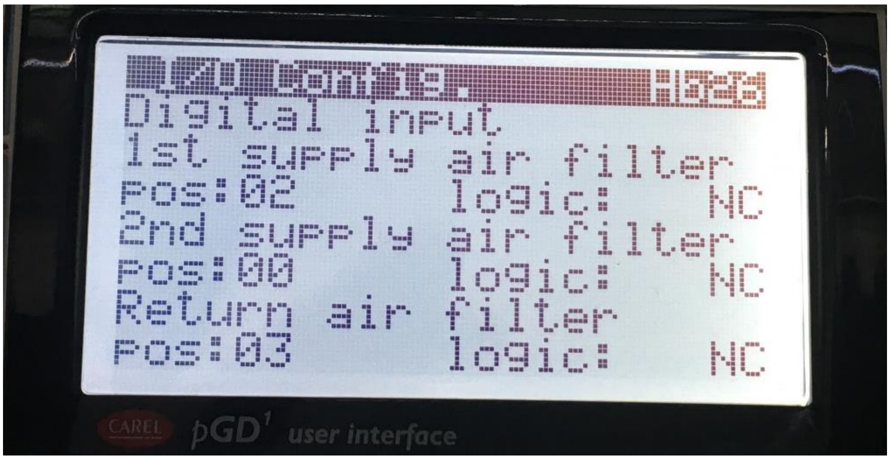


Figure 80 – Mapping of Digital Inputs (Filters)

3.3.3.4 Mapping of Digital Outputs

The digital outputs such as Running Alarm, for a bypass damper and power supply for Motor supply and extraction. The logic of digital outputs is usually Normally Open (NO) or Normally Closed (NC). When a signal is interrupted to a NO contact, it is closes the contact. Similarly, in case of NC contact it is usually closed, and when a signal is interrupted, it opens the contact. The output of this digital output is either 0 or 1. The pGD mapping of digital outputs is represented in Figure 81.

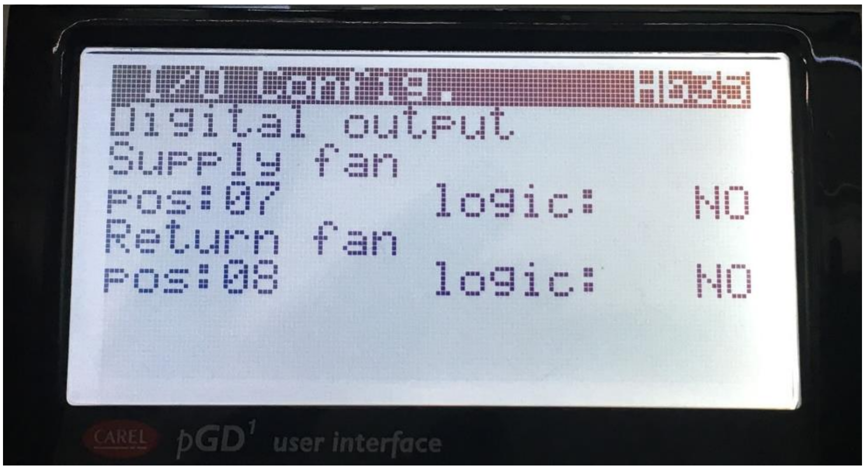


Figure 81 – Mapping of Digital Outputs (Fans)

3.3.3.5 Mapping of Damper Settings

The maximum percentage of opening of the dampers are fixed for fresh air damper at 100%. The maximum percentage of opening for the mixing damper is fixed at 70%. The pGD mapping of damper settings is represented in Figure 82.

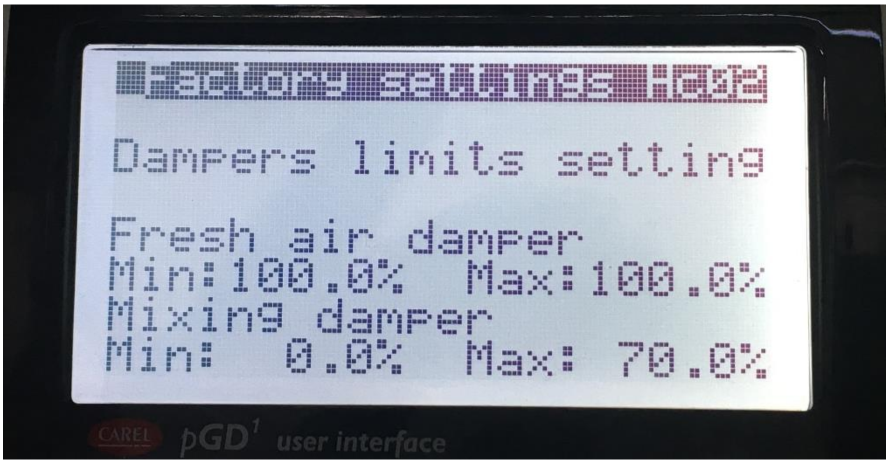


Figure 82 – Mapping of damper settings

3.3.3.6 Mapping of Thermoregulation Settings

The control used in the control is a Proportional + Integral (P+I) controller. The automatic switching of cooling/heating is turned to YES. This switching will switch the heating or cooling function of the unit. The pGD mapping of selection of controller type is represented in Figure 83.

Figure 83 – Mapping of temperature regulation

3.3.3.7 Mapping of Set Points

The setpoints are 15°C and 35°C for summer and 15°C and 35°C for winter. The controller is selected as Proportional + Integral controller. The differential temperature 3°C and the neutral zone is 1°C. The pGD mapping of temperature set limits is represented in Figure 84.

Figure 84 – Mapping of Temperature set limits

3.3.3.8 Mapping of Inverter Motors

The minimum and maximum power for supply inverter and return inverter is at 40% and 100% respectively. The set point for supply air flow is calculated with respect to the flow rate and air flow. The same is done for set point of return air flow. The pGD mapping of supply and return inverter is represented in Figure 85.

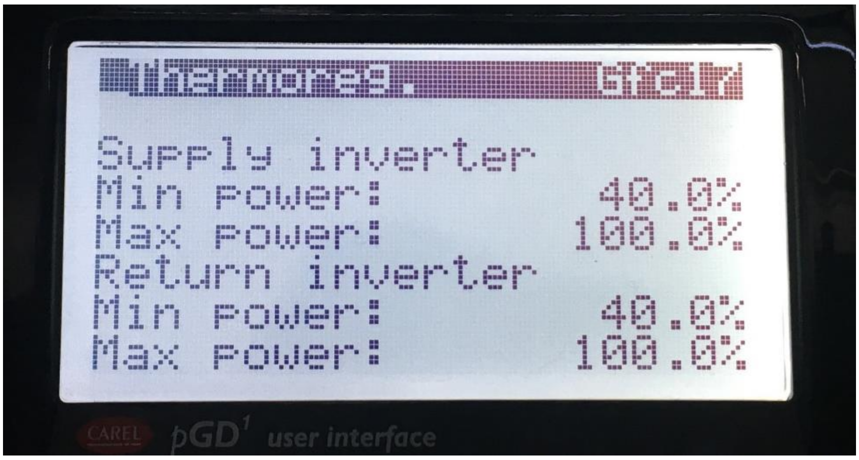


Figure 85 – Mapping of inverter power

3.3.3.9 Mapping of Air Flow

The setpoint of supply pressure control is automatically calculated by the controller with the setpoint of airflow and motor constant. The supply pressure control set point is calculated by ratio of setpoint of airflow and motor constant and squaring it. The setpoint of return pressure control is also calculated by the same method. The pGD mapping of Air Flow settings is represented in Figure 86.

Figure 86 – Mapping of supply air flow

The pGD mapping of supply press control is represented in Figure 87.

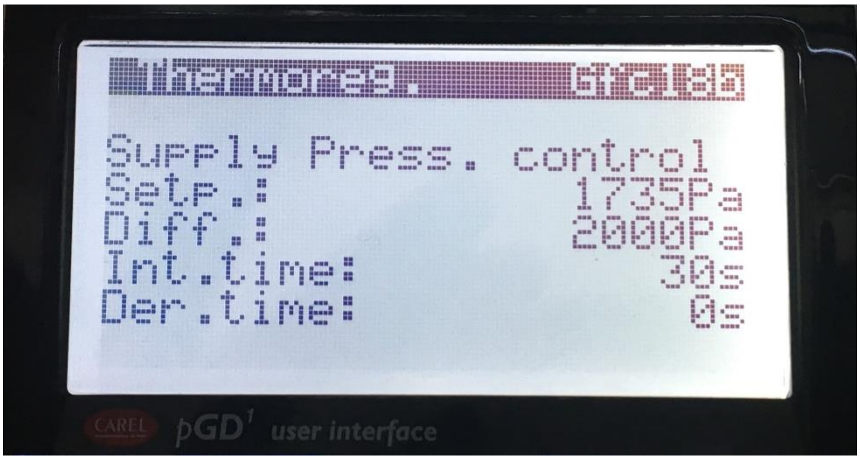


Figure 87 – Mapping of supply press control

3.4 Working

The temperature of the area under consideration is maintained in three different methods using the UTA RP 50.

1. Free heating/Free cooling.
2. Mixing and recovery.

3. Mixing and bypass recovery.

Free heating/Free cooling:
In air-conditioning systems, the free heating/free cooling functions are used to heat or cool the room by using either a part or all the fresh air intake when the temperature and relative humidity conditions allow. Free cooling and free heating [1] are thus considered as a free source of energy, activated with priority over cascade control in cooling and heating. Request is shared between the various cascade control devices. The function has two stages

1. Check whether the outside temperature or enthalpy conditions are favourable compared to the return air conditions.
2. Control the opening of the fresh air damper based on the cooling/heating request.

Free cooling and Free heating by temperature are activated when:

1. The outside temperature is closer to the temperature set point than the return temperature, or
2. The outside and return temperature straddle the set point.

Free cooling (cooling request active):

When the difference between the return temperature and external temperature is greater than the differential temperature (diff_temp), then the free cooling request is activated. The free cooling request stops when the difference between the return temperature and external temperature reduces below 0. The free cooling process is represented in Figure 88.

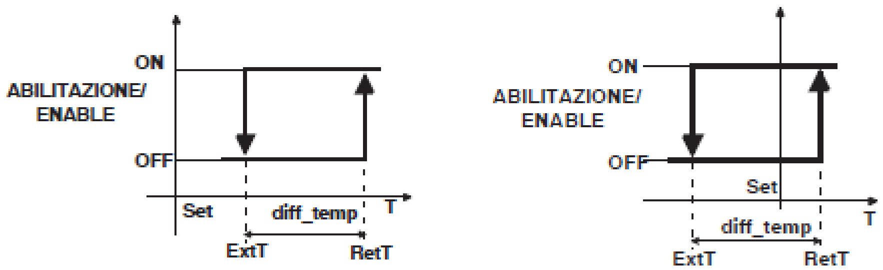


Figure 88 – Free Cooling [1]

Free heating (heating request active):

When the difference between the external temperature and return temperature is greater than the differential temperature (diff_temp), then the free heating request is activated. The free heating request stops when the difference between the external temperature and return temperature reduces below 0. The free heating is represented in Figure 89.

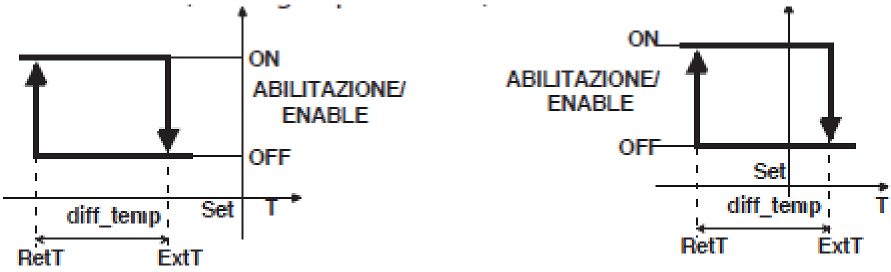


Figure 89 – Free Heating [1]

When the free cooling/free heating is activated, the by-pass dampers are opened at 100% while the mixing damper is at 0%. The supply air flow is maintained at ~12600 m^3/h and the return air flow are maintained at ~12600 m^3/h. The process of dampers is represented in Figure 90. When the function is activated, the external air damper and mixing damper are controlled proportionally to the free heating/free cooling request. When the two dampers are used, the two control signals are similar.

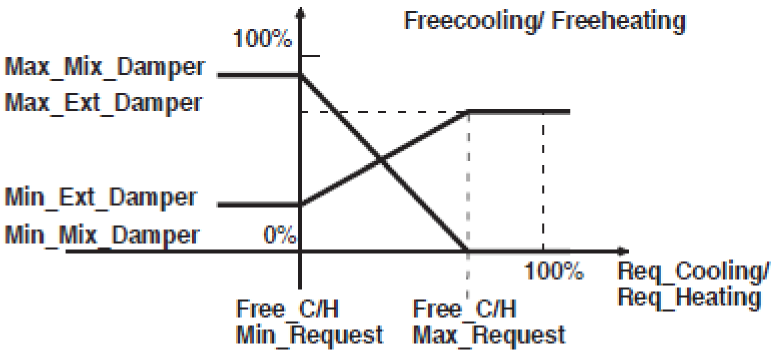


Figure 90 – Free Heating/Free Cooling Dampers [1]

The air flow during free heating/free cooling process is represented in Figure 91.

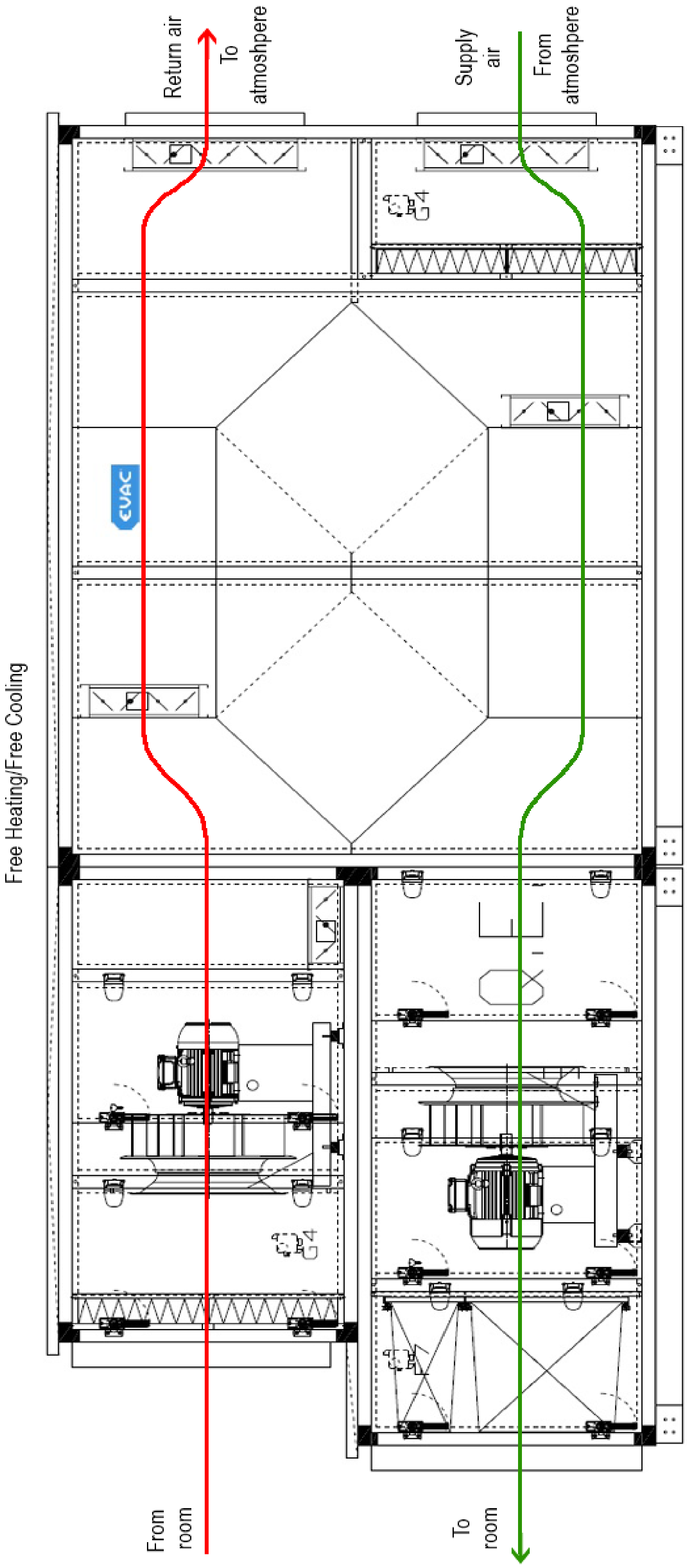


Figure 91 – Free cooling and Free heating

Mixing and recovery:

If the AHU is fitted with a heat recovery unit, the heat contained in the exhaust air is recovered and transferred to the primary air so as to preheat or precool it, if the conditions are favourable: consequently, free cooling/free heating and heat recovery are mutually exclusive. When the AHU is in heat recovery mode, the bypass damper on the heat recovery unit is closed.

In cascade control the request is shared between the various devices available. Heat recovery is thus considered a free source of energy free, activated with priority in cascade control in cooling and heating modes.

Recovery in cooling:

When the difference between the external temperature and return temperature is greater delta recovery (delta_recov), then the cooling recovery request is activated. The recovery cooling stops when the difference of external temperature and return temperature is less than the difference between the delta_recov and recovery differential (diff_recov), the recovery cooling is switched off. The recovery process for cooling is represented in Figure 92.

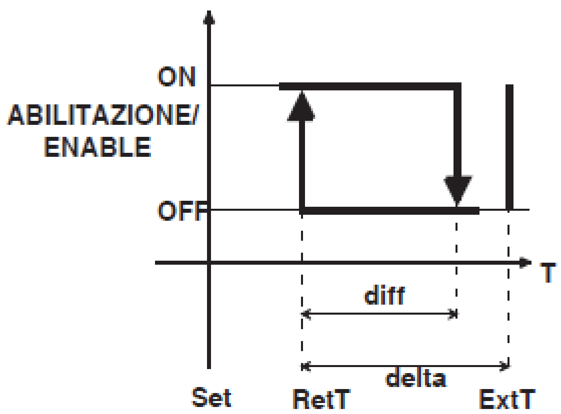


Figure 92 – Recovery in cooling [1]

Recovery in heating:

When the difference between the return temperature and external temperature is greater recovery delta (delta_recov), then the heating recovery request is activated. The recovery heating stops when the difference of return temperature and external temperature is less than the difference between the delta_recov and diff_recov, the recovery heating is switched off. The recovery process for heating is represented in Figure 93.

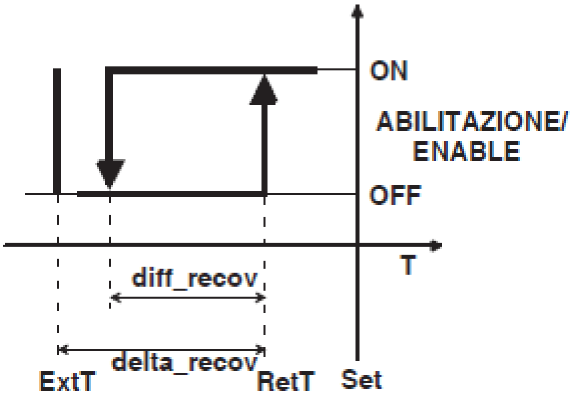


Figure 93 – Recovery in heating [1]

When the recovery is activated, the by-pass dampers are closed at 100% while the mixing damper is at 60%. The supply dampers are open at 50-100% and the air flow is maintained at less than ~6300 m^3/h and the mixture air flow is maintained at 6K. The return air flow of ~12600 m^3/h is divided into less than ~6300 m^3/h and the rest air is passed on to the atmosphere.

The air flow during mixing and recovery process is represented in Figure 94.

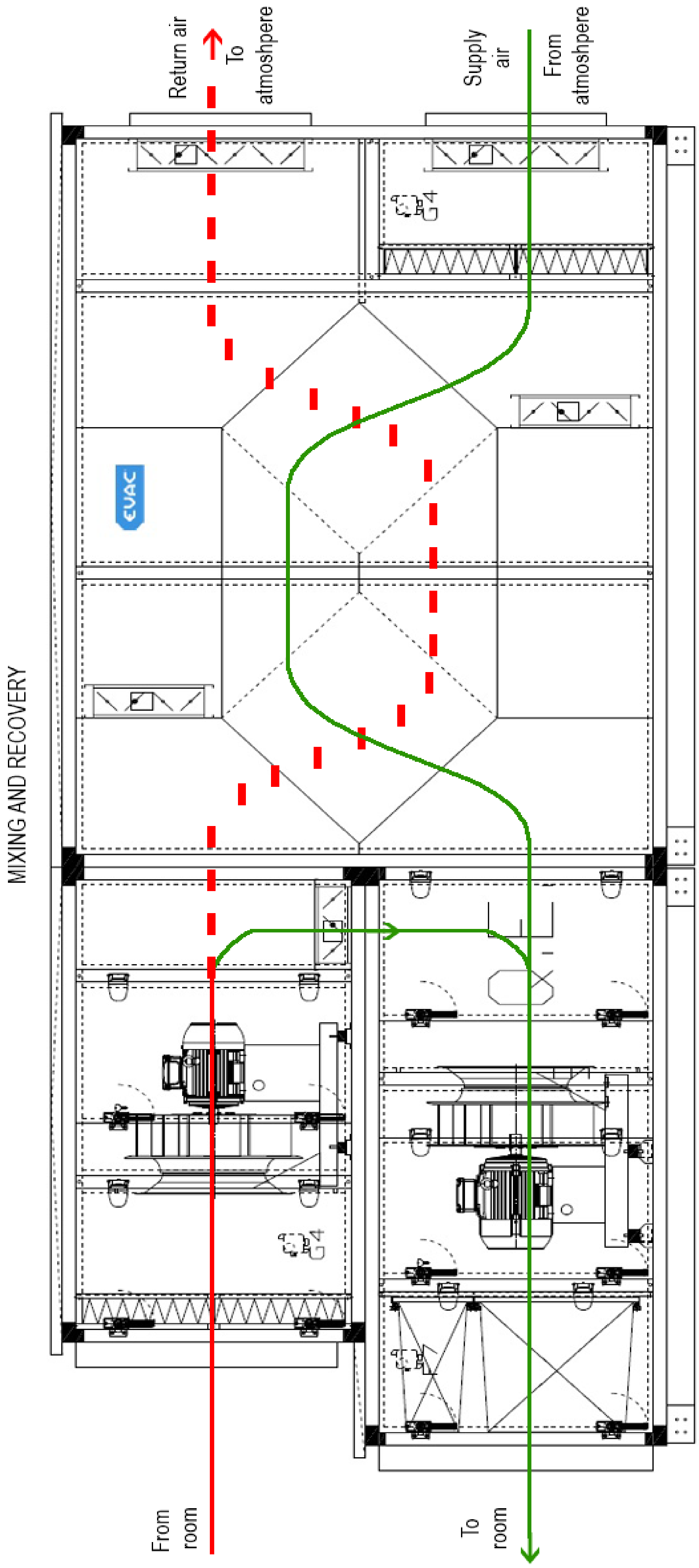


Figure 94 – Mixing and recovery

Mixing and By-pass:

When the recovery is activated, the by-pass dampers are open at 100% while the mixing damper is at 60% and the recovery is at 0%. The supply dampers are open at 50-100% and the air flow is maintained at less than ~6300 m^3/h and the mixture air flow is maintained at 6300 m^3/h. The return air flow of ~12600 m^3/h is divided into less than ~6300 m^3/h and the rest air is passed on to the atmosphere.

The air flow during mixing and bypass process is represented in Figure 95.

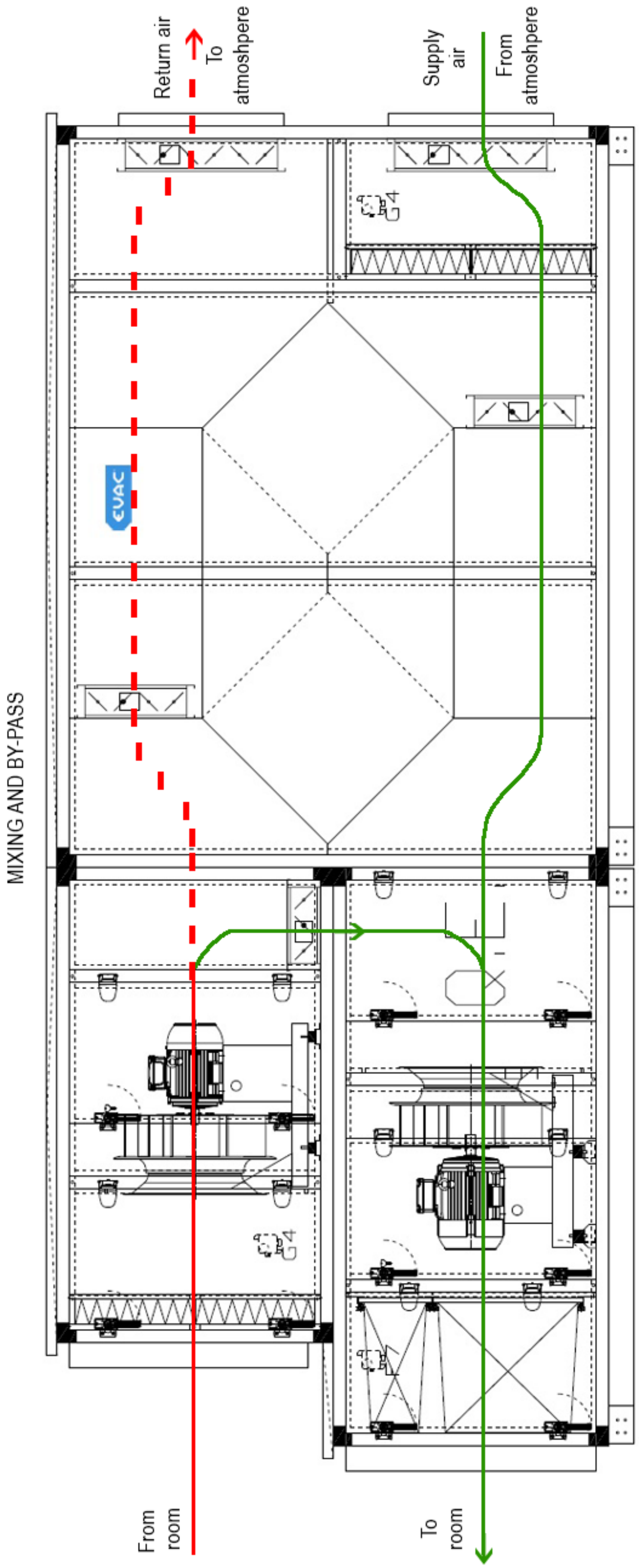


Figure 95 – Mixing and Bypass

3.5 Testing

The following testing of the unit was done at EVAC. The test report has been attached as an annexure.

1. Analog inputs such as the temperature probes, flow meters were tested.
2. Digital inputs like the remote on-off, filter alarms and fire alarm was tested.
3. The rotation of the fans was tested.
4. The Analog outputs such as dampers, signals to the inverter were tested.
5. Digital outputs such as on-off to the supply and return motor and bypass damper was tested.
6. The different modes of operation – Manual and Auto was tested.
7. The summer and winter set points were adjusted to test the temperature and flow.
8. The recovery unit was tested.
9. The different modes of working – Free heating/Free cooling, Mixing and Bypass, Bypass and recovery was tested.

The commissioning was performed at the site of Farfetch. The commissioning sheet has been attached as an annexure. The tests performed in EVAC were reperformed at the site at the along with a few modifications.

1. The connections were rechecked, since the unit consists of two parts, it was necessary to check the connections again.
2. The frequency of the inverter was modified to 50Hz to adjust the speed of the fan with the duct construction.
3. The three dampers were tested according to the design specification.
4. The flow was reduced by 30% as the air flow was proving to be noisy.
5. The working hours and sleep hours were set, such that the unit would start and stop automatically.
6. The three modes of working - Free heating/Free cooling, Mixing and Bypass, Bypass and recovery was tested.

3.6 Result

The following results were obtained from the test results of the unit at EVAC and from the commissioning at the site of Farfetch. The overall unit during testing at EVAC is as shown in the Figure 96 and the installation of the unit at site is represented Figure 97.

Figure 96 – EVAC RP 50 Plus 50 at EVAC

Figure 97 – EVAC RP 50 Plus 50 at Farfetch

1. The temperature was found to be controlled around the setpoint 23°C during the day and during the night, the unit was switched off as per the automatic on-off time programmed in the PLC. The temperature vs time graph result of the unit is represented in Figure 98.

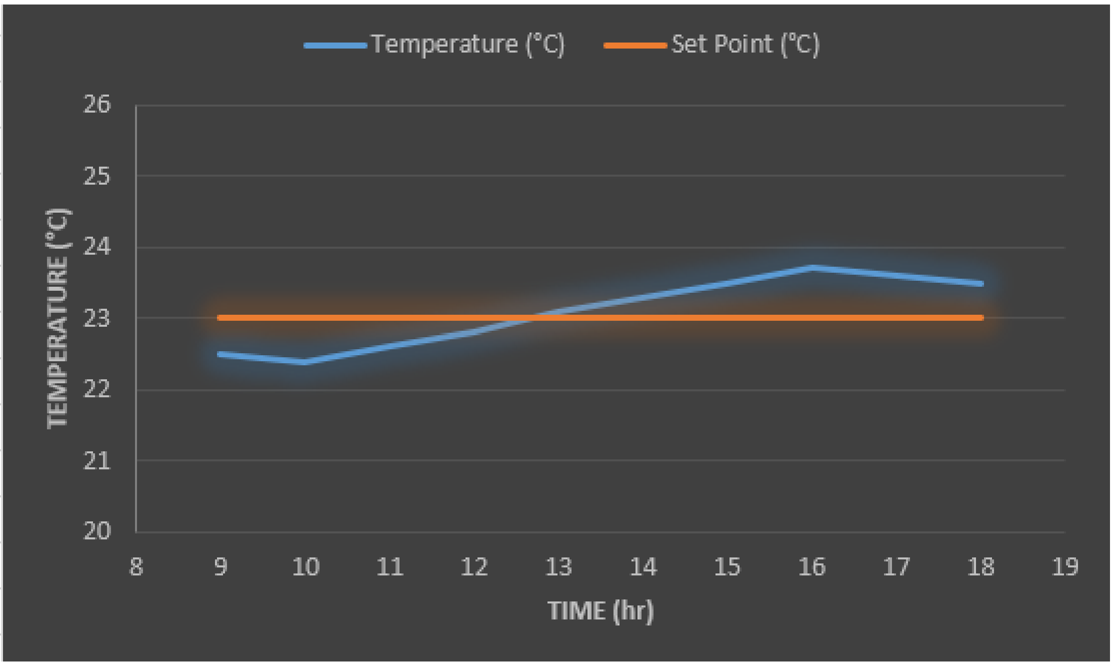


Figure 98 – Return Temperature vs Time

2. The unit UTA-4 had encountered a problem that once the automatic on-ff timings were set and the unit was restarted, the controller was also reset. Thus, arrangements were made to replace the controller.

3. The air flow was maintained at 12,618 m^3/h and the air flow for the for the recovery was maintained at 6,309 m^3/h. The air flow was later reduced by 30% since there was excess noise due to the air flow from the unit in the area under consideration.

CONCLUSIONS

4 CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

This chapter deals with the conclusions drawn from the studies carried out during this dissertation. This appears as complete, to the analysis made in each of the chapters presented.

Some key points were drawn from the development of the projects, adverse problems and the path covered for some of the choices throughout the development of this project.

4.1 General Conclusions

The present dissertation focuses on the study of the types of Air Handling Units in order to be able to design and configure the CAREL pCO5+ controller to meet the requirements of the client proposed by EVAC. The installation was done at the client's place of AvePark, Barco and commissioning were done at the client place. There were few problems that were encountered after the commissioning and it were cleared to give a comfortable working environment to the employees of the organization.

Developing this project on Air Handling Units an interesting work because of its enormous potential in the development of a clean and safe environment in places such as offices, schools, hospitals, etc. where the temperature and humidity has to be maintained to improve the quality. Knowledge about this area was increasing during the time in the curricular internship was carried out and the internship was rewarding to learn the different types of Air Handling Units and controlling methods.

It can be concluded that the Air Handling Units play a major role in controlling the temperature, providing clean air and ensuring safety to large spaces. The other benefits of using an Air Handling Unit include controlling the humidity, better energy efficiency and since the unit is controlled automatically, the working of the unit can also be adjusted according the time that is required.

4.2 Suggestions for future work

The work developed throughout this document allows the system to be even more enhanced. In this subchapter, the author has proposed a suggestion for the future work.

The unit can not be remotely monitored hence the implementation of tERA, a remote monitoring system can be added to monitor the unit from a remote location. tERA is a simple configurable CAREL platform for centralized and remote monitoring of Air Handling Units in industrial and commercial applications that aquires data and sends using the internet. It has been developed as a compete solution that aquires and displays the data needed to analyse the system operation in real time. The benefits apart from remote monitoring is the lower maintanance cost. The data can be accessed through a remote connection using a PC, smartphone or tablet.

REFERENCES AND OTHER SOURCES OF INFORMATION

5 REFERENCES AND OTHER SOURCES OF INFORMATION

1. Carel, *FLSTDMAHUE - Application for managing air handling units with integrated DEC - IEC User Manual.*

2. evac, *www.evac.pt*.

3. Reddy, B.V., *Pharmaceutical Air Handling system-A Review.* 2013.

4. Aziz, M., Z. Zain, and S. Baki. *Monitoring on performance of air handling unit system: Air conditioning system studies in Engineering Complex, UiTM Shah Alam*. in *Control and System Graduate Research Colloquium (ICSGRC), 2011 IEEE*. 2011. IEEE.

5. Zhang, Y., et al., *Analysis of thermal performance and energy savings of membrane based heat recovery ventilator.* Energy, 2000. **25**(6): p. 515-527.

6. Vedavarz, A., S. Kumar, and M.I. Hussain, *The handbook of heating, ventilation and air conditioning for design and implementation*. 2005: Industrial Press, Incorporated.

7. Mirinejad, H., et al., *Control Techniques in Heating, Ventilating and Air Conditioning (HVAC) Systems 1.* 2008.

8. Wang, S.K. and S.K. Wang, *Handbook of air conditioning and refrigeration*. Vol. 49. 2000: McGraw-Hill New York.

9. Erickson, K.T., *Programmable Logic Controllers: An emphasis on design and application*. 2005: Dogwood Valley Press.

10. Hudedmani, M.G., et al., *Programmable Logic Controller (PLC) in Automation.* Advanced Journal of Graduate Research, 2017. **2**(1): p. 37-45.

11. Pawar, R. and N. Bhasme, *Application of PLC's for Automation of Processes in Industries.* International Journal of Engineering Research and Applications, 2016. **6**(6): p. 53-59.

12. Friese, K.-H., G. Stecher, and H.-M. Wiedenmann, *Ntc temperature sensor and process for producing ntc temperature sensing elements*. 1992, Google Patents.

13. Friese, K.-H. and H.-M. Wiedenmann, *Ptc temperature sensor for use in an exhaust gas system*. 1993, Google Patents.

14. Baker, B., *Temperature sensing technologies.* AN679, Microchip Technology Inc, 1998.

15. Carel, *Passive Temperature Probes - User Manual.*

16. instruments, H., *Air Flow and Velocity Transmitters DPT-Flow Series Manual.*

17. Belimo, *Modulating Damper Actuator.*

18. Belimo, *On-Off damper actuator.*

19. U.S. Department of the Interior Bureau of Reclamation Denver, C., *Design Guide for Heating, Ventilating, and Air Conditioning Systems.* 2006.

20. Trott, A.R. and T. Welch, *Refrigeration and air conditioning*. 1999: Butterworth-Heinemann.

21. University, M., *Commissioning Methodologies*

22. Katipamula, S., M.R. Brambley, and L. Luskay, *Automated proactive techniques for commissioning air-handling units.* Journal of solar energy engineering, 2003. **125**(3): p. 282-291.

23. Le, T., G. Knabe, and G. Henze, *Fault Detection and Diagnosis for Control Strategies in Air Handling Units.* Montreal: In IBPSA, 2005.

24. Visier, J. *Commissioning of HVAC systems for improved energy performance: the annex 40 approach*. in *Proceedings of the International Short Symposium on HVAC Commissioning. Kyoto, Japan*. 2003.

25. Gillis, W.L. and E.A. Cudney, *A standard for the commissioning process.* Frontiers of Engineering Management, 2015. **2**(1): p. 39-51.

26. Guo, C., Q. Song, and W. Cai. *Supply air temperature control of AHU with a cascade control strategy and a SPSA based neural controller*. in *Neural*

Networks, 2005. IJCNN'05. Proceedings. 2005 IEEE International Joint Conference on. 2005. IEEE.

27. Sun, Y., et al. *AHU control strategies in the VAV system*. in *Innovative Computing, Information and Control (ICICIC), 2009 Fourth International Conference on*. 2009. IEEE.

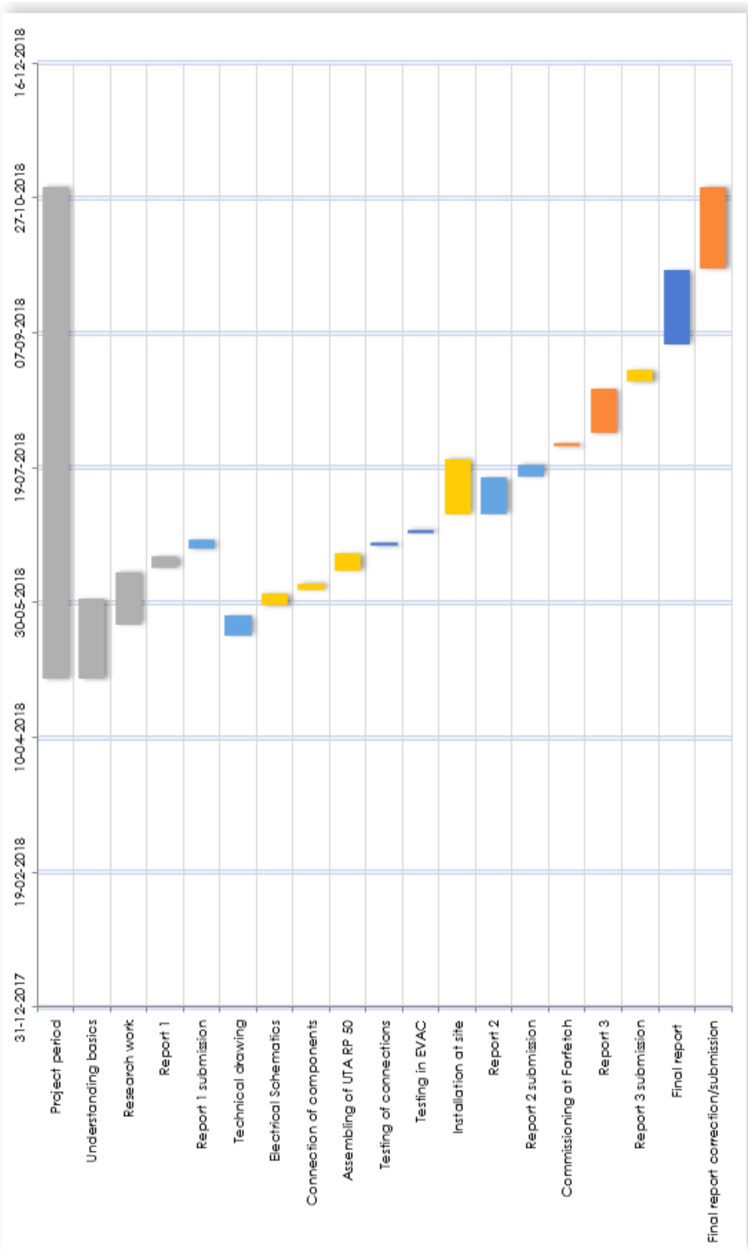
28. Qian, W. and M. Qinglin. *A new energy-saving air handling unit for clean operating room*. in *Digital Manufacturing and Automation (ICDMA), 2010 International Conference on*. 2010. IEEE.

29. Chen, Y., et al. *Control strategy research for the combined air handling unit*. in *Chinese Automation Congress (CAC), 2015*. 2015. IEEE.

ANNEXES

6 ANNEXES

6.1 ANNEX1 – PROJECT TIMELINE



Temperature Control of Air Handling Unit using Carel PCO5+ CONTROLLER			
TASK NAME	START	END	DURATION (days)
Project period	02-05-2018	31-10-2018	182
Understanding basics	02-05-2018	31-05-2018	29
Research work	22-05-2018	10-06-2018	19
Report 1	12-06-2018	16-06-2018	4
Report 1 submission	19-06-2018	22-06-2018	3
Technical drawing	18-05-2018	25-05-2018	7
Electrical Schematics	29-05-2018	02-06-2018	4
Connection of components	04-06-2018	06-06-2018	2
Assembling of UTA RP 50	11-06-2018	17-06-2018	6
Testing of connections	20-06-2018	21-06-2018	1
Testing in EVAC	25-06-2018	26-06-2018	1
Installation at site	02-07-2018	22-07-2018	20
Report 2	02-07-2018	15-07-2018	13
Report 2 submission	16-07-2018	20-07-2018	4
Commissioning at Farfetch	27-07-2018	28-07-2018	1
Report 3	01-08-2018	17-08-2018	16
Report 3 submission	20-08-2018	24-08-2018	4
Final report	03-09-2018	30-09-2018	27
Final report correction/submission	01-10-2018	31-10-2018	30

6.2 ANNEX3 – DATASHEETS

6.2.1 Datasheet of DPT flow 5000

HK INSTRUMENTS | AIR FLOW AND VELOCITY TRANSMITTERS
USER-FRIENDLY MEASURING DEVICES

DPT-FLOW SERIES

INSTALLATION INSTRUCTIONS

INTRODUCTION

Thank you for choosing an HK Instruments DPT-Flow series air flow transmitter. The DPT-Flow series is intended for use in commercial environments. The DPT-Flow measures air flow, velocity and differential pressure. It is designed to be used in combination with air flow measuring probes (i.e. FloXact), dampers or with centrifugal fans that provide differential pressure connections and K-values.

The DPT-Flow series of air flow transmitters is comprised of DPT-Flow-1000, DPT-Flow-2000, DPT-Flow-5000 and DPT-Flow-7000 with measurement ranges of 0–1000 Pa, 0–2000 Pa, 0–5000 Pa and 0–7000 Pa respectively. All models come with display and manual pushbutton zero point calibration. Optional autozero calibration is also available.

APPLICATIONS

DPT-Flow series devices are commonly used in HVAC/R systems for:

- air flow monitoring across centrifugal fans and blowers
- in-duct air flow monitoring
- VAV applications

⚠ WARNING

- READ THESE INSTRUCTIONS CAREFULLY BEFORE ATTEMPTING TO INSTALL, OPERATE OR SERVICE THIS DEVICE.
- Failure to observe safety information and comply with instructions can result in PERSONAL INJURY, DEATH AND/OR PROPERTY DAMAGE.
- To avoid electrical shock or damage to equipment, disconnect power before installing or servicing and use only wiring with insulation rated for full device operating voltage.
- To avoid potential fire and/or explosion do not use in potentially flammable or explosive atmospheres.
- Retain these instructions for future reference.
- This product, when installed, will be part of an engineered system whose specifications and performance characteristics are not designed or controlled by HK Instruments. Review applications and national and local codes to assure that the installation will be functional and safe. Use only experienced and knowledgeable technicians to install this device.

SPECIFICATIONS

Performance

Accuracy (from applied pressure):
Models 1000 and 2000:
Pressure < 125 Pa = 1 % + ±2 Pa
Pressure > 125 Pa = 1 % + ±1
Pa Models 5000 and 7000:
Pressure < 125 Pa = 1.5 % + ±2 Pa
Pressure > 125 Pa = 1.5 % + ±1 Pa
(Accuracy specifications include: general accuracy, temperature drift, linearity, hysteresis, long term stability, and repetition error)
Thermal effects:
Temperature compensated across the full spectrum of capability
Overpressure:
Proof pressure: 25 kPa
Burst pressure:30 kPa
Zero point calibration:
Automatic autozero or
manual pushbutton
Response time:
1.0−20 s, selectable via menu

Technical Specifications

Media compatibility:
Dry air or non-aggressive gases
Pressure units (select via menu):
Pa, kPa, mbar, inWC, mmWC, psi
Pressure output scale (select via menu):

	DPT-Flow-1000	DPT-Flow-2000	DPT-Flow-5000	DPT-Flow-7000
Pa	100-1,000	200-2,000	500-5,000	700-7,000
kPa	0.1-1.0	0.2-2.0	0.5-5.0	0.7-7.0
mbar	1-10	2.0-20	5.0-50	7.0-70
mmWC	10-100	20-200	50-500	70-700
inWC	0.4-4.0	0.8-8.0	2.0-20	2.5-30

Flow units (select via menu):
Volume: m3/s, m3/hr, cfm, l/s, none
Velocity: m/s, ft/min
Flow output scale (select via menu):

Units	Range
m3/s	0.025-50
m3/hr	100-200,000
cfm	50-100,000
l/s	25-50,000
m/s	1-100
f/min	200-20,000

Measuring element:
MEMS
Environment:
Operating temperature: -10...50 °C, with autozero (-AZ) calibration -5...50 °C
Storage temperature: -20...70 °C
Humidity: 0 to 95 % rH, non condensing

Physical

Dimensions:
Case: 90.0 x 95.0 x 36.0 mm
Weight:
150 g
Mounting:
2 each 4.3 mm screw holes, one slotted
Materials:
Case: ABS
Lid: PC
Duct connectors: ABS
Tubing: PVC
Protection standard:
IP54

Display
2-line display (12 characters/line)
Line 1: Volume or velocity measurement
Line 2: Pressure measurement
Size: 46.0 x 14.5 mm
Electrical connections:
4-screw terminal block
Wire: 0.2–1.5 mm^2 (12–24 AWG)
Cable entry:
Strain relief: M16
Knockout : 16 mm
Pressure fittings
Male ø 5.0 mm and 6.3 mm

Electrical

Voltage:
Circuit: 3-wire (V Out, 24 V, GND)
Input: 24 VAC or VDC, ±10 %
Output: 0–10 V, selectable via jumper
Power consumption: <1.0 W
Resistance minimum: 1 kΩ
Current:
Circuit: 3-wire (mA Out, 24 V, GND)

Input: 24 VAC or VDC, ±10 %
Output: 4–20 mA, selectable via jumper
Power consumption: <1.2 W
Maximum load: 500 Ω
Minimum load: 20 Ω

Conformance

Meets requirements for CE marking:
EMC Directive 2014/30/EU
RoHS Directive 2011/65/EU
WEEE Directive 2012/19/EU

COMPANY WITH MANAGEMENT SYSTEM CERTIFIED BY DNV GL = ISO 9001 = ISO 14001 =

RoHS 2 2011/65/EU

6.2.2 *Datasheet of Belimo LM24A-TP On-Off Actuator*

BELIMO

Technical data sheet LM24A-TP

Damper actuator for adjusting dampers in technical building installations

- **Air damper size up to approx. 1 m²**
- **Nominal torque 5 Nm**
- **Nominal voltage AC/DC 24 V**
- **Control Open-close, 3-point**
- **With connecting terminals**

Technical data

Electrical data	Nominal voltage	AC/DC 24 V
	Nominal voltage frequency	50/60 Hz
	Nominal voltage range	AC 19.2...28.8 V / DC 19.2...28.8 V
	Power consumption in operation	1 W
	Power consumption in rest position	0.2 W
	Power consumption for wire sizing	1.5 VA
	Connection supply / control	Terminals 4 mm² (cable Ø 4...10 mm, 3-wire)
	Parallel operation	Yes (note the performance data)
Functional data	Torque motor	Min. 5 Nm
	Direction of motion motor	Selectable with switch 0 (ccw rotation) / 1 (cw rotation)
	Manual override	Gear disengagement with push-button, can be locked
	Angle of rotation	Max. 95°
	Angle of rotation note	can be limited on both sides with adjustable mechanical end stops
	Running time motor	150 s / 90°
	Sound power level motor	35 dB(A)
	Spindle driver	Universal spindle clamp 6...20 mm
	Position indication	Mechanically, pluggable
Safety	Protection class IEC/EN	III Safety extra-low voltage
	Protection class UL	UL Class 2 Supply
	Degree of protection IEC/EN	IP54
	Degree of protection NEMA/UL	NEMA 2, UL Enclosure Type 2
	EMC	CE according to 2004/108/EC
	Certification IEC/EN	IEC/EN 60730-1 and IEC/EN 60730-2-14
	Certification UL	cULus according to UL 60730-1A, UL 60730-2-14 and CAN/CSA E60730-1:02
	Mode of operation	Type 1
	Rated impulse voltage supply / control	0.8 kV
	Control pollution degree	3
	Ambient temperature	-30...50°C
	Non-operating temperature	-40...80°C
	Ambient humidity	95% r.h., non-condensing
	Maintenance	Maintenance-free
Weight	Weight approx.	0.46 kg

Safety notes

- The device must not be used outside the specified field of application, especially not in aircraft or in any other airborne means of transport.
- Outdoor application: only possible in case that no (sea)water, snow, ice, insolation or aggressive gases interfere directly with the actuator and that is ensured that the ambient conditions remain at any time within the thresholds according to the data sheet.
- Only authorised specialists may carry out installation. All applicable legal or institutional installation regulations must be complied during installation.

6.2.3 *Datasheet of Belimo LM24A-SR-TP Modulating Actuator*

BELIMO

Technical data sheet **LM24A-SR**

Modulating damper actuator for adjusting dampers in technical building installations

- **Air damper size up to approx. 1 m²**
- **Nominal torque 5 Nm**
- **Nominal voltage AC/DC 24 V**
- **Control Modulating DC (0)2...10 V**
- **Position feedback DC 2...10 V**

Technical data

Electrical data	Nominal voltage	AC/DC 24 V
	Nominal voltage frequency	50/60 Hz
	Nominal voltage range	AC 19.2...28.8 V / DC 19.2...28.8 V
	Power consumption in operation	1 W
	Power consumption in rest position	0.4 W
	Power consumption for wire sizing	2 VA
	Connection supply / control	Cable 1 m, 4 x 0.75 mm²
	Parallel operation	Yes (note the performance data)
Functional data	Torque motor	Min. 5 Nm
	Positioning signal Y	DC 0...10 V
	Positioning signal Y note	Input impedance 100 kΩ
	Operating range Y	DC 2...10 V
	Position feedback U	DC 2...10 V
	Position feedback U note	Max. 1 mA
	Position accuracy	±5%
	Direction of motion motor	Selectable with switch 0 / 1
	Direction of motion note	Y = 0 V: At switch position 0 (ccw rotation) / 1 (cw rotation)
	Manual override	Gear disengagement with push-button, can be locked
	Angle of rotation	Max. 95°
	Angle of rotation note	can be limited on both sides with adjustable mechanical end stops
	Running time motor	150 s / 90°
	Sound power level motor	35 dB(A)
	Spindle driver	Universal spindle clamp 6...20 mm
	Position indication	Mechanically, pluggable
Safety	Protection class IEC/EN	III Safety extra-low voltage
	Protection class UL	UL Class 2 Supply
	Degree of protection IEC/EN	IP54
	Degree of protection NEMA/UL	NEMA 2, UL Enclosure Type 2
	EMC	CE according to 2004/108/EC
	Certification IEC/EN	IEC/EN 60730-1 and IEC/EN 60730-2-14
	Certification UL	cULus according to UL 60730-1A, UL 60730-2-14 and CAN/CSA E60730-1:02
	Mode of operation	Type 1
	Rated impulse voltage supply / control	0.8 kV
	Control pollution degree	3
	Ambient temperature	-30...50°C
	Non-operating temperature	-40...80°C
	Ambient humidity	95% r.h., non-condensing
	Maintenance	Maintenance-free
Weight	Weight approx.	0.51 kg

6.2.4 Datasheet of Temperature probe (NTC)

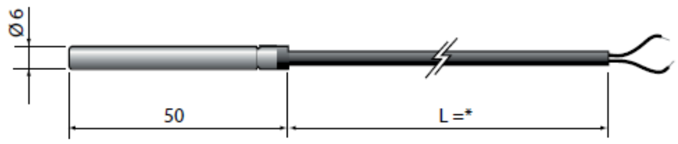
2.3 Models NTC*WH*

Storage conditions	-50T105 °C
Operating range	-50T105 °C
Connections	Stripped ends, dimensions: 5±1 mm
Sensor	NTC 10 kΩ ±1% a 25 °C Beta 3435
Precision	± 0,3 °C @ 25 °C ± 1 °C @ 80 °C ±1,2 °C @ -20 °C
Dissipation factor (in air)	ca. / approx. 2,2 mW/°C
Thermal constant over time (in water)	ca. / approx. 30 s
Cable	Two-wire with double sheath, AWG22, tinned copper with electrical resistance ≤63 Ω/km - Insulation: TPE specific for immersion in water on outer sheath, PP/Co inside on wires, OD 3.5 mm max
Sensitive element index of protection	IP68
Sensitive element housing	PP/Co with AISI 316 outer cap
Classification according to protection against electric shock (sensitive element and cable)	Supplementary insulation for 250 Vac;
Category of resistance to heat and fire	Flame retardant
Standard	NSF (only for 1,5-3-6 m versions)

Tab. 2.b

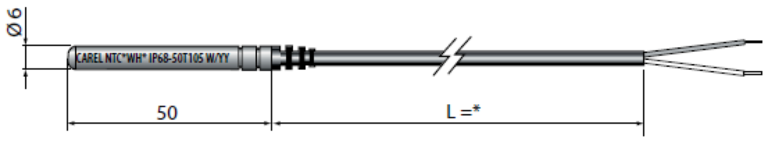
Version 1

* = see table of product codes in price list



Rys. 2.c

Version 2



Rys. 2.d

6.2.5 *Datasheet of Inverter (WEG cfw 500)*

DATASHEET
Variable Speed Drives

Product coding	: CFW500A01P0T4NB20
Product code	: 11575804
Product reference	: CFW500
Accessory module (control)	: CFW500-IOS

Basic data

Power supply	: 380-480 V
Input minimum-maximum voltage	: 323-528 V
- In	: 3
- Out	: 3

Supply voltage range	380-480 V	
Overload cicle	Normal Overload (ND)	Heavy Overload (HD)
Rated current (HD)	1	1
Overload current for 60 sec (HD)	2	2
Overload current for 3 sec (HD)	2	2

Maximum applicable motor:

Voltage/Frequency	Power (HP/kW) [1]	
	Normal Overload (ND)	Heavy Overload (HD)
380V / 50Hz	Not applicable	0,33 / 0,25
380V / 60Hz	Not applicable	0,33 / 0,25
400V / 50Hz	Not applicable	0,5 / 0,37
400V / 60Hz	Not applicable	0,33 / 0,25
440V / 50Hz	Not applicable	0,33 / 0,25
440V / 60Hz	Not applicable	0,33 / 0,25
460V / 60Hz	Not applicable	0,5 / 0,37
480V / 60Hz	Not applicable	0,5 / 0,37

Accessory module (control)	: CFW500-IOS
Dynamic braking [2]	: Standard without braking
External electronic suply 24Vcc	: Not available
Safety Stop	: Not available
Internal RFI filter	: Without filter
External RFI filter	: Not available
Link Inductor	: No
Memory card	: Not included in the product
USB port	: Only with plug-in
Line frequency	: 50/60Hz
Line frequency range (minimum - maximum)	: 48-62 Hz
Phase unbalance	: less or equal to 3% of input rated line voltage
Transient voltage and overvoltage	: Category III
Single-phase input current [3]	: Not applicable
Three-phase input current [3]	: 1,2 A
Power factor	: 0,83
Displacement factor	: 0,98
Rated efficiency	: ≥ 97%
Maximum connections (power up cycles - on/off) per hour	: 10 (1 each 6 minutes)
DC power supply	: Not allow
Standard switching frequency	: 5 kHz
Selectable switching frequency	: 2,5 and 15 kHz
Real-time clock	: Not available
COPY Function	: Yes, by MMF

Dissipated power:

Mounting type	Overload	
	ND	HD
Surface	20 W	20 W
Flange	Not applicable	Not applicable

Output voltage	: 24 Vcc
Maximum capacity	: 150 mA
Power supply	: Switched-mode power supply
Control method	: V/f (escalar) and VVW
Encoder interface	: Only with plug-in
Control output frequency	: 0-500 Hz
Frequency resolution	: 0,015 Hz

1 / 3

DATASHEET

Variable Speed Drives

- Speed resolution	: 1% of rated speed
- Speed range	: 1:20
- Speed resolution	: 1% of rated speed
- Speed range	: 1:30
- Speed resolution	: Not applicable
- Speed range	: Not applicable
- Speed resolution	: Not applicable
- Speed range	: Not applicable
Quantity (standard)	: 1
Levels	: 0-10V, 0-20mA and 4-20mA
For voltage input	: 100 kΩ
Impedance for current input	: 500 Ω
Function	: Programmable
Maximum allowed voltage	: 30 Vcc
Digital inputs - Quantity (standard)	: 4
Activation	: Active low and high
Maximum low level	: 5 V (low) e 15 V (high)
Minimum high level	: 9 V (low) e 20 V (high)
Input current	: 4,5 mA
Maximum input current	: 5,5 mA
Function	: Programmable
Maximum allowed voltage	: 30 Vcc

Analog outputs

Analogic outputs - Quantity (standard)	: 1
Levels	: 0 to 10V, 0 to 20mA and 4 to 20mA
RL for voltage output	: 10 kΩ
RL for current output	: 500 Ω
Function	: Programmable
Digital outputs - Quantity (standard)	: 1 NO/NC relay and 1 transistor
Maximum voltage	: 240 Vca and 24 Vcc
Maximum current	: 0,5 A and 150 mA
Function	: Programmable

- Modbus-RTU (with accessory: Any plug-in module)
- Modbus/TCP (with accessory CFW500-CEMB-TCP)
- Profibus DP (with accessory: CFW500-CPDP)
- Profibus DPV1 (with accessory: CFW500-CPDP)
- Profinet (with accessory CFW500-CEPN-IO)
- CANopen (with accessory: CFW500-CCAN)
- DeviceNet (with accessory: CFW500-CCAN)
- EtherNet/IP (with accessory CFW500-CETH-IP)
- EtherCAT (Not available)
- BACnet (Not aplicable)

- Output phase-phase overcurrente/Short
- Overcurrent/Short circuit phase-ground
- Under/Overvoltage in power
- Heat sink overtemperature
- Motor overload
- IGBT's modules overload
- Fault/External alarm
- Programming error

Avaliability	: Included in the product
Installation	: Fixed HMI
Number of HMI buttons	: 9
Display	: Numeric LCD
Indication accuracy	: 5% of rated current
Speed resolution	: 0,1 Hz
Standard HMI degree of protection	: IP20
HMI battery type	: Not applicable
HMI battery life expectancy	: Not applicable
Remote HMI type	: Accessory
Remote HMI frame	: Not applicable
Remote HMI degree of protection	: IP54
Enclosure	: IP20
Degree of pollution	: 2
RoHS	: Yes
Conformal Coating	: 3C2
- Size	: A

2 / 3

DATASHEET
Variable Speed Drives

- Height : 189 mm / 7.4 in
- Width : 75 mm / 2.95 in
- Depth : 150 mm / 5.91 in
- Weight : 0,8 kg / 1.8 lb

Mechanical Installation

Mounting position : Surface or rail DIN
Fixing screw : M4
Tightening torque : 2 N.m / 1.48 lb.ft
Allows side-by-side assembly : Yes, maximum ambient temperature 40°C
- Top : 15 mm / 0.59 in
- Bottom : 40 mm / 1.57 in
- Front : 30 mm / 1.18 in
- Side : 10 mm / 0.39 in

Cable gauges and tightening torques:

	1,5 mm² (16 AWG)	0,5 N.m / 0.37 lb.ft
	Not applicable	0,5 N.m / 0.37 lb.ft
	2,5 mm² (14 AWG)	0,5 N.m / 0.37 lb.ft
	0,5 to 1,5 mm² (20 to 14 AWG)	0,5 N.m / 0.37 lb.ft

SoftPLC : Yes, incorporated
Maximum breaking current : Not available
Minimum resistance for the brake resistor : Not available
Recommended aR fuse : FNH00-20K-A
Recommended circuit breaker : MPW18-3-D016
Disconnect switch : Not applicable
Motor coupling box : Not applicable

	- - - - - - -
	- EN 61800-3 - Adjustable speed electrical power drive systems - Part 3: EMC product standard including specific test methods. - EN 55011 - Limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment. - CISPR 11 - Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement. - EN 61000-4-2 - Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 2: Electrostatic discharge immunity test. - - - -
	- EN 60529 e UL 50

Certifications

6.3 ANNEX2 – SCHEMATIC DRAWINGS

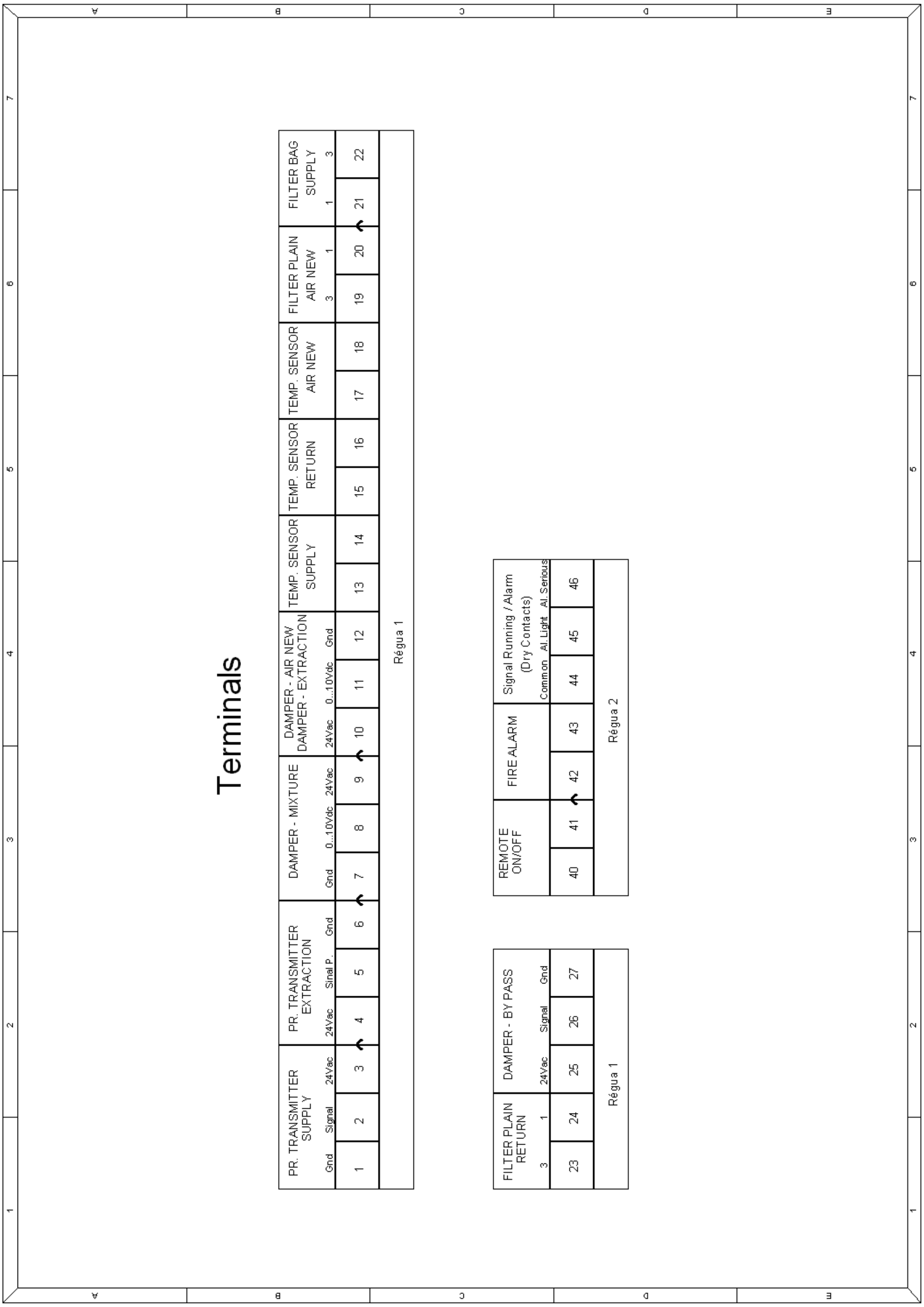
Annex2 represents the schematic drawing of the unit

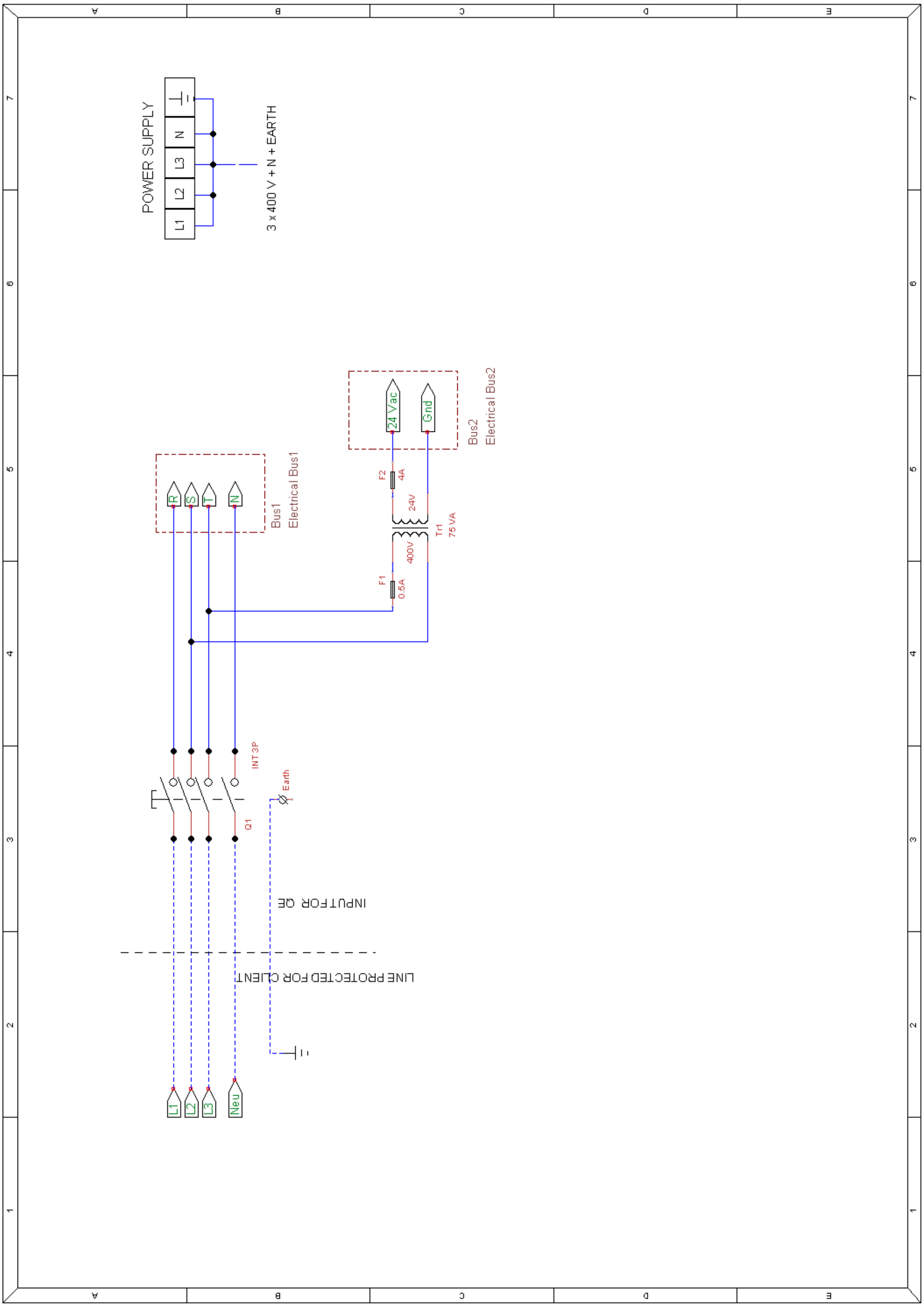
Electrical Specifications

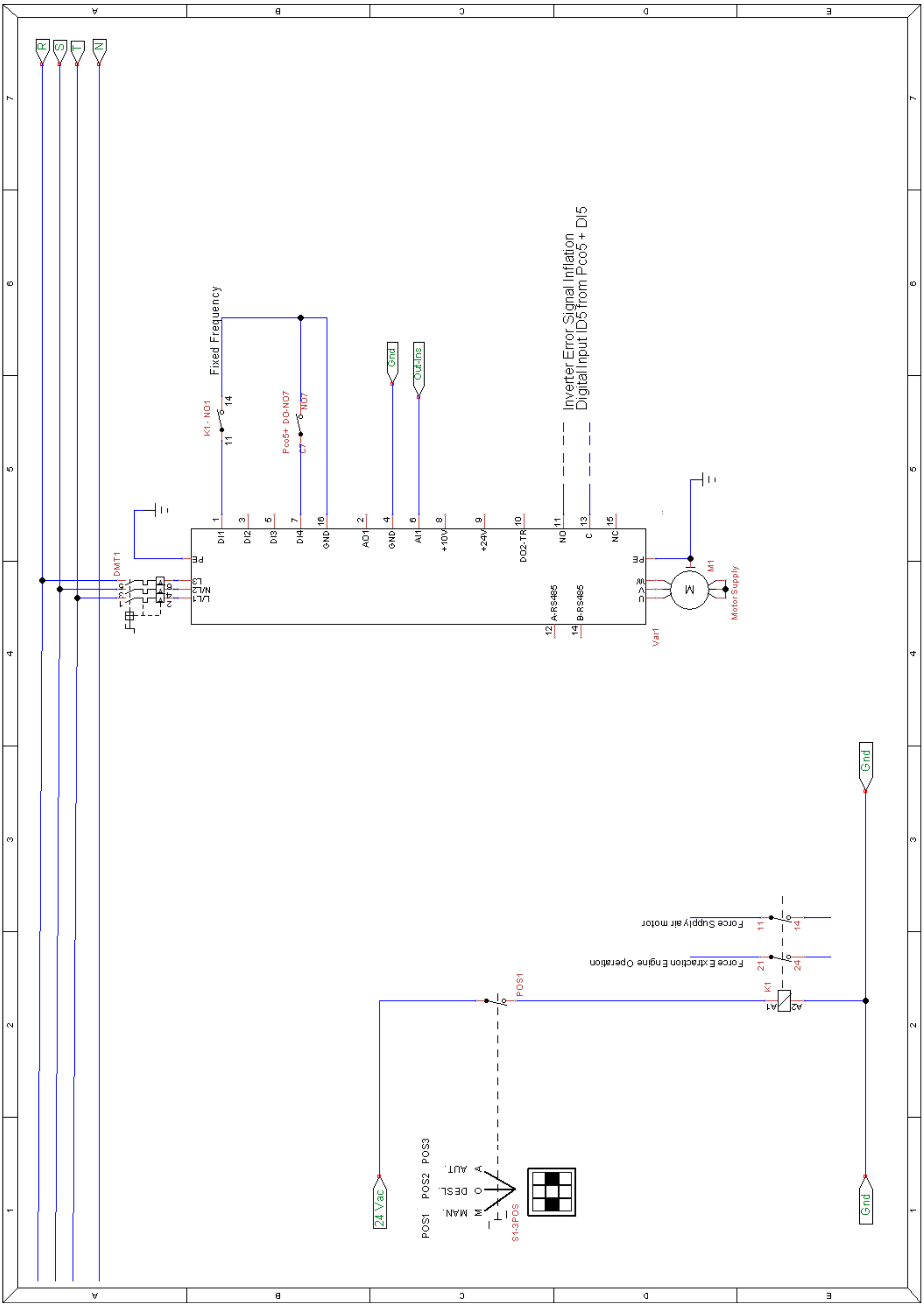
	UTA4
SUPPLY MOTOR	5,5kW (~17,1A)
EXTRACTION MOTOR	4kW (~12A)
MOTOR REC. ROTATIVO	-----------------------------
COILS	
TOTAL POWER (Imax)	9,5kW (~20A)

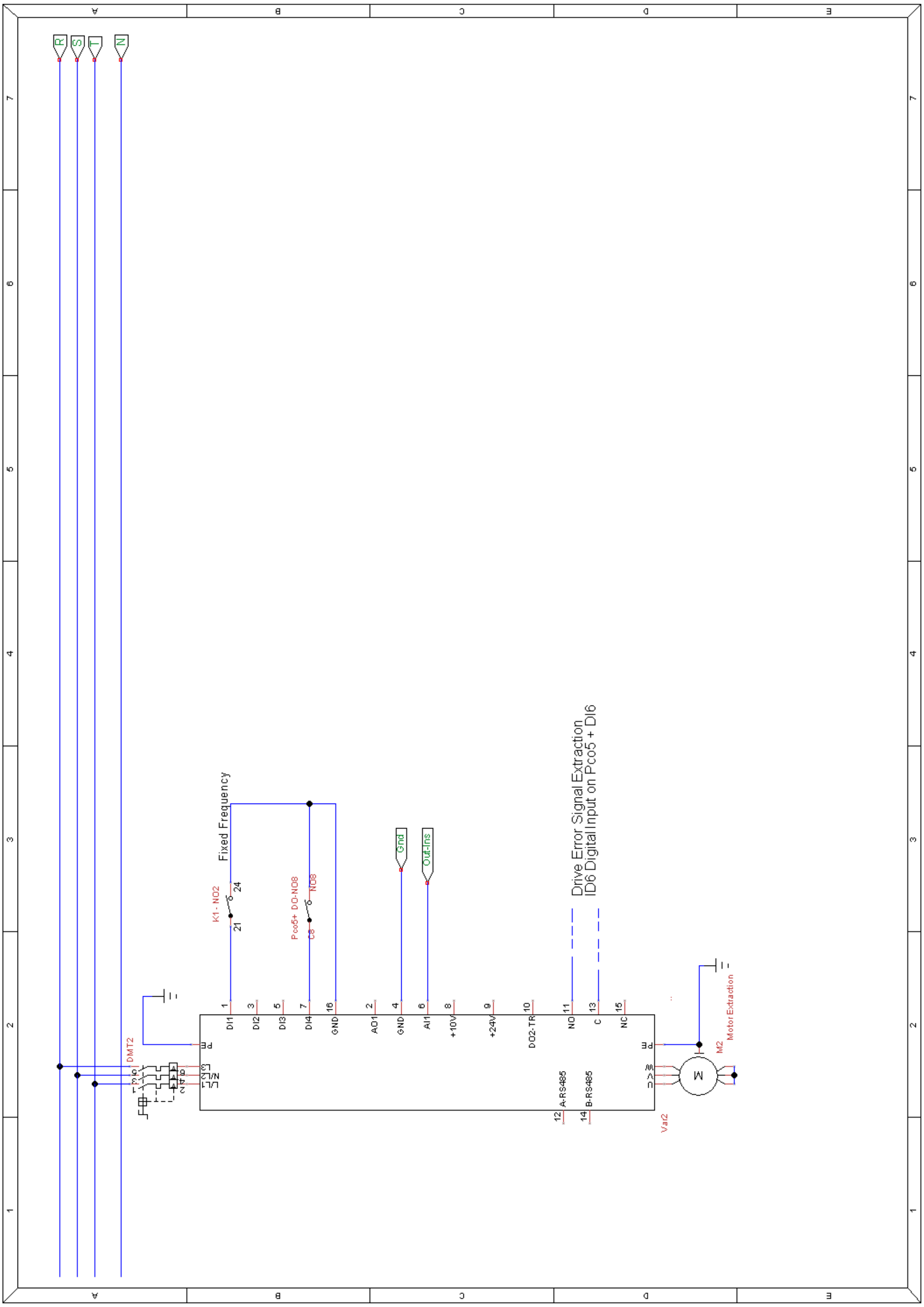
POWER SUPPLY QE	3 x 400Vac + N 50Hz
AUXILARY CIRCUITS	24Vac 50Hz

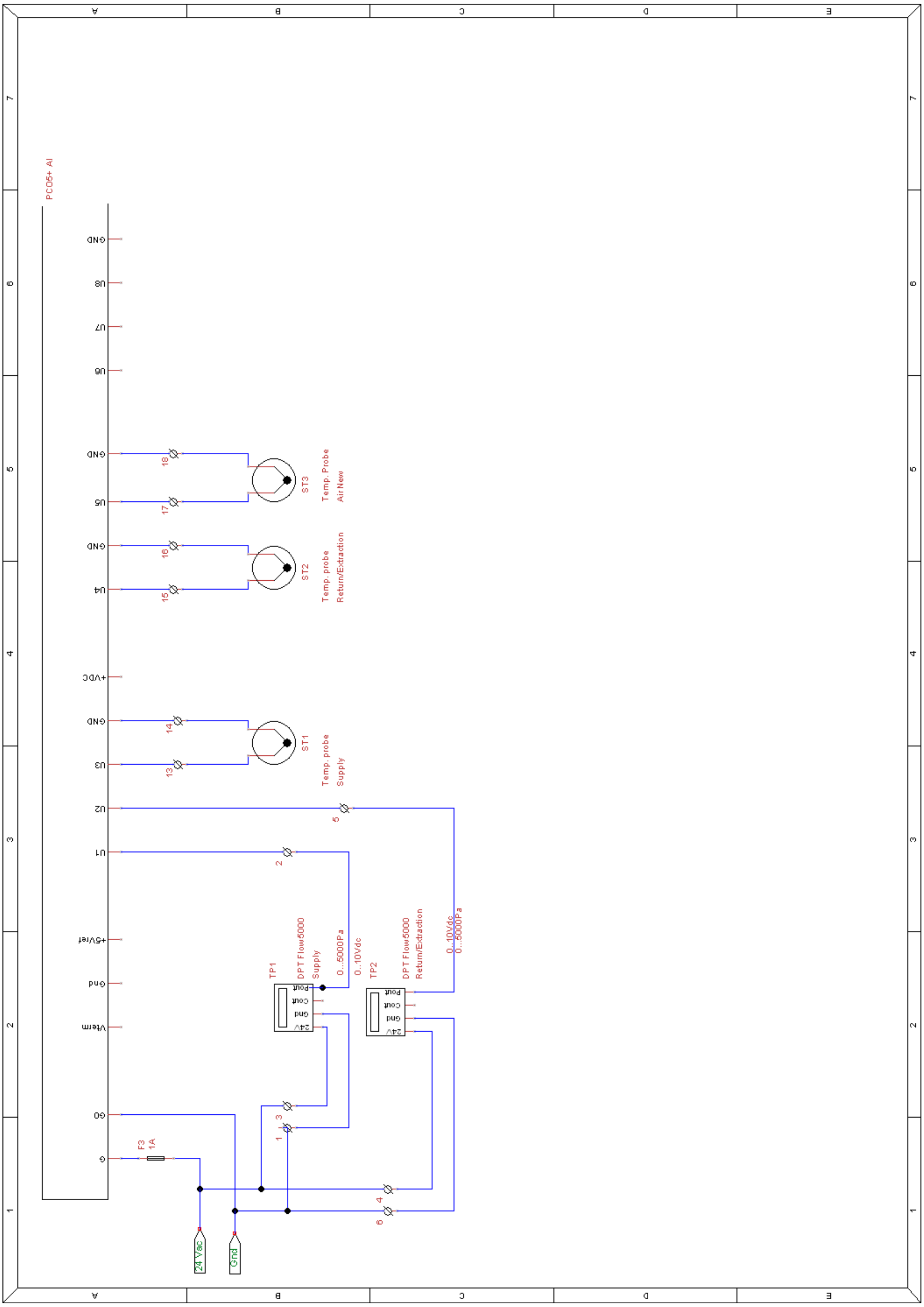
Title: Temperature Control		
Author: Sabhapathy, Equipamento Ventilação e Ar Condicionado		
File: E:\EVAC\Temperatu ... Temperature Control.dsn		Document
Revision: 1	Date: 26-05-2018	Sheets: 1

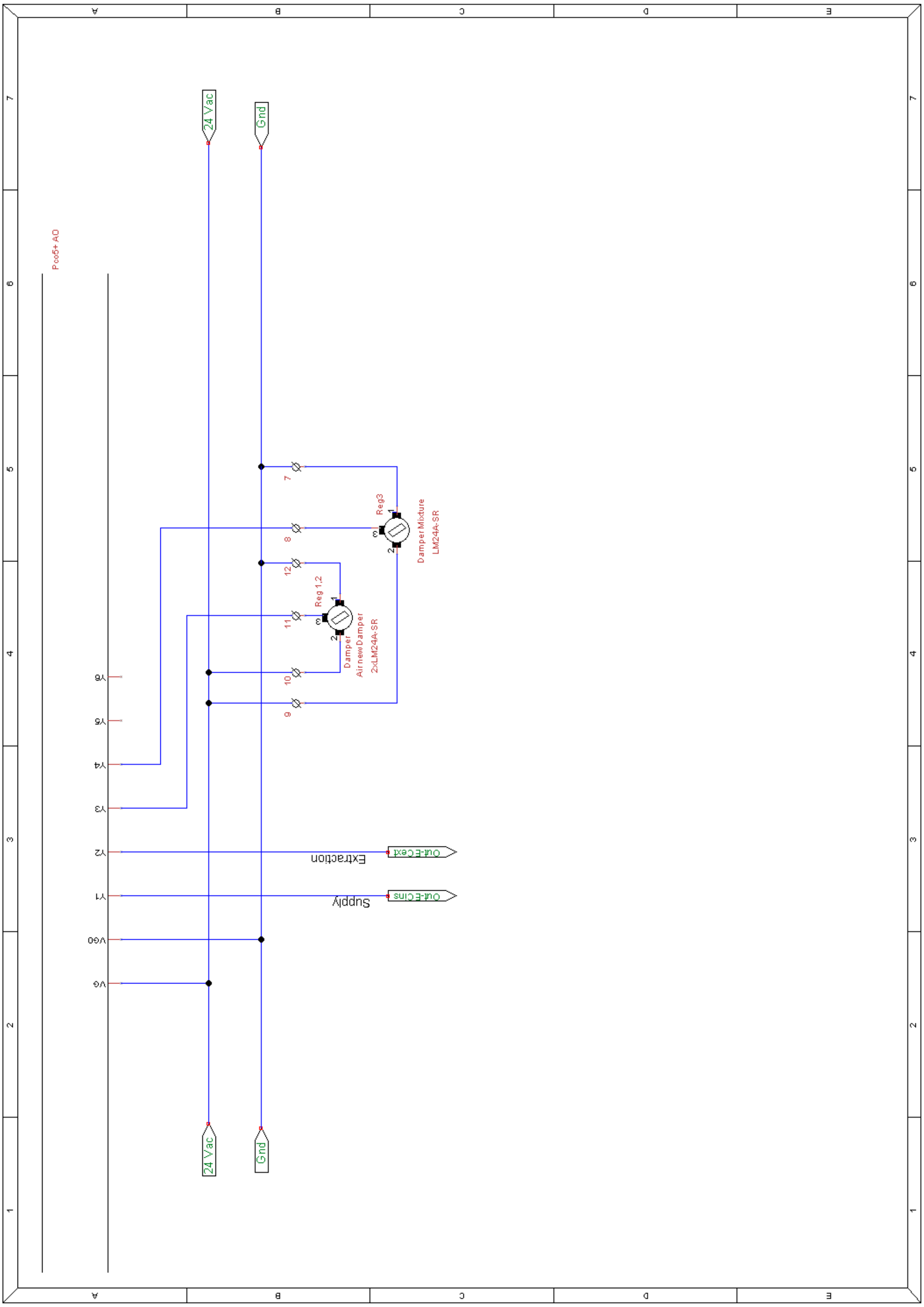

Terminals
PR. TRANSMITTER SUPPLY
Gnd
Signal
24Vac
1
2
3
PR. TRANSMITTER EXTRACTION
24Vac
Sinal P.
Gnd
4
5
6
DAMPER - MIXTURE
Gnd
0...10Vdc
24Vac
7
8
9
DAMPER - AIR NEW DAMPER - EXTRACTION
24Vac
0...10Vdc
Gnd
10
11
12
TEMP. SENSOR SUPPLY
13
14
TEMP. SENSOR RETURN
15
16
TEMP. SENSOR AIR NEW
17
18
FILTER PLAIN AIR NEW
3
1
19
20
FILTER BAG SUPPLY
1
3
21
22
Régua 1
FILTER PLAIN RETURN
3
1
23
24
DAMPER - BY PASS
24Vac
Signal
Gnd
25
26
27
Régua 1
REMOTE ON/OFF
40
41
FIRE ALARM
42
43
Signal Running / Alarm (Dry Contacts)
Common
Al. Light
Al. Serious
44
45
46
Régua 2


POWER SUPPLY
L1
L2
L3
N
3 x 400 V + N + EARTH
R
S
T
N
Bus1
Electrical Bus1
24 Vac
Gnd
Bus2
Electrical Bus2
F2
4A
24V
Tr1
75 VA
400V
F1
0.5A
INT 3P
Q1
Earth
INPUT FOR QE
LINE PROTECTED FOR CLIENT
L1
L2
L3
Neu

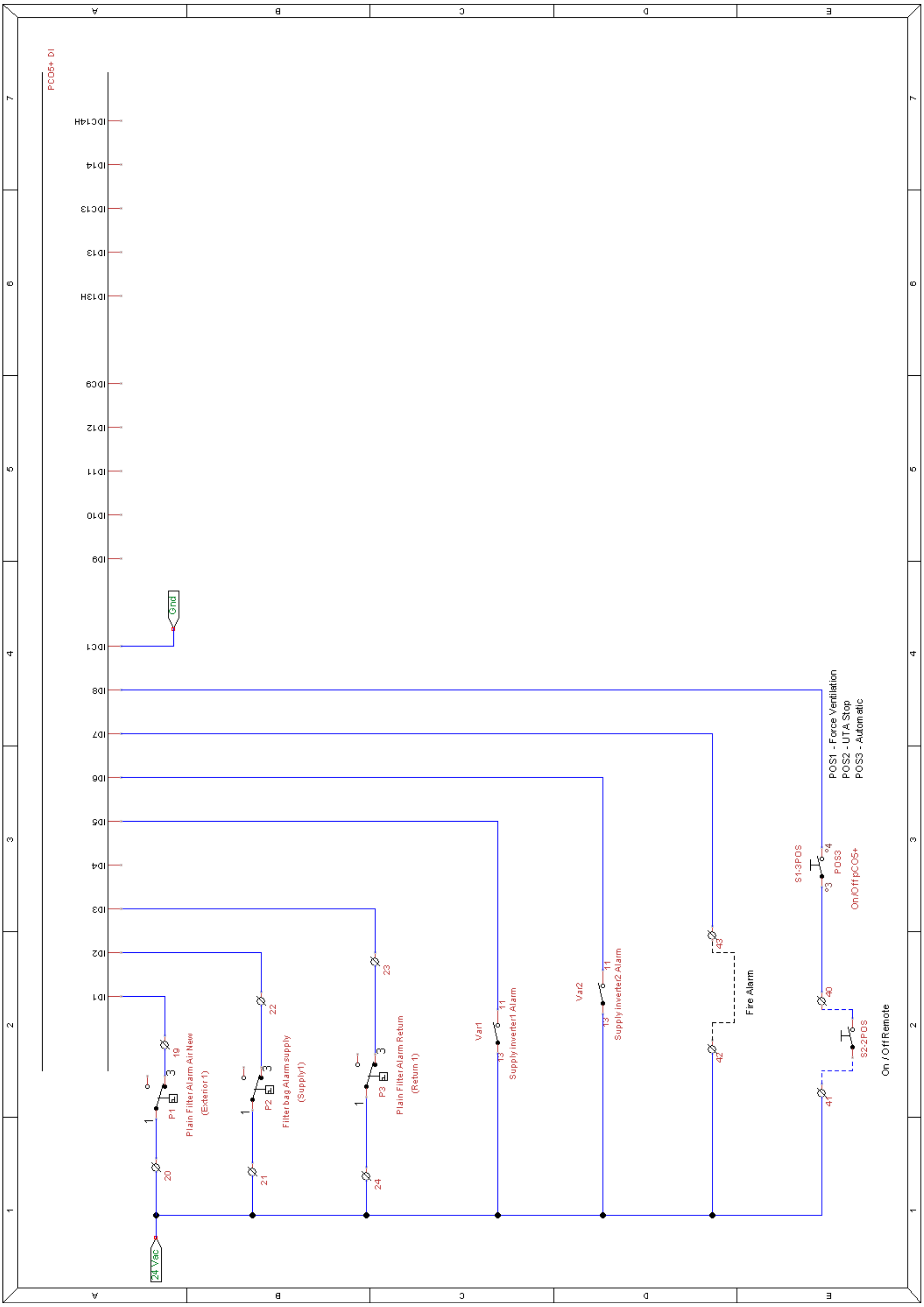

R
S
T
N
Fixed Frequency
K1 - NO1
Pco5+ DO-NO7
Gnd
Out-Ins
Inverter Error Signal Inflation
Digital Input ID5 from Pco5 + DI5
DMT1
DI1
DI2
DI3
DI4
GND
AO1
GND
AI1
+10V
+24V
DO2-TR
NO
C
NC
PE
A-RS485
B-RS485
Var1
M1
Motor Supply
Force Supply air motor
Force Extraction Engine Operation
K1
POS1
24 Vac
Gnd
S1-3POS
POS1
POS2
POS3
MAN.
DESL.
AUT.

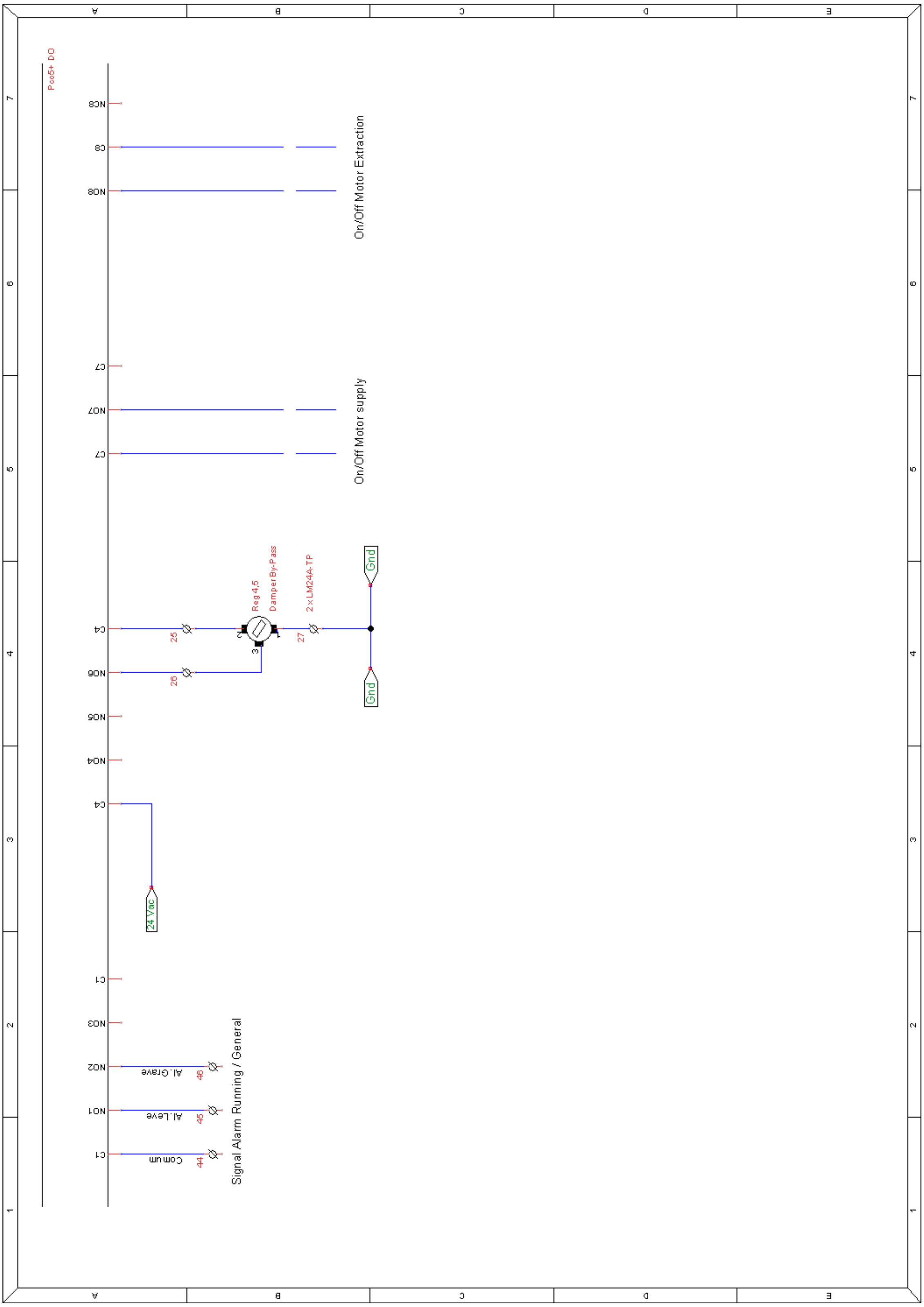

R
S
T
N
DMT2
K1 - NO2
Fixed Frequency
Pco5+ DO-NO8
Gnd
Out-Ins
DI1
DI2
DI3
DI4
GND
AO1
GND
AI1
+10V
+24V
DO2-TR
NO
C
NC
PE
A-RS485
B-RS485
Drive Error Signal Extraction
ID6 Digital Input on Pco5 + DI6
M2
Motor Extraction
Var2

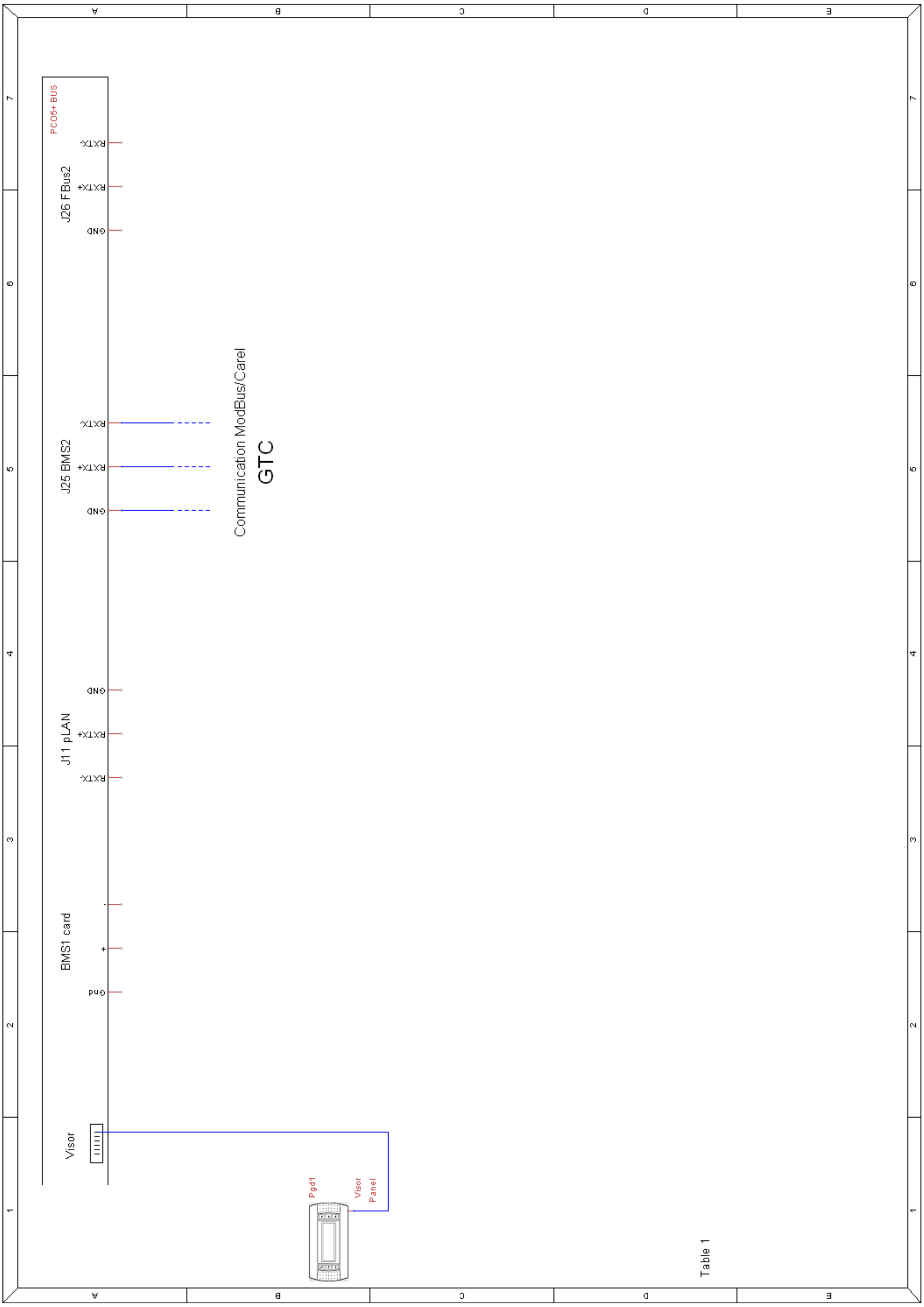

PCO5+ AI
GND
U8
U7
U6
GND
U5
GND
U4
+VDC
GND
U3
U2
U1
+5Vref
Gnd
Vterm
G0
G
F3
1A
ST3
Temp. Probe
Air New
ST2
Temp. probe
Return/Extraction
ST1
Temp. probe
Supply
TP1
DPT Flow5000
Supply
0...5000Pa
0...10Vdc
TP2
DPT Flow5000
Return/Extraction
0..10Vdc
0...5000Pa
24 Vac
Gnd



Pco5+ AO
24 Vac
Gnd
Y1
Y2
Y3
Y4
Y5
Y6
VG
VG0
Supply
Extraction
Out-E.Cins
Out-E.Cext
Reg3
Damper Mixture
LM24A-SR
Reg 1.2
Damper
Air new Damper
2xLM24A-SR


PCO5+ DI
IDC14H
ID14
IDC13
ID13
ID13H
IDC9
ID12
ID11
ID10
ID9
Gnd
IDC1
ID8
ID7
ID6
ID5
ID4
ID3
ID2
ID1
P1
Plain Filter Alarm Air New
(Exterior 1)
P2
Filter bag Alarm supply
(Supply1)
P3
Plain Filter Alarm Return
(Return 1)
Var1
Supply inverter1 Alarm
Var2
Supply inverter2 Alarm
Fire Alarm
S1-3POS
POS3
On/Off pCO5+
POS1 - Force Ventilation
POS2 - UTA Stop
POS3 - Automatic
S2-2POS
On / Off Remote
24 Vac


Pco5+ DO
NC8
C8
NO8
On/Off Motor Extraction
C7
NO7
C7
On/Off Motor supply
C4
NO6
25
26
Reg 4,5
Damper By-Pass
2 x LM24A-TP
27
Gnd
Gnd
NO5
NO4
C4
24 Vac
C1
NO3
NO2
NO1
C1
Al. Grave
Al. Leve
Comum
46
45
44
Signal Alarm Running / General


PCO5+ BUS
J26 FBus2
RXTX-
RXTX+
GND
J25 BMS2
RXTX-
RXTX+
GND
Communication ModBus/Carel
GTC
J11 pLAN
GND
RXTX+
RXTX-
BMS1 card
-
+
Gnd
Visor
Pgd1
Visor
Panel
Table 1

6.4 ANNEX3 – DATASHEET

Annex3 represents the datasheet of the unit

OF	CLIENTE	MODELO
333.233	SOMAGAS	UTA-RP 50 plus 50

DATA	OBRA	REFERÊNCIA
12-2017	Farfetch em Taipas	UTA 4

FILTRO

DESIGNAÇÃO		EFIC.	P INICIAL	P FINAL	P CONSID.
		-	Pa	Pa	Pa
Filtro Plano	INS	G4	61	150	106
Filtro Saco	INS	F7	114	200	157
Filtro Plano	RET	G4	61	150	106

ATRAVANCAMENTO

Altura x Largura x Comprimento	mm	2270x1362x5190
Peso Total	kg	1201

RECUPERADOR

DESIGNAÇAO		CAUDAL	INVERNO								VERÃO							
			ENTRADA		SAIDA		EFIC.	P	POTENCIA		ENTRADA		SAIDA		EFIC.	P	POTENCIA	
		m³/h	ºC	%	ºC	%	%	Pa	SENS.	TOTAL	ºC	%	ºC	%	%	Pa	SENS.	TOTAL
H20700/50 - 1262	INS.	6.309	0	90	15,5	31	77	151	32,6	32,6	32	40	27,0	53	71	157	10,6	10,6
	RET.	6.309	20	50	7,1	99	65	153	32,6	32,6	25	50	30,0	37	71	157	10,6	10,6

REGISTO/CAUDAIS

DESIGNAÇÃO		MÁXIMO			
		CAUDAL	REGULAÇÃO	VEL.	P
		m³/h	º	m/s	Pa
NO 1000x600	AR NOVO	12.618	0	5,8	16
NO 1000x600	AR EXAUSTÃO	12.618	0	5,8	16
NO 1000x300	AR RETORNO	6.309	45	5,8	(794)
NO 1000x400	BY-PASS REC A.N.	12.618	0	8,7	(32)
NO 1000x400	BY-PASS REC A.E.	12.618	0	8,7	(32)

VENTILADOR

DESIGNAÇÃO		CAUDAL	$P_{Ext.}$	VEL. ROT.	POT. VEIO	$P_{EST.}$	$P_{DIN.}$	P_{TOTAL}	COEF.
		m³/h	Pa	rpm	kW	Pa	Pa	Pa	m².s/h
P5601	INS.	12.618	300	1.800	3,63	737	71	808	311
P5601	RET.	12.618	300	1.715	3,06	582	71	653	311

MOTOR

POT. NOMINAL		VEL. ROT.	EFIC.	VEL.	TENS.	COR.	POT. EL.		FREQ.
		rpm	-	-	V	A	kW		Hz
5,5 kW	INS.	1.460	IE 2	1-N	400 V	10,5	4,25		60 - 62 - 63
4 kW	RET.	1.440	IE 2	1-N	400 V	8,11	3,64		59 - 60

NÍVEL DE RUÍDO

-	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LWS
	dB	dB	dB	dB	dB	dB	dB	dB	dB(A)
INSUFLAÇÃO - DESCARGA	78	83	78	76	74	64	59	56	77
INSUFLAÇÃO - ADMISSÃO	75	79	76	71	68	63	59	55	73
RETORNO - EXAUSTÃO	79	82	78	76	75	70	67	64	79
RETORNO - EXTRACÇÃO	77	83	80	77	75	72	69	65	80
EXTERIOR	70	76	70	67	65	64	47	39	71

6.5 ANNEX4 – TEST AND COMMISSIONING REPORT

Annex4 represents the test report at EVAC and the commissioning report at Farfetch. The test report at EVAC

OF:	Ref.:	Cliente:	Modelo:
333233	UTA 4	Somagas	

Controlo de caudal Constante			
Setpoint:		Caudal:	12618/12618
Pressão:		CPFN:	311/311

Controlo de Temperatura / Humidade			
Controlador:		Contactores:	
Relé:		Fusíveis:	
Disjuntor Motor:		Disjuntor Magnético:	
Transformador:		Interruptor:	
Arrancador Suave:		Variador:	
Diferencial:		Visor:	

Sondas	Tipo	NA	C	NC
Sonda T. Insuflação	ntc	☐	☒	☐
Sonda T. Retorno	ntc	☐	☒	☐
Sonda T. Exterior	ntc	☐	☒	☐
Sonda H. Insuflação		☐	☐	☐
Sonda H. Retorno		☐	☐	☐
Sonda H. Exterior		☐	☐	☐

Servomotores	Tipo	NA	C	NC
Exterior	LM24A-SR-TP	☐	☒	☐
Mistura	LM24A-SR-TP	☐	☒	☐
Expulsão	LM24A-SR-TP	☐	☒	☐
By-pass	LM24A-TP	☐	☒	☐

Válvulas	Tipo	NA	C	NC
Arrefecimento		☐	☐	☐
Aquecimento		☐	☐	☐
Pós Aquecimento		☐	☐	☐

Alarmes Críticos	Tipo	NA	C	NC
Disparo Térmico	Insuflação ☒ Retorno ☐	☐	☒	☐
C. Partida	Insuflação ☒ Retorno ☐	☐	☒	☐
Filtros	F. Plano ☒ F. Saco ☒ F. Absoluto ☒	☐	☒	☐
Fogo		☐	☐	☐
Resistências Eléctricas		☐	☐	☐

Observações:	DPTs Flow 5000D mapped 0…5000 PA
☐ Ensaio OBRA	
☒ Ensaio EVAC	
☐ Arranque pelo cliente	

The commissioning report of the unit performed at Farfetch.

Arrefecimento

Setpoint Temp.	18	Diferencial:	3	Zona morta:	1
Setpoint Humid.		Diferencial:		Zona morta:	

Item	Medições	NA	C	NC
Temp. Exterior (ºC)	25.6	☐	☒	☐
Temp. Retorno/Sala (ºC)	23.7	☐	☒	☐
Temp. Insuflação (ºC)	22.9	☐	☒	☐
Humidade Exterior (%)		☐	☐	☐
Humidade Retorno/Sala (%)		☐	☐	☐
Humidade Insuflação (%)		☐	☐	☐
Válvula De Frio (%)		☐	☐	☐
Válvula De Quente (%)		☐	☐	☐
Válvula De Pós-Aquecimento (%)		☐	☐	☐
Registo Ar Novo (%)	100	☐	☒	☐
Registo Ar Expulso (%)	100	☐	☒	☐
Registo Mistura (%)	0	☐	☒	☐
Registo Bypass	ON	☐	☒	☐
Humidificador (%)		☐	☐	☐
	Fs = 74.3%, 57.5 Hz – 5.5A / Fr = 71.5%, 52.3Hz, 6A	☐	☐	☐

Aquecimento

Setpoint Temp.	29	Diferencial:	3	Zona morta:	1
Setpoint Humid.		Diferencial:		Zona morta:	

Item	Medições	NA	C	NC
Temp. Exterior (ºC)	23.4	☐	☒	☐
Temp. Retorno/Sala (ºC)	26.4	☐	☒	☐
Temp. Insuflação (ºC)	24	☐	☒	☐
Humidade Exterior (%)		☐	☐	☐
Humidade Retorno/Sala (%)		☐	☐	☐
Humidade Insuflação (%)		☐	☐	☐
Válvula De Frio (%)		☐	☐	☐
Válvula De Quente (%)		☐	☐	☐
Válvula De Pós-Aquecimento (%)		☐	☐	☐
Registo Ar Novo (%)	100	☐	☒	☐
Registo Ar Expulso (%)	100	☐	☒	☐
Registo Mistura (%)	65	☐	☒	☐
Registo Bypass	OFF	☐	☒	☐
Humidificador (%)		☐	☐	☐
	Fs = 78.5%, 54.8Hz, 5.6A/Fr = 78.7%, 55Hz, 6.3A	☐	☐	☐

Consumos Motor	Medições	NA	C	NC
Insuflação (I_{INS})		☐	☐	☐
Retorno (I_{RET})		☐	☐	☐

Obs.:
1. Working time fixed at 6H to 22H
2. Flow = 12580 m^3/h changed to 8900 m^3/h
3. Controller damaged, clock not working. Need to be changed.