Refrigeration and HVAC

Building HVAC

Direct Digital Control (BACnet)

Courseware Sample

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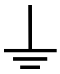
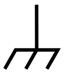
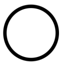
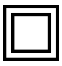
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, lifting hazard
	Caution, belt drive entanglement hazard
	Caution, chain drive entanglement hazard
	Caution, gear entanglement hazard
	Caution, hand crushing hazard
	Notice, non-ionizing radiation
	Consult the relevant user documentation.
	Direct current
	Alternating current

Safety and Common Symbols

Symbol	Description
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

This product introduces students to the basic principles of heating, ventilation, and air conditioning (HVAC). It covers components used in HVAC systems, and teaches skills required to work in the HVAC field. Throughout the activities, students develop practical knowledge on how to install, maintain, and troubleshoot HVAC systems. They become familiar with a variety of HVAC systems.

The equipment in this line of products is designed for full modularity. It can be used to implement several types of HVAC systems and circuits. The equipment uses residential, industrial, and commercial devices. This give students an experience that is as close as possible to actual work in the HVAC field.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual objectives

When you have completed this manual, you will be able to:

- describe the operation of HVAC systems, sub-systems, and components.
- wire HVAC control circuits.
- read and understand technical documents such as wiring diagrams.
- troubleshoot malfunctions and determine how to correct them.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Prerequisite

Basic electrical knowledge is a prerequisite to this manual. It is assumed that you have a general understanding of these concepts:

- Voltage, current, and power (for both dc and ac circuits)
- Basic electrical components: power source, resistor/potentiometer, inductor, capacitor, transformer, diode, transistor
- Ohm's law
- Series and parallel circuits
- Electrical measurement using a digital multimeter (DMM)

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

HVAC Systems

DISCUSSION OUTLINE

The Discussion of Fundamentals covers the following points:

- What is HVAC?
- Anatomy of an HVAC system
- Air-handling unit
- Direct digital control

DISCUSSION OF FUNDAMENTALS

What is HVAC?

HVAC stands for Heating, Ventilating, and Air Conditioning. The field of HVAC is very large and encompasses many different processes. The complexity of HVAC systems ranges from simple domestic heaters to high-reliability air conditioning systems on submarines.

HVAC systems exist in a wide range of sizes. Industrial cooling equipment may cover an area 10 000 times larger than a domestic unit. To put this in perspective, it is like comparing the area a mini-fridge covers to the area of an American football field (Figure 1). Considering the variations in complexity and size, it is easy to understand why HVAC is such a broad field.

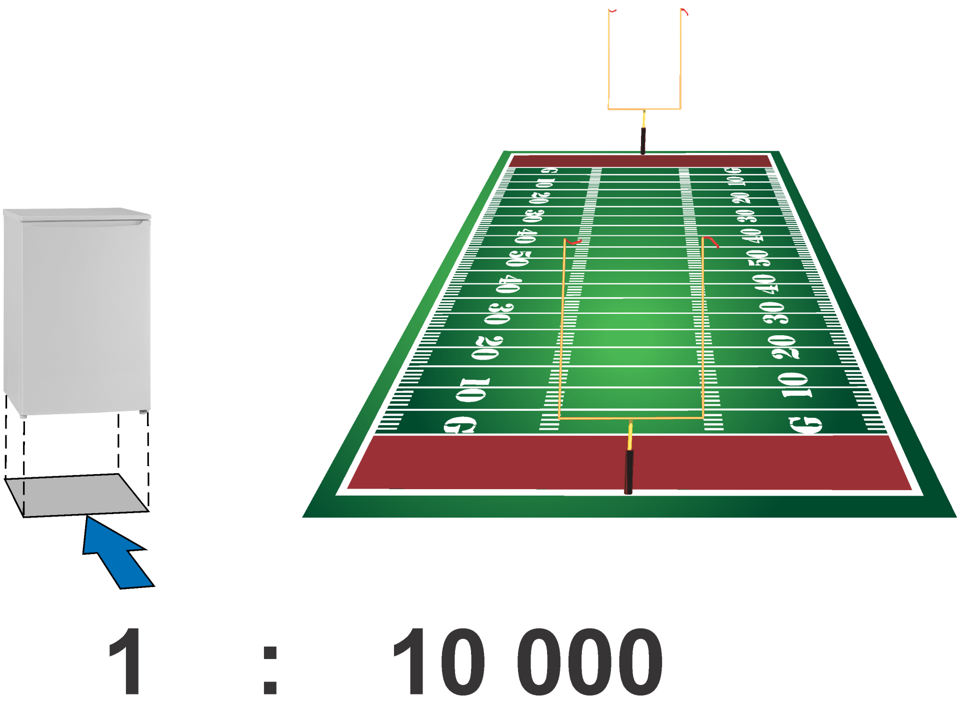

Figure 1. HVAC systems can vary greatly in size.

The expression air conditioning in the acronym HVAC can be misleading. The meaning of air conditioning has shifted over the years to more than cooling. Nowadays, air conditioning includes every aspect necessary to provide total control of air. This includes temperature control, humidity control, fresh air supply, air filtration, and air movement.

Since HVAC is based on principles of engineering, thermodynamics, fluid mechanics, electricity, physics, electronics, process control, and even social behavior, it is difficult to master every aspect of HVAC at once. Rather, focusing on a particular application helps to gradually shed light on the HVAC field as a whole.

Anatomy of an HVAC system

Understanding the processes that HVAC equipment controls is important; especially when you need to configure, install, or troubleshoot such equipment. Seven processes come into play when achieving total control of air quality in an HVAC system:

1. heating
2. cooling
3. humidifying
4. dehumidifying
5. cleaning
6. ventilating
7. air movement

In a standard HVAC system, specialized devices control these processes. Being able to identify those devices and understand their influence on the seven main processes is essential to understand HVAC systems.

Figure 2 shows an example of an HVAC system for a small to medium-sized building. On the top of the building is the rooftop unit, which is an enclosed air-handling unit. Rooftop units have several advantages. Being installed on the roof, they do not require valuable building space. Also, since they are pre-designed, design cost and delays are minimal. On the other hand, the choice of rooftop units is limited to what is available on the market. Moreover, the maintenance of rooftop units must be performed no matter the outdoor conditions.

Rooftop units are a specific type of air-handling units. For large buildings, packaged units are neither convenient nor efficient. In this case, the air-handling unit is in a dedicated room. Large air-handling units are often custom made to fit the specifics of a building. They may include boilers and chillers as sources of heating and cooling.

The role of an air-handling unit is to condition air according to the needs of the building occupants. To achieve this, the unit takes air from outside as well as return air from inside. It regulates the temperature, relative humidity, pressure, and air quality. The air-handling unit distributes conditioned air to the different building areas via ducts. Local controllers, heaters, and dampers are also part of a complete HVAC systems.

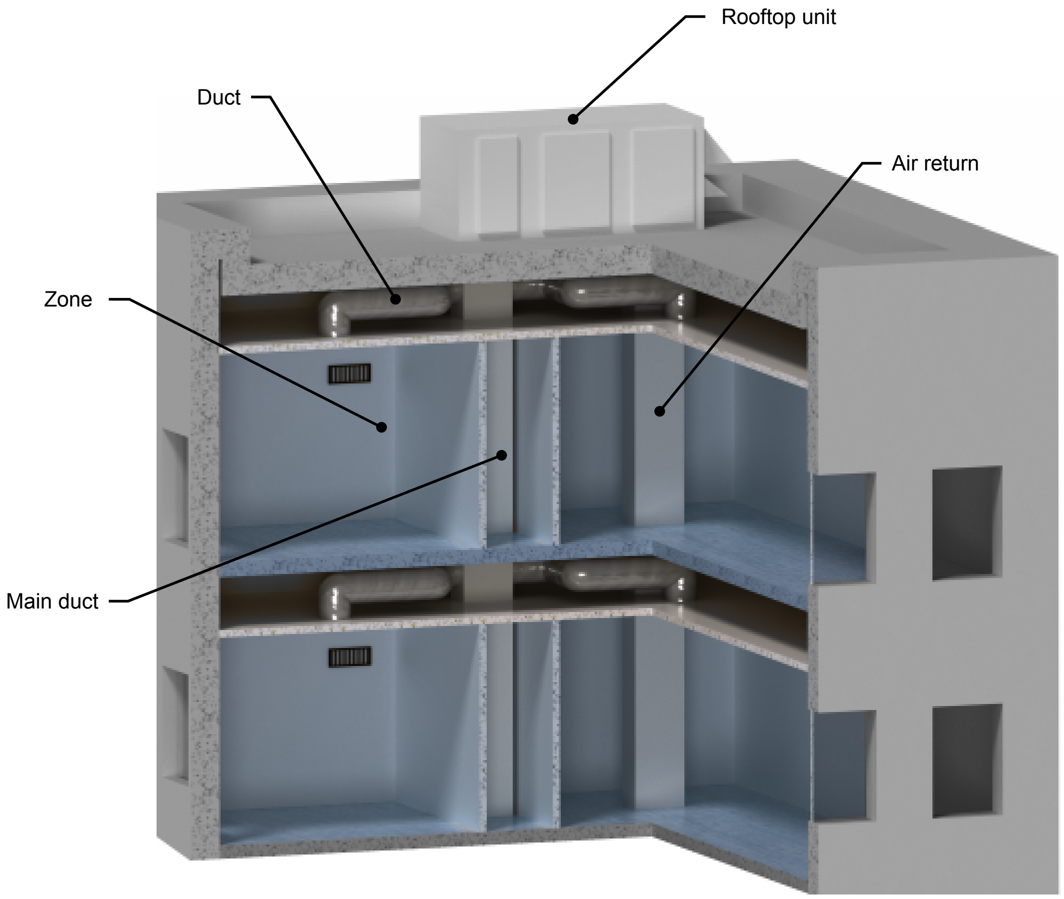

Figure 2. HVAC system.

Air-handling unit

Before diving into a maze of ducts and control devices, it is important to study the heart of most HVAC systems: the air-handling unit. The air-handling unit is responsible for the air supply and air conditioning of a building area controlled by the HVAC system. It includes several components that contribute to air conditioning and distribution. Some of these components are shown in Figure 3.

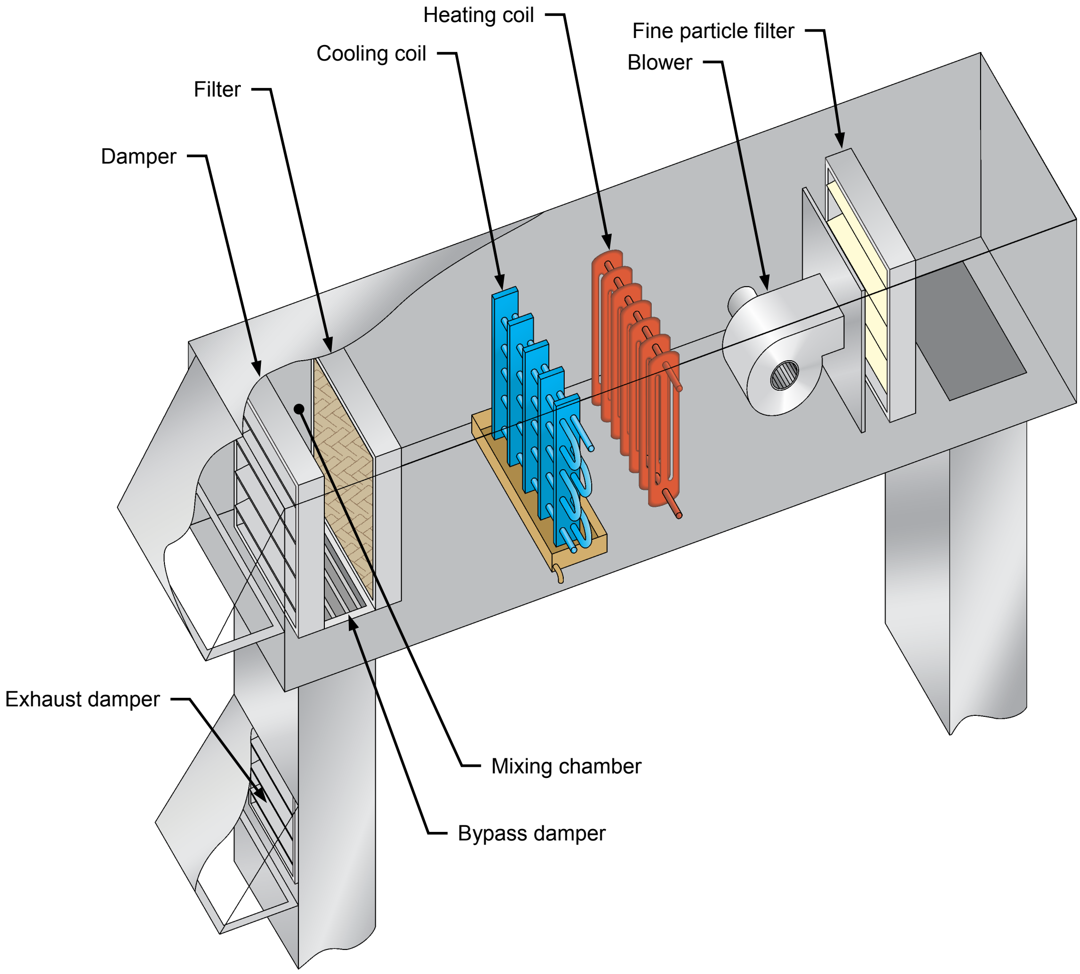

Figure 3. Common air-handling unit components.

At the left of the air-handling unit is an opening that allows fresh air to enter the unit. A damper allows adjustment of the amount of air that enters the unit for conditioning. The space after the damper is the **mixing chamber**. This is where the fresh air is mixed with return air before conditioning. A filter removes undesired particles from the mixed air. After the filtering, the conditioning process begins. Air passes through both a cooling coil and a heating coil. The control system activates the coils according to the signals sent by the control system. After cooling or heating, a humidifier may adjusts air moisture to make it comfortable for the building occupants. Once air is conditioned, a powerful fan blows it into the main duct. This duct supplies air to the secondary ducts, which are connected to each zone in the building.

Figure 3 shows a typical configuration for an air-handling unit. This particular configuration includes a variable speed blower. Reducing the speed of the blower prevents high static pressure from building up in the ducts when several zone dampers are closed. This can occur in a variable air volume systems where the air flow in the ducts may vary according to the demand.

A **zone** is an area where an HVAC system controls and monitors temperature, humidity, pressure, and other parameters. A single HVAC system can control one zone (single-zone system) or multiple zones (multi-zone system). Typically, each zone in an HVAC system contains a thermostat and sometimes a humidistat. Other devices enabling occupants to adjust the different parameters in the zone may be available. Walls, doors, or windows can delimit a zone, but this is not mandatory. In large open areas, zones can be a section of the full area. Conversely, a zone can be a group of rooms for which the parameters will vary together.

Figure 4 and Figure 5 show typical air-handling units for a medium-sized building. Figure 6, Figure 7, Figure 8, and Figure 9 show air-handling unit components, namely an economizer damper, particle filters, a cooling coil, and a blower.

Figure 4. Typical air-handling unit.

Figure 5. Typical air-handling unit.

Figure 6. Dusty economizer damper.

Figure 7. Particle filters.

Figure 8. Cooling coil.

Figure 9. Blower.

Air-handling unit controller

The air-handling unit has its own controller. This controller activates the various components of the unit according to the information it receives from different sensors.

Figure 10 shows an air-handling unit connected to a simplified controller. Figure 11 shows an air-handling unit controller board. The eyes and ears of the controller are the sensors connected to its inputs. Using the information from those sensors, the controller activate the fresh air damper, fan, heating coil, and cooling coil via its outputs. Other types of inputs and outputs may also be available to accommodate different types of installations.

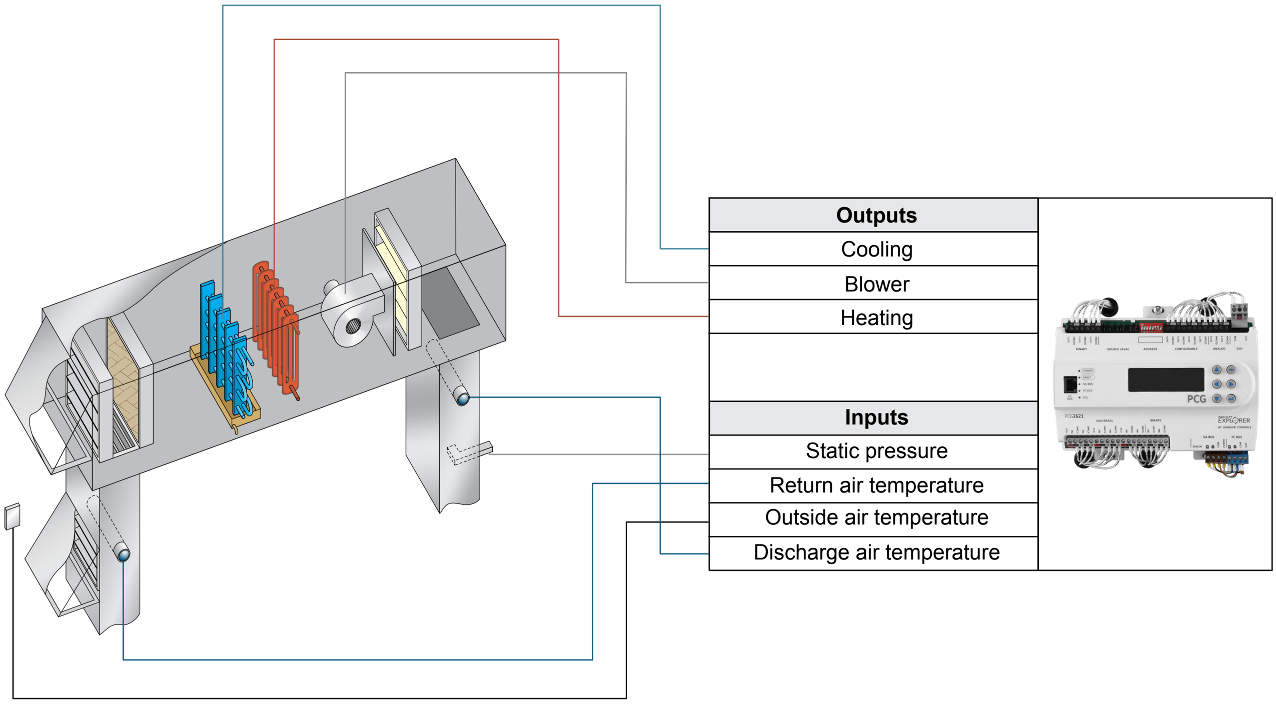

Figure 10. HVAC system.

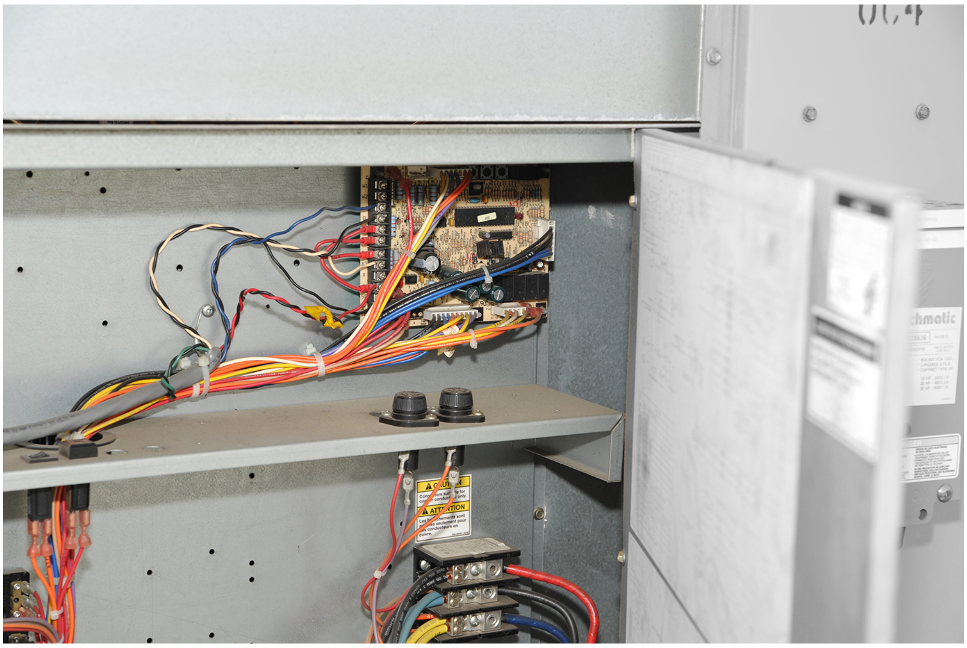

Figure 11. Air-handling unit controller board.

Direct digital control

There are several types of controls for HVAC systems. The choice of the type of controls should always depend on the availability of maintenance and repair expertise. When few trained technicians are available, controls should be simple and reliable. However, when expertise is readily available on site or can be easily contracted (such as for a building in a metropolitan area, for example), using more advanced controls can improve system performance and save energy. One type of advanced controls commonly used in HVAC systems is direct digital control or **DDC**.

When using DDC to control an HVAC system, most of the data in the system is processed using a programmable controller that can be customized for specific needs. This programmable controller is usually accessed using dedicated software that allows operators to monitor and control the system components remotely.

During operation, the programmable controller receives analog and digital signals (e.g., measured data, status alerts) from the different sensors in the system. Then, according to its control logic, the controller sends analog and digital signals to the different controlled devices in the system, instructing them to turn on or off, for example. This process is summarized in Figure 12. Note that DDC-controlled HVAC systems use the same types of sensors as other HVAC systems, the only difference being that the control logic is done via software instead of a preprogrammed controller.

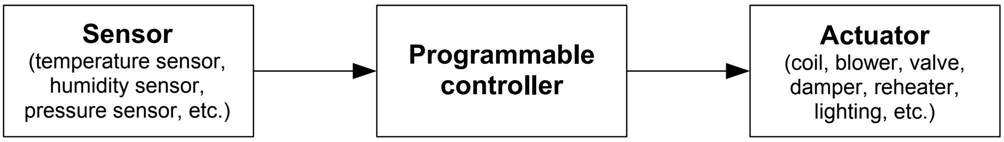

Figure 12. DDC controlled HVAC system operation.

The main advantage of HVAC systems controlled using DDC over other systems is that they are much simpler. This is because all communications in the system are relayed to and by the programmable controller, enabling technicians to easily interact with the system devices and troubleshoot system faults. DDC-controlled HVAC systems also allow better and more efficient control, as well as the ability to record information regarding system operation, making it possible to improve system efficiency and assess system health.

Exercise 1

Familiarization with the Building HVAC Controls Training System

EXERCISE OBJECTIVE

- Configure a computer and software for downloading a program to a programmable controller.
- Implement a simple direct digital control (DDC) on an HVAC system.
- Understand how the controller programming software manages inputs and outputs.
- Familiarize yourself with the commissioning mode of the software and understand how this mode can be used to test an HVAC system.
- Experiment with an SCADA interface.
- Troubleshoot the control transformer.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Building HVAC Controls Training System
- Network architecture
- Programmable controller software

DISCUSSION

Building HVAC Controls Training System

Keeping in mind the overview of an HVAC control system presented earlier, we will look at the training system and correlate the different components in the training system with actual industrial components.

System overview

The Building HVAC Controls Training System is modular and allows the implementation of several DDC configurations. The following modules are required to complete the exercises in this manual: a power source, a transformer, two programmable controllers, a temperature sensor, a supervisory controller, and the HVAC layout. Each of these modules is described below.

The power source and transformer modules provide power to all other modules. The power source provides power from the local ac network to the transformer, supervisory controller, and HVAC layout, while the transformer provides 24 V ac power to the programmable controllers.

The HVAC layout is the heart of the system; it simulates building infrastructure (ducts, sensors, heaters, etc.) and allows the variation of environmental variables such as air temperature and pressure. The remaining modules are two identical programmable controller, a temperature sensor, and a supervisory controller. Figure 13 shows these modules installed in a workstation.

To simulate the various sensors normally connected to the air-handling unit or controller(s), knobs are available on the HVAC layout. These knobs send input signals to the controllers and simulate parameters such as temperature, air pressure, and CO_2 level variations.

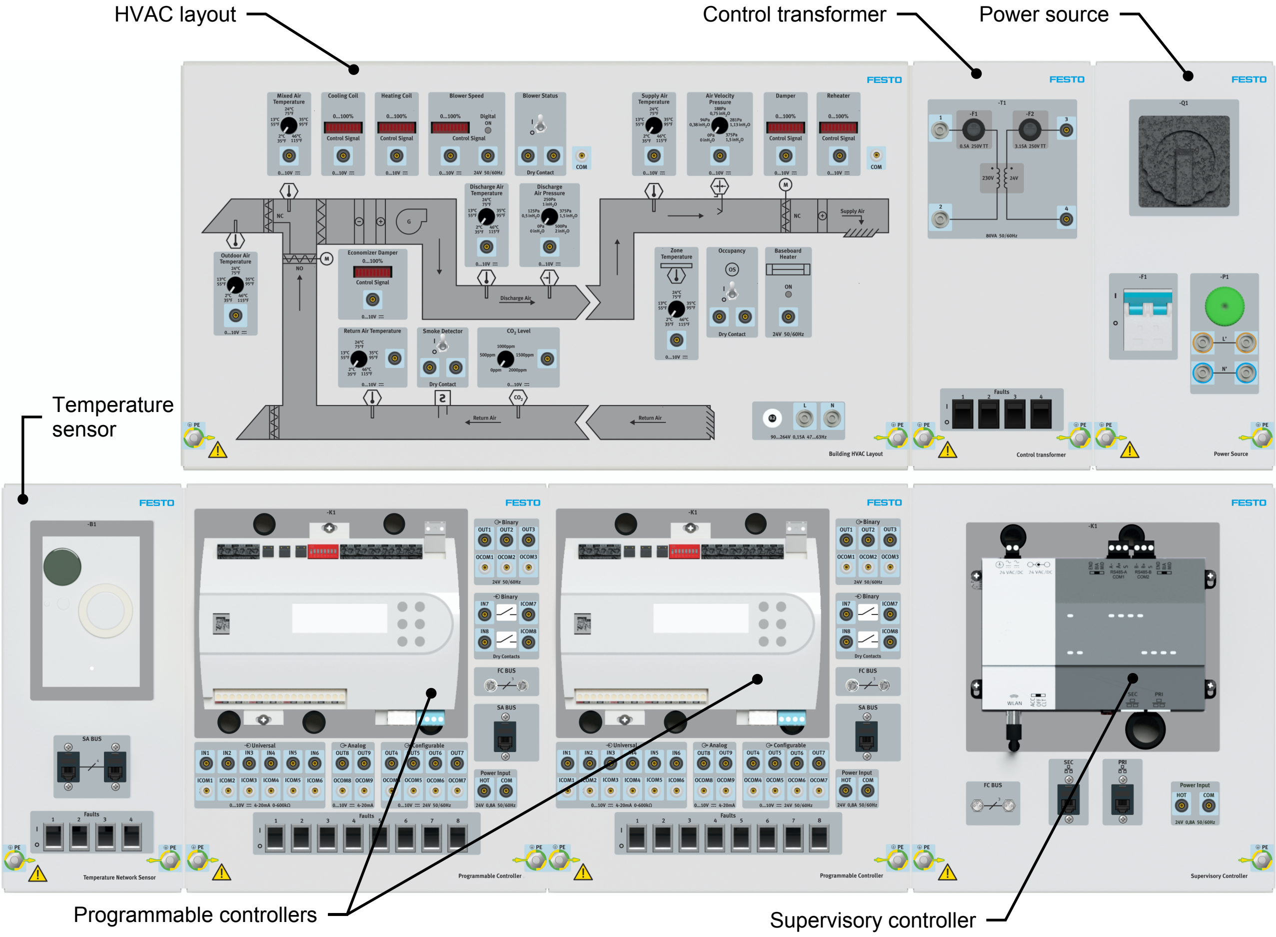

Figure 13. Building HVAC Controls Training System.

Power source

The power source module connects to a standard wall outlet to provide power to the other modules of the system. The voltage output of the power source depends on the local ac power network voltage. Figure 14 shows a power source rated for a 230 V ac power network.

A thermal-magnetic circuit breaker provides overcurrent and short-circuit protection. If the intensity of the current flowing from the power source ever reaches a value greater than the breaker current rating for a certain length of time, the circuit breaker opens the circuit, thus preventing damage to the power source and other equipment. To turn power back on, set the breaker disconnect switch to the I position and turn the main power switch on.

When the power source module is on, power is available through the L and N jacks. Use the provided 4 mm test leads to connect the power source to the other devices.

⚠ CAUTION

Always verify the power specification of a module before connecting it to the power source.

⚠ CAUTION

To reduce the risk of electrical shock in case of malfunction, always connect the ground (green and yellow) terminals of each module in series with the ground terminals of the power source.

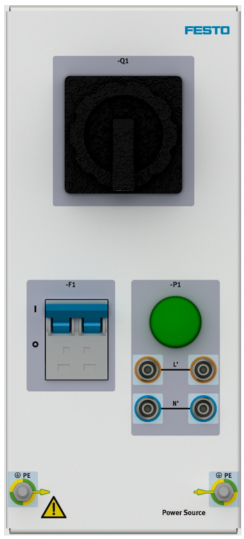

Figure 14. Power source module.

Control transformer

The control transformer module (Figure 15) decreases the line voltage from the power source down to a voltage of 24 V, which is required by several modules of the training system. To obtain the required voltage at the secondary winding, be sure to connect the primary winding of transformer to a power supply that match the control transformer specifications.

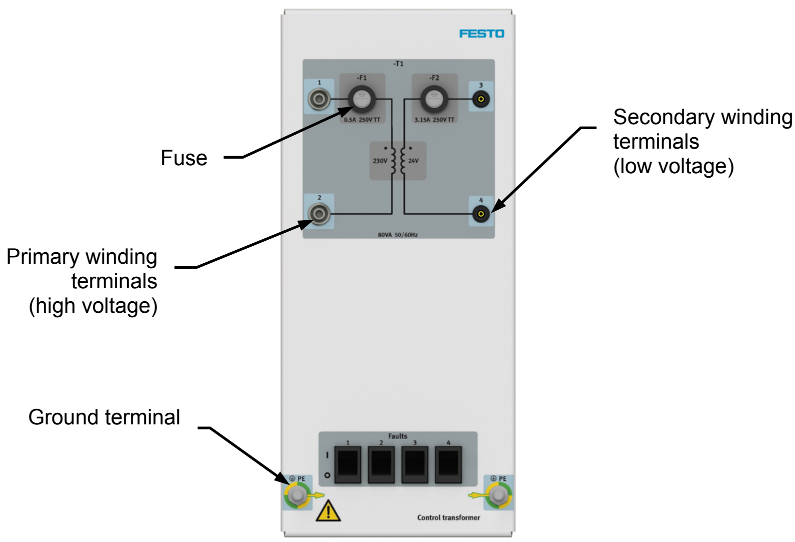

Figure 15. Control transformer module (230 V version).

CAUTION

Never apply more than the rated voltage to the transformer terminals.

The connections to the primary winding of the control transformer are made through 4 mm test leads (high voltage), and the connections to the secondary winding are made through 2 mm test leads (low voltage). Fuses protect the primary and secondary windings.

This module is also equipped with four fault switches and two ground terminals.

The faults for the control transformer module are listed below:

Fault 1: The 0 V terminal on the primary windings is in open circuit.
Fault 2: Dummy fault (this fault switch has no effect)
Fault 3: The 0 V terminal on the secondary windings is in open circuit.
Fault 4: The 24 V terminal on the secondary windings is in open circuit.

Programmable controller

The main distinguishing feature of a DDC HVAC system in comparison to a “classic” HVAC system is the type of controller it uses. The programmable controller shown in Figure 16 is a typical controller found in DDC systems. It has different types of inputs. These inputs receive signals from external devices such as sensors. The controller treats these signals according to the programmed logic, then sends signals to the appropriate devices connected to the controller outputs.

The programmable controllers are general purpose controllers. Each device has the same hardware, but can be programmed for a specific task. For example, a controller can be programmed to control a zone in a building, while another controller of the same type can be programmed to control an air-handling unit. This is one of the great advantage of programmable controllers, over HVAC controllers which have a fix logic and can only be configured.

The programmable controller module must be powered using a 24 V ac source, provided by the secondary windings of the control transformer module.

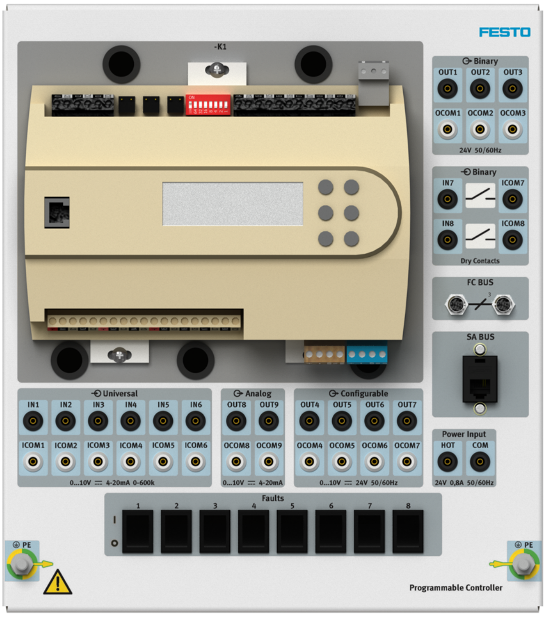

Figure 16. Programmable controller module.

The programmable controller module has six universal inputs, two binary inputs, two analog outputs, three binary outputs, and four configurable outputs. The logic of the controller determines how the inputs and outputs are used. The general characteristics of the inputs and outputs are given in Table 1.

A sensor/actuator bus (SA bus) and a field controller bus (FC bus) are also available on the controller. Both require a special cable for connection. The SA bus is used for connection to sensors such as a temperature sensor. The FC bus, on the other hand, is used for connection to a supervisory controller, allowing commissioning or programming using a computer.

The programmable controller module is also equipped with eight fault switches and two ground terminals.

Table 1. Programmable controller inputs and outputs.

Type of input/output	Quantity	Description
Universal input	6	Can be used either as an analog input or a binary input. When used as an analog input, the following modes are available: • voltage mode (0-10 V dc) • current mode (4-20 mA) • resistive mode (0-2 kΩ)
Binary input	2	Can be used as a dry contact in maintained mode or as a pulse counter
Analog output	2	Two modes are available for an analog output: • voltage mode (0-10 V dc) • current mode (4-20 mA)
Binary output	3	24 V ac triac
Configurable output	4	Can be used either as an analog output (0-10 V dc) or as a binary output (24 V ac triac)

The faults for the programmable controller modules are listed below:

Fault 1: Configurable output 5 (OUT5) is in open circuit.
Fault 2: Short-circuit between binary input 8 (IN8) and its common terminal (ICOM8)
Fault 3: Cancels Fault 8
Fault 4: Analog output 9 (OUT9) is in open circuit.
Fault 5: Universal input 1 (IN1) is in open circuit.
Fault 6: Binary input 7 (IN7) is in open circuit.
Fault 7: Short-circuit between universal input 3 (IN3) and its common terminal (ICOM3)
Fault 8: Binary output 1 (OUT1) is in open circuit.

Temperature sensor

The temperature sensor module shown in Figure 17 is usually networked with similar sensors to provide temperature information to the building controller(s). It is also used to adjust the temperature set point. Although this sensor is equipped with an internal temperature sensor, it is only used in this manual to send set point information to a controller. The temperature is provided to the controller via the HVAC layout. For this reason, only the terminals required for powering the sensor and for set point information are available. The wiring of this sensor is done using special cables with RJ12 connectors.

The temperature sensor module is also equipped with four fault switches and two ground terminals.

Figure 17. Temperature sensor module.

The faults for the temperature sensor module are listed below:

Fault 1: Dummy fault (this fault switch has no effect)
Fault 2: The + terminal is in open circuit.
Fault 3: The - terminal is in open circuit.
Fault 4: The COM terminal is in open circuit.

Supervisory controller

The supervisory controller shown in Figure 19 can be used to access the configuration and status of the controller(s) from a remote computer. This type of device is typically used by technicians to troubleshoot HVAC systems (using a laptop computer, for example). In the case of the supervisory controller shown below, any device connected to the controller can access a SCADA interface via a web browser (Figure 18).

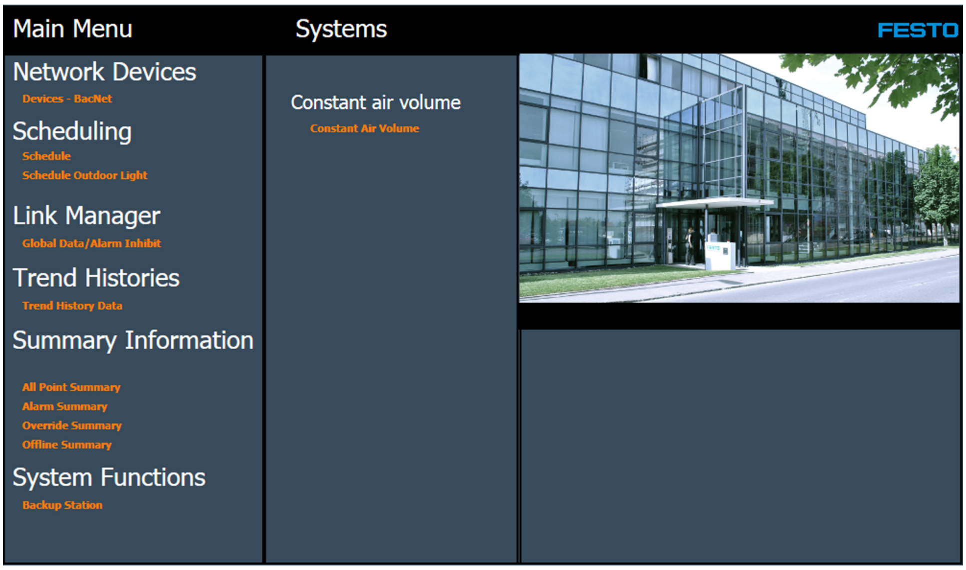

Figure 18. SCADA interface main window.

The supervisory controller module must be powered using the local ac power network voltage, obtained from the power source module. The supervisory controller has M8 connectors to connect it to devices like programmable controllers via an FC bus.

Figure 19. Supervisory controller module.

HVAC layout

The HVAC layout of the Building HVAC Controls Training System represents the infrastructure of a building to which the programmable controller(s) connect. The faceplate of this module can be divided into two regions, as shown in Figure 20.

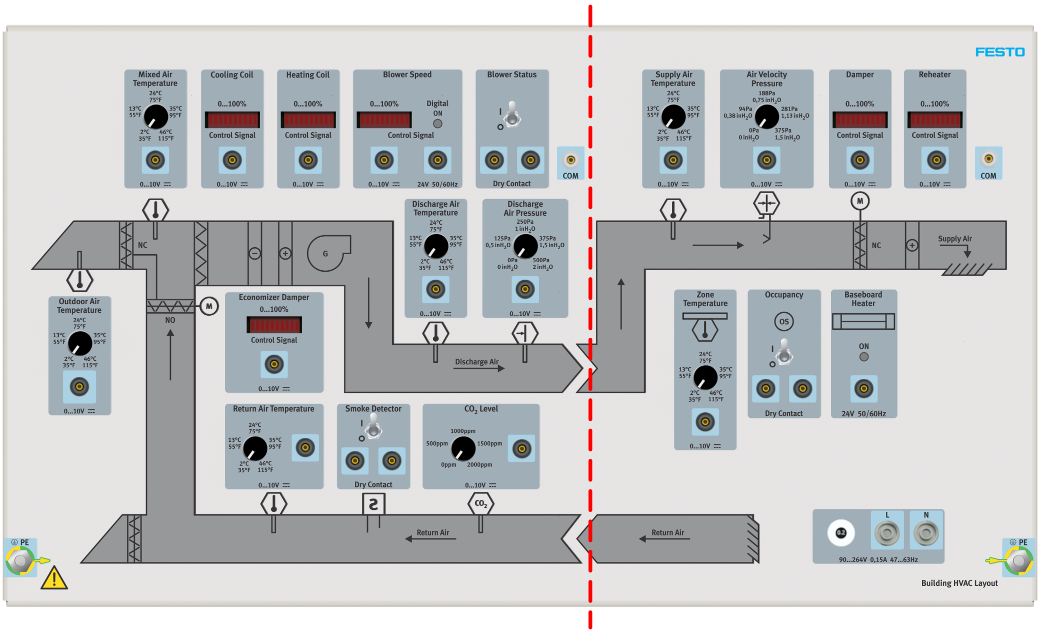

Figure 20. HVAC layout.

The first section represents the air-handling unit and the various temperature and pressure sensors. Buttons and connectors related to a particular device or section of the diagram are usually located close to that device or section. For example, the mixed air temperature button is located close to the representation of the temperature sensor on the faceplate. Adjusting the different buttons allows you to simulate the output signals sent by the different sensors normally available in a building HVAC system. 2 mm leads relay the output signals from the simulated sensors to the controller module.

Figure 21 shows the components in the first section of the HVAC layout, while Table 2 and Table 3 list the functions of the various terminals, switches, and buttons. Further information regarding the various components of the HVAC layout is provided as required by the exercises in this manual.

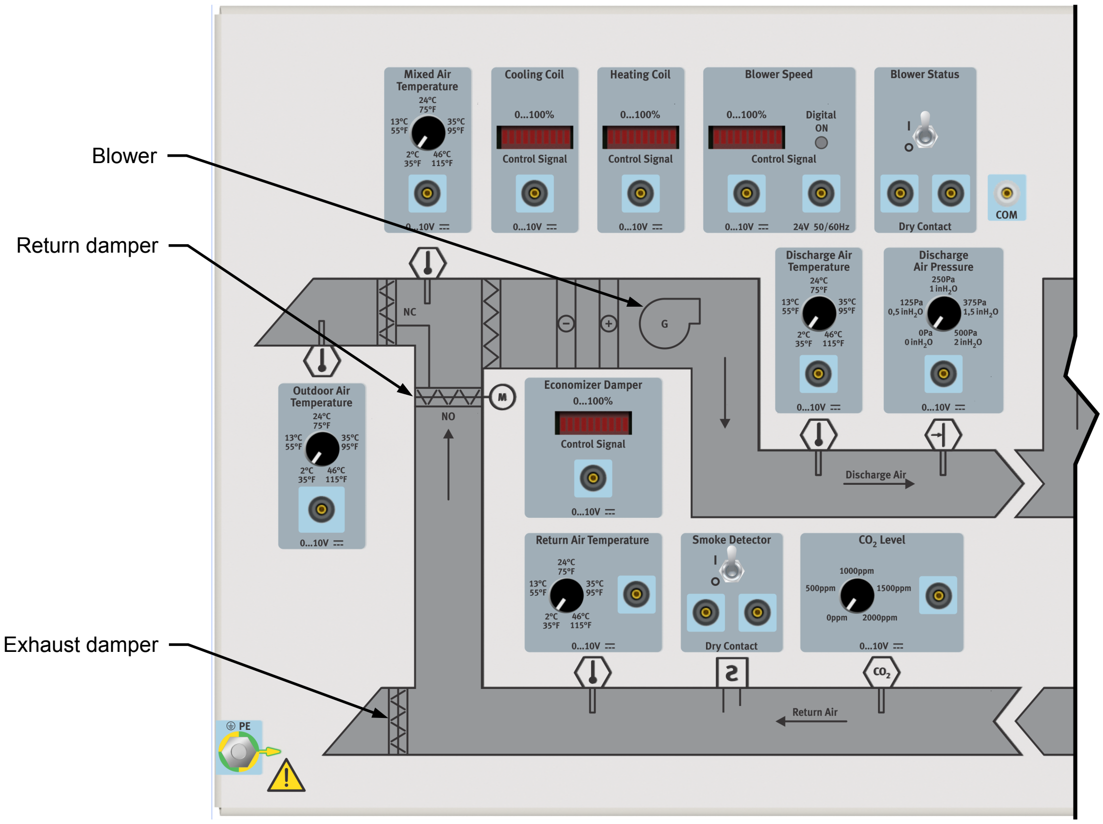

Figure 21. HVAC layout – Air-handling unit section.

Table 2. HVAC layout – Air-handling unit section terminals.

Terminal identification	Description
Mixed Air Temperature	0-10 V dc analog output for the simulated temperature sensor of the mixed air
Cooling Coil	Input for the 0-10 V dc control signal of the cooling coil. A bar meter represents the level of the control signal. 10 bars indicate maximum cooling, while no bar indicates no cooling.
Heating Coil	Input for the 0-10 V dc control signal of the heating coil. A bar meter represents the level of the control signal. 10 bars indicate maximum heating, while no bar indicates no heating.
Blower Speed (analog)	Input for the 0-10 V dc control signal of the blower. A bar meter represents the level of the control signal. 10 bars indicate that the blower is running at full speed, while no bar indicates that the blower is stopped.
Blower Speed (digital)	Digital input (24 V ac) for the control signal of the blower. A green LED indicates when the blower is on.
Blower Status	Dry contacts indicating the blower status. If the switch is set to the I position, the contact is closed. If the switch is set to the O position, the contact is open.
COM	Common terminal
Economizer Damper	Input for the 0-10 V dc control signal of the economizer damper. A bar meter represents the level of the control signal. 10 bars indicate that the normally closed (NC) damper is fully open, while no bar indicates that the damper is fully closed. Note that the normally open (NO) return damper closes as the signal level increases because the two dampers are mechanically linked and operate simultaneously.
Discharge Air Temperature	0-10 V dc analog output for the simulated temperature sensor of the air supply
Discharge Air Pressure	0-10 V dc analog output for the simulated pressure sensor of the air supply
Outdoor Air Temperature	0-10 V dc analog output for the simulated outdoor air temperature sensor
Return Air Temperature	0-10 V dc analog output for the simulated temperature sensor of the return air
Smoke Detector	Dry contacts indicating the status of the smoke detector. If the switch is set to the I position, the contact is closed. If the switch is set to the O position, the contact is open.
CO_2 Level	0-10 V dc analog output for the simulated CO_2 level sensor

Table 3. HVAC layout – Air-handling unit section switches and buttons.

Switch/button identification	Description
Mixed Air Temperature	Sets the simulated air temperature in the mixed air section
Blower Status	Simulates a sensor indicating the blower status. Setting it to I indicates that the blower is running, while setting it to O indicates that the blower is stopped.
Discharge Air Temperature	Sets the simulated air temperature in the supply duct
Discharge Air Pressure	Sets the simulated air pressure in the supply duct
Outdoor Air Temperature	Sets the simulated outdoor air temperature
Return Air Temperature	Sets the simulated air temperature in the return duct
Smoke Detector	Simulates a smoke detector. Setting it to I indicates that there is smoke, while setting it to O indicates that there is no smoke.
CO_2 Level	Simulates the CO_2 level sensor output

The second section of the HVAC layout represents the infrastructure of the building, including the zone damper, reheater, zone sensors, and baseboard heater. LEDs and bar meters indicate the status of the different elements. 2 mm leads relay the output signals from the simulated sensors to the controller module

Figure 22 shows the layout of the building and identifies the main components, while Table 4 and Table 5 list the functions of the various terminals, switches, and buttons.

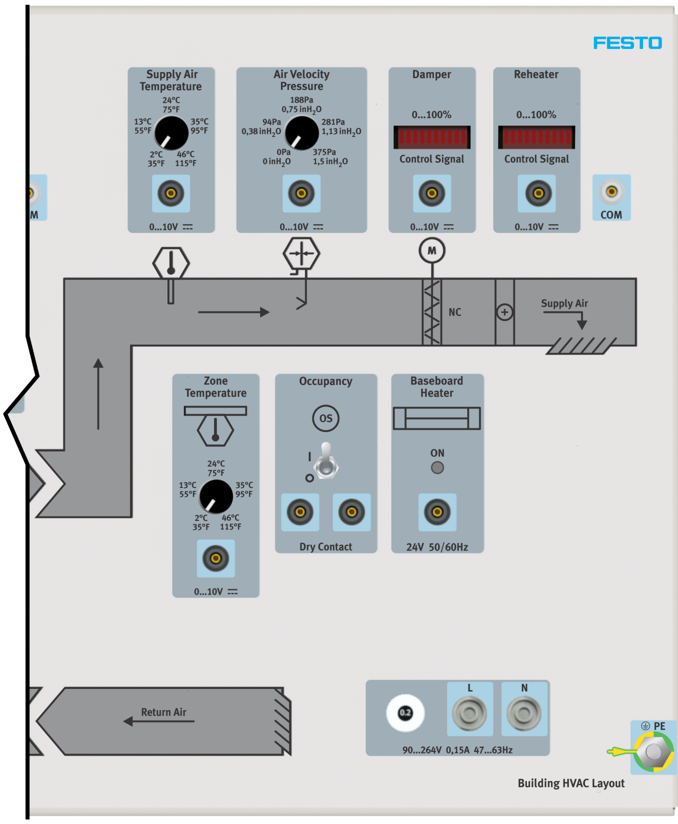

Figure 22. HVAC layout – zone section.

Table 4. HVAC layout – Zone section terminals.

Terminal identification	Description
Supply Air Temperature	0-10 V dc analog output for the simulated supply air temperature sensor
Air Velocity Pressure	0-10 V dc analog output for the simulated air velocity pressure sensor
Zone Humidity (humidity control add-on only, see Exercise 4)	0-10 V dc analog output for the simulated zone humidity sensor
Damper	Input for the 0-10 V dc control signal of the damper. A bar meter represents the level of the control signal. 10 bars indicate that the damper is fully open, while no bar indicates that the damper is fully closed.
Humidifier (humidity control add-on only, see Exercise 4)	Input for the 0-10 V dc control signal of the humidifier. A bar meter represents the level of the control signal. 10 bars indicate that the humidifier is in full operation, while no bar indicates that the humidifier is off.
Reheater	Input for the 0-10 V dc control signal of the reheater. A bar meter represents the level of the control signal. 10 bars indicate maximum heating, while no bar indicates no heating.
COM	Common terminal
Zone Temperature	0-10 V dc analog output for the simulated zone temperature sensor
Occupancy	Dry contacts indicating the occupancy. If the switch is set to the I position, the contact is closed, thereby indicating that the zone is occupied. If the switch is set to the O position, the contact is open, thereby indicating that the zone is unoccupied.
Baseboard Heater	Digital input (24 V ac) for the control signal for the baseboard heater. A green LED indicates that the baseboard heater is on.
L	Input for the line connector from the power source
N	Input for the neutral connector from the power source

Table 5. HVAC layout – Air-handling unit section switches and buttons.

Switch/button identification	Description
Supply Air Temperature	Sets the simulated supply air temperature
Air Velocity Pressure	Sets the simulated air velocity pressure (0 Pa to 375 Pa or 0 inH_2O to 1.5 inH_2O)
Zone Humidity (humidity control add-on only, see Exercise 4)	Sets the simulated relative humidity in the zone
Zone Temperature	Sets the simulated temperature in the zone
Occupancy	Simulates an occupancy sensor. Setting it to I indicates that the zone is occupied, while setting it to O indicates that the zone is unoccupied.

Network architecture

In a typical HVAC system, several devices such as sensors and controllers are networked. Due to the variety of devices found in an HVAC system, different parts of the network use different communication protocols such as Ethernet, TCP/IP, BACnet, LonWorks, etc. Figure 23 shows a simple network using components similar to the devices of the Building HVAC Controls Training System. In this case, devices communicate over an SA bus or FC bus using the BACnet MS/TP protocol. Other communication protocols such as LonWorks and Modbus are also common in HVAC network.

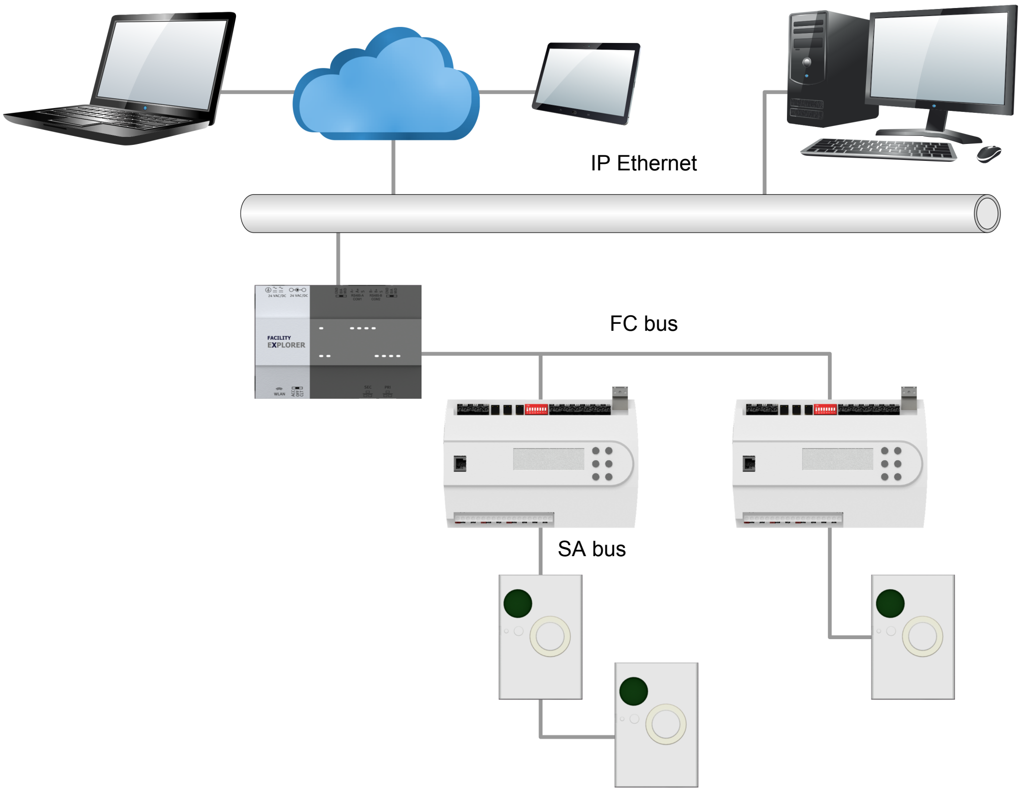

Figure 23. Typical HVAC network architecture (BACnet MS/TP communication bus).

BACnet MS/TP

BACnet is a standardized protocol[1] that establish communication mechanisms for building automation and control systems. BACnet stands for Building Automation and Control Network. The BACnet protocol architecture is based on the Open Systems Interconnection model (OSI), which divides the protocol into layers. Each layer is responsible for a series of communication functions. Figure 24 shows the layered architecture defined by the BACnet protocol.

The BACnet application layer defines several standard objects and services to ease communication between devices. Examples of BACnet objects are: calendar, access user, event log, schedule, timer, etc.

The network layer is responsible of the communication between BACnet networks. This allows two networks to communicate with each other, even if each network use a different data link technology.

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[1] ASHRAE/ANSI Standard 135

The data link and physical layers overlap each other for some protocols. Note that only some of the supported protocols are shown in Figure 24. The data link and physical layers includes protocols and technologies such as Ethernet, Point-to-Point, BACnet/IP, ZigBee, and LonTalk etc.

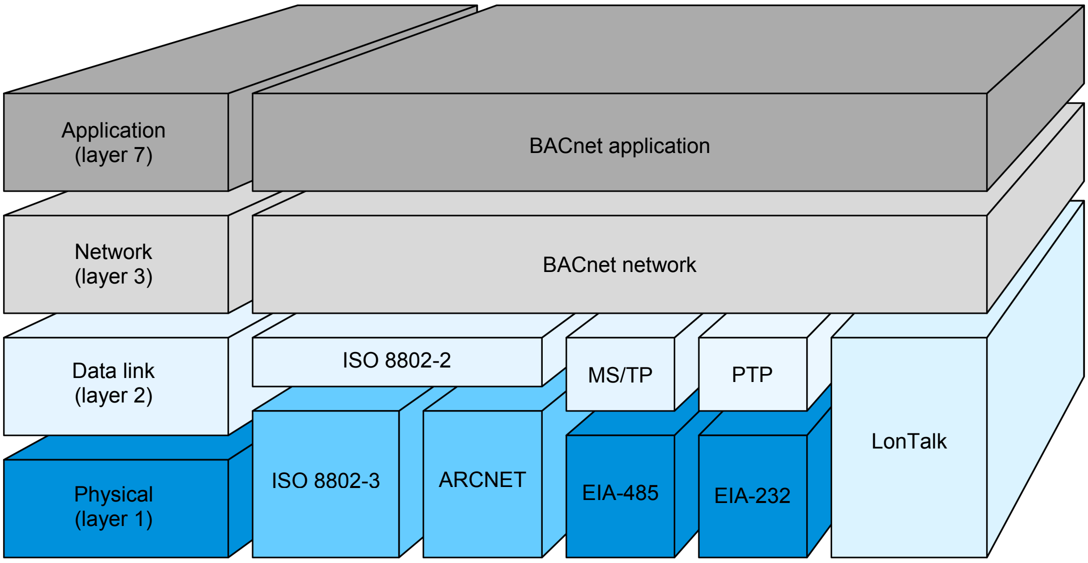

Figure 24. BACnet layered architecture.

BACnet MS/TP is what is used by the devices of the Building HVAC Controls Training System. MS/TP stands for Master-Slave/Token-Passing, it is the protocol used over the data link layer.

Programmable controller software

When a DDC system is used in an HVAC installation, one or more programmable controllers are required. As their name implies, these controllers must be programmed in order to be used. For this purpose, manufacturers provide software that allows the accomplishment of several tasks, such as programming and configuring the controller.

The software used to program the controller in the Building HVAC Controls Training System is PCT, which stands for Programmable Controller Tool. Figure 25 shows a screenshot of a typical window of the PCT software. As you can see, a lot of information is displayed onscreen, and a lot of other information, options, and data are available from various tables and windows. Mastering the software requires many hours of study, however, simply learning how to navigate through the menus and how to use the software for commissioning and troubleshooting is enough for the purposes of this course.

Figure 25 shows the PCT software with an opened application (in this software, an application is a program designed for a controller). In this screenshot, the main window is opened on the control tab. This tab contains all basic information for the control scheme of the system. On the left-hand side of the screen is a list of the various inputs available on the controller. Each input is associated with several attributes. In the middle of the screen is a list of the different set points, states, and controls associated with the inputs (and outputs). Finally, on the right-hand side of the screen is a list of the various outputs available on the controller.

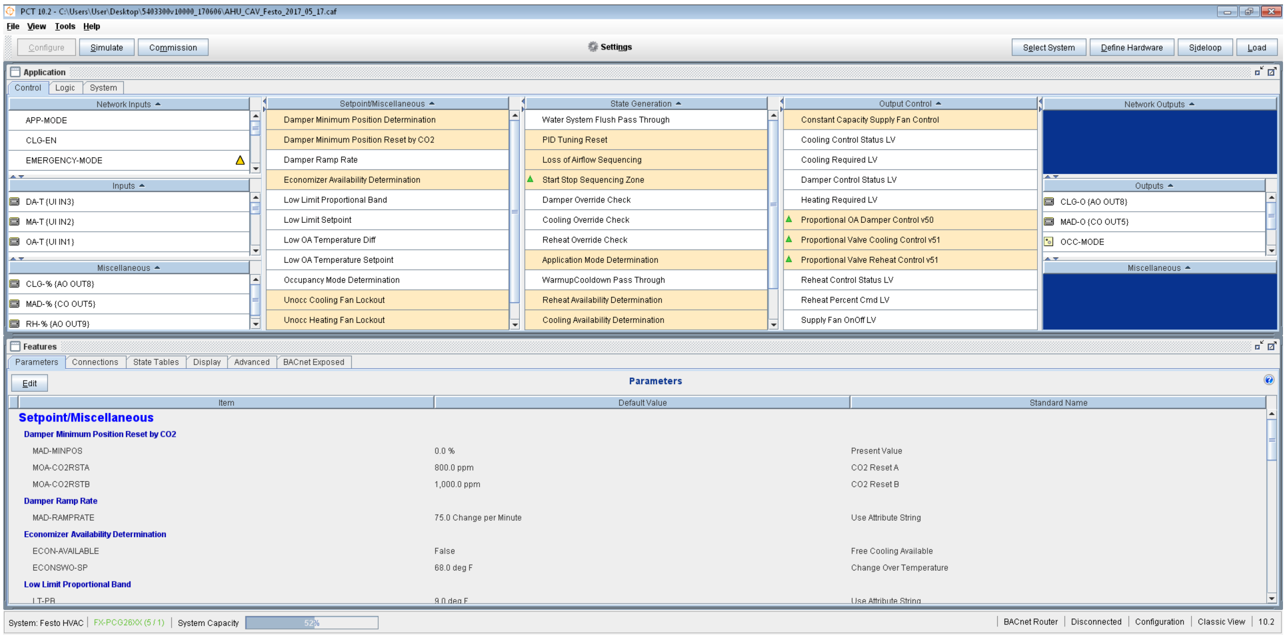

Figure 25. Programmable controller software (PCT from Johnson Controls©).

Even without being readily familiar with the logic of the controller, the control tab of the application gives a lot of easily understandable information. The most useful information for the moment is the list of all inputs and outputs available on the controller, as well as the short description of their function in the actual program.

As you become more and more familiar with the software, you will learn several tricks and tools that will help you commission and troubleshoot systems, as well as help you understand the complexity of HVAC process control.

Figure 26. View on the air-handling unit of a local train in Switzerland[2].

[2] Photo by Fabian Grunder (FabiBerg), April 9, 2006 via Wikipedia: https://commons.wikimedia.org/wiki/File:THURBO_GTW_2-8_EW-2.JPG. Available under a Creative Commons Attribution-Share Alike 3.0 Unported (CC BY-SA 3.0): https://creativecommons.org/licenses/by-sa/3.0.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
  High-voltage connections. Controller low-voltage connections. Network connections. Input and output connections.
- Loading the program into the controller
  Changing the IP address.
- Testing the controller in the commission mode
- Troubleshooting the control transformer module

PROCEDURE

Set up and connections

This section shows the recommended setup and connections to familiarize yourself with the controllers and components of the Building HVAC Controls Training System.

1. All exercises require most of the modules in the system. Therefore, it is recommended to install all the modules in a workstation and wire only those required in the exercise. Install the modules in a workstation as shown in Figure 27.

Only one of the programmable controllers is used in this exercise. Be sure to make all required connections on the same controller, and none on the other.

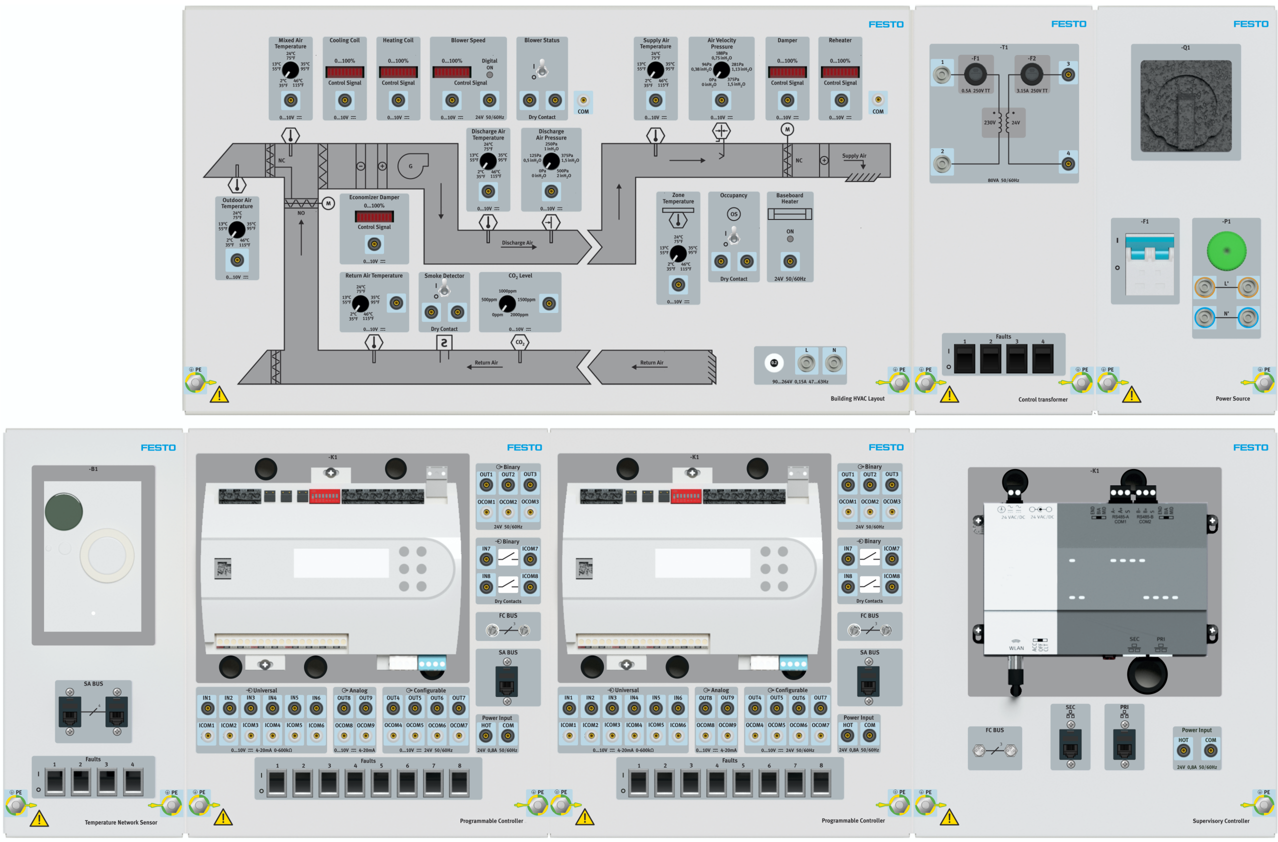

Figure 27. Building HVAC Controls Training System.

2. Make sure the main power switch on the power source is set to the O (off) position, then connect it to an ac power outlet.

3. Make sure the fault switches on all modules are set to the O position.

4. Once the equipment is securely installed in a workstation, you are ready to make the connections. Since the system requires a significant amount of connections, we will proceed by steps in this familiarization exercise to make the wiring process as clear and simple as possible.

High-voltage connections

5. First, we will connect the different devices that require power directly from the ac network (high-voltage connections). Figure 28 shows the connections required to provide power from the local ac network to the control transformer and HVAC layout. Connect these modules using 4 mm leads.

   The control transformer module converts the power it receives from the local ac network to 24 V ac power. Make sure to respect the electrical specifications of the control transformer.

   Connect the ground (green and yellow) terminals of each module in series with the ground terminals of the power source. Grounding connections are shown in green in Figure 28.

   Do not turn the power source on yet.

6. In the following exercises, we will not use figures such as Figure 28 to represent the system connections. Instead, we will use wiring diagrams similar to the one shown in Figure 29. This type of diagram allows connections to be clearly and simply represented, and is close to what is found in the industry. For this reason, it is recommended that you become familiar with it. Take a look at Figure 29 and compare it to Figure 28. Make sure you understand each connection shown in this diagram. Notice that the ground connections are not shown on the wiring diagram and that new connections are shown in blue.

   Table 6 lists the different identifiers used in the wiring diagrams with their corresponding name on the HVAC layout. Most of the time, the identifier is created after the first letter of each word in the name of the component. For example, MAT stands for mixed air temperature.

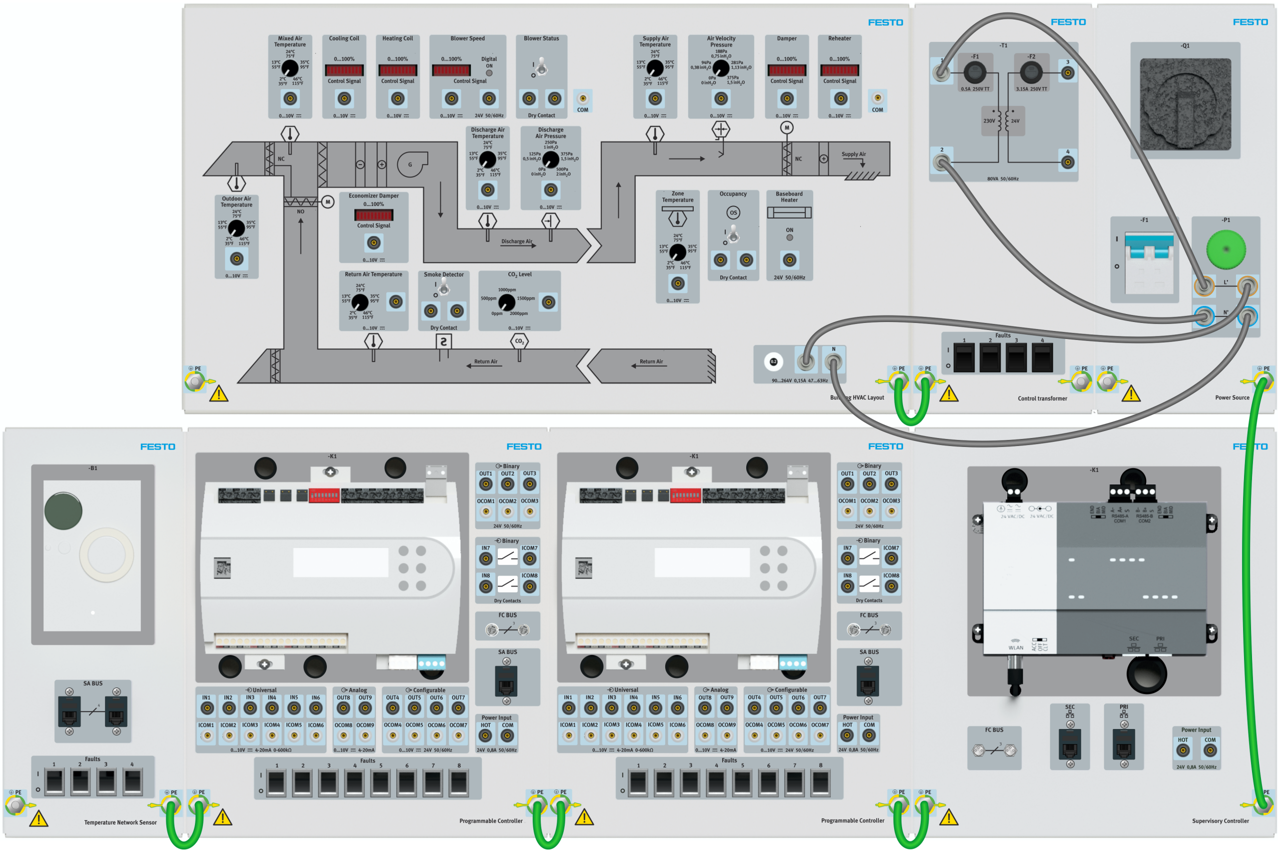

Figure 28. High-voltage connections.

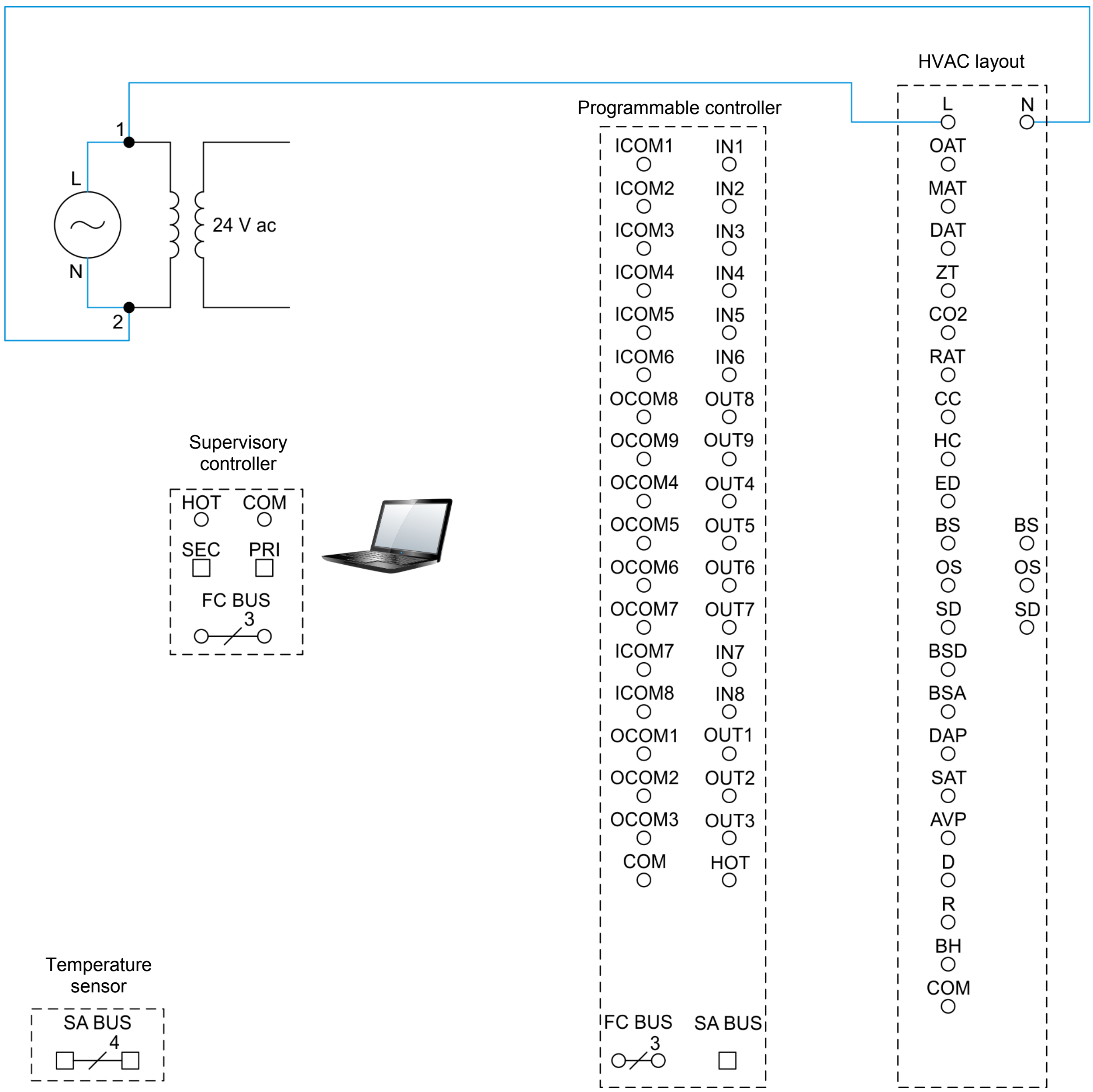

Figure 29. High-voltage connections – wiring diagram.

Table 6. Identifiers in the wiring diagrams and their corresponding name on the HVAC layout.

identifier	Name on the HVAC layout	Name in PCT software
HC	Heating Coil	RH-O
CC	Cooling Coil	CLG-O
BSA	Blower Speed (analog)	SF-O
BSD	Blower Speed (digital)	SF-C
BS	Blower Status	SF-S
COM	COM (common connector)	N/A
D	Damper	DPR-O
R	Reheater	RH-O
ED	Economizer Damper	MAD-O
SD	Smoke Detector	RA-SD
OS	Occupancy	OCC-S
L	L (line connector)	N/A
N	N (neutral connector)	N/A
MAT	Mixed Air Temperature	MA-T
SAT	Supply Air Temperature	DA-T
AVP	Air Velocity Pressure	DA-VP
DAT	Discharge Air Temperature	DA-T
DAP	Discharge Air Pressure	DA1-P
OAT	Outdoor Air Temperature	OA-T
RAT	Return Air Temperature	RA-T
CO2	CO_2 Level	RA-Q
ZT	Zone Temperature	ZN-T
BH	Baseboard Heater	SUPHTG-C

Controller low-voltage connections

7. The supervisory controller and the programmable controllers require 24 V ac power. Use 2 mm leads to connect one of the programmable controllers and the supervisory controller to the transformer, as shown in Figure 30. Figure 31 shows the corresponding wiring diagram.

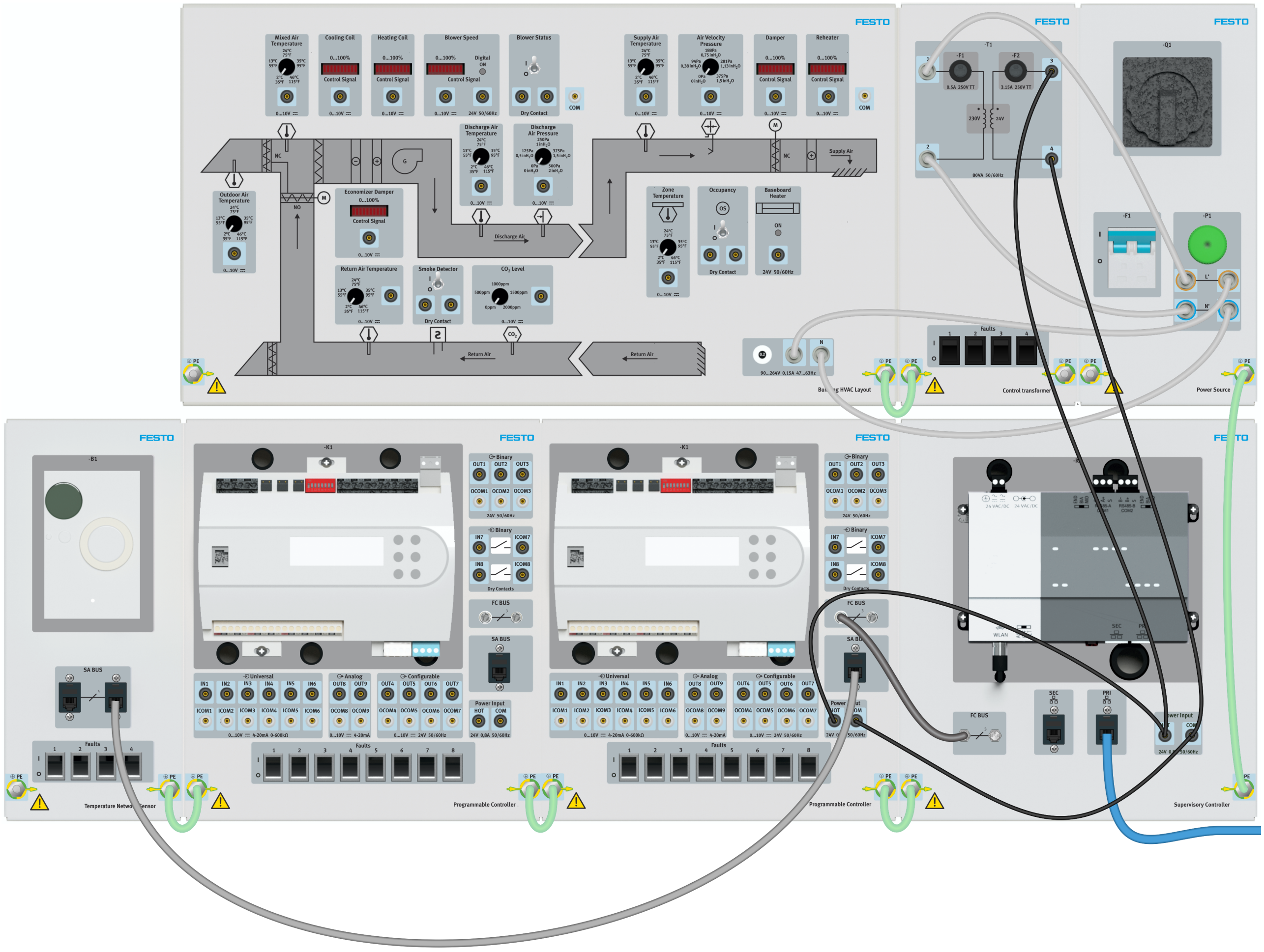

Figure 30. Controller low-voltage connections and network connections.

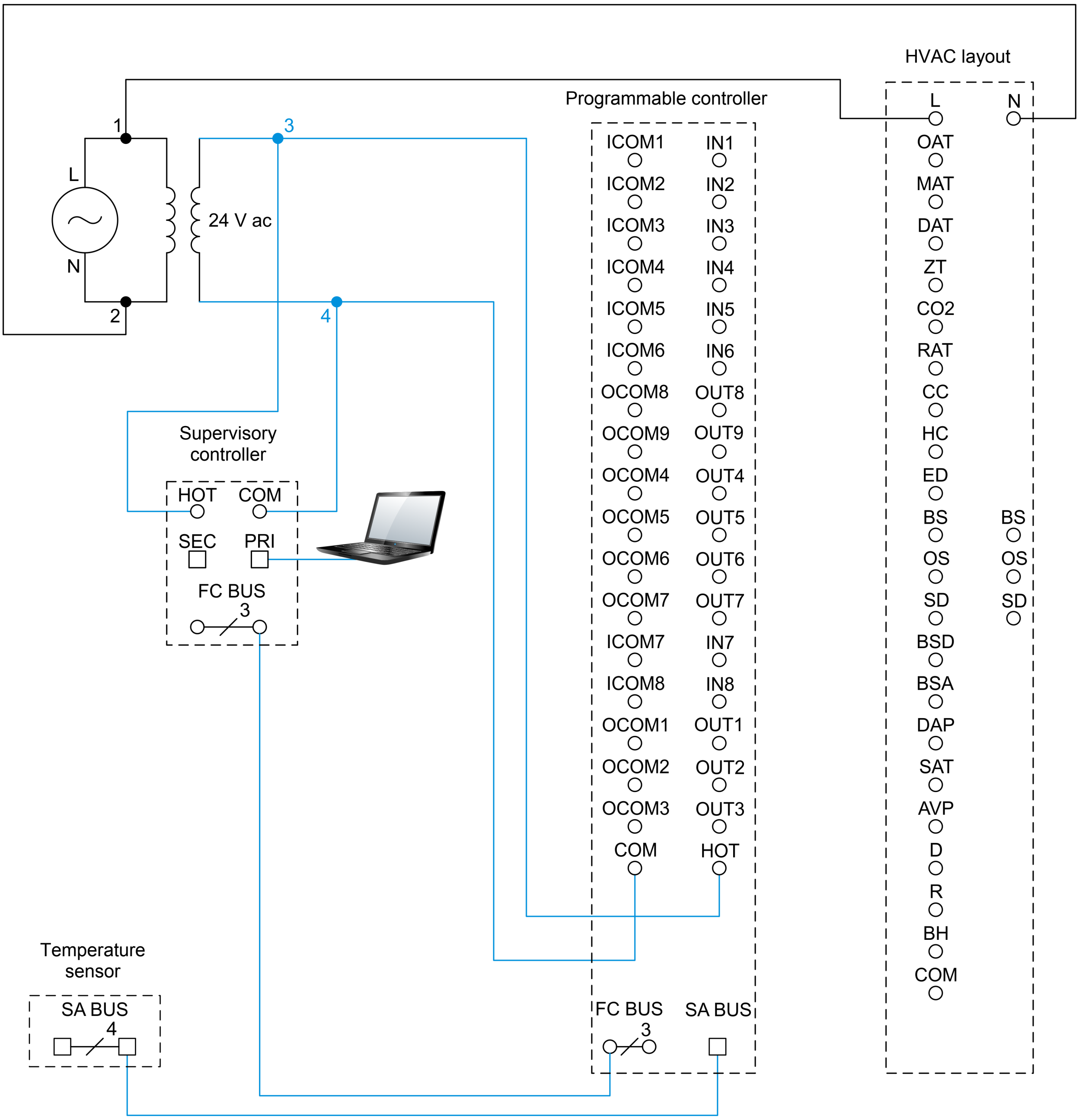

Figure 31. Controller low-voltage connections and network connections – wiring diagram.

Network connections

8. Figure 30 and Figure 31 also show the required network connections. There are three different types of network connections in this setup:

   - an Ethernet connection between the supervisory controller and a computer;
   - a connection between the supervisory controller and the programmable controller. This connection uses the FC bus protocol;
   - a connection between the programmable controller and the temperature sensor. This connection uses the SA bus protocol.

In a typical installation, the FC bus and SA bus network connections require wiring several terminals. However, with this training system, only one cable is required for each network connection. Moreover, a specific type of cable is associated to each network protocol to reduce the risk of errors.

9. Use an Ethernet cable for the Ethernet connection between the supervisory controller and a computer. Connect the Ethernet cable to both the primary (PRI) Ethernet port of the supervisory controller and the Ethernet port of the computer.

Use a cable with RJ12 connectors for the connection, using the SA bus protocol, between the programmable controller and the temperature sensor. Note that 24 V power is provided to the temperature sensor via this network cable.

Use a cable with M8 connectors for the connection, using the FC bus protocol, between the programmable controller and the supervisory controller.

10. Make sure the controller is set as the end of line device (EOL). To do so, remove the cover of the controller and turn <u>on</u> the end of line switch as shown in Figure 32.

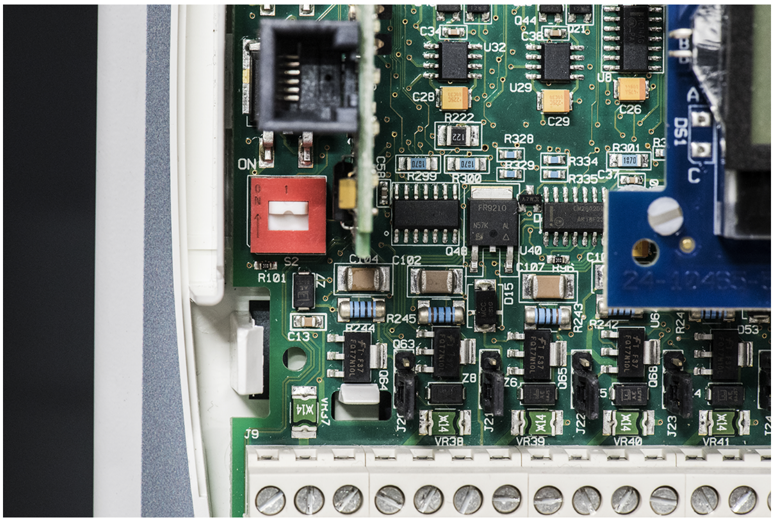

Figure 32. Turn on the end of line switch of the controller.

Input and output connections

In this familiarization exercise, you will connect only some of the inputs and outputs of the programmable controller to the HVAC layout. This does not correspond to a fully functional HVAC setup. Several components such as the economizer damper, the heating coil, and several sensors will not be connected.

11. The programmable controller has different types of inputs and outputs requiring different connection strategies. Use Figure 33 and Figure 34 to connect some of the inputs and outputs of the programmable controller to the HVAC layout. Be careful to connect the modules as shown in the figures. The following exercises cover in detail the different types of inputs and outputs of the controller.

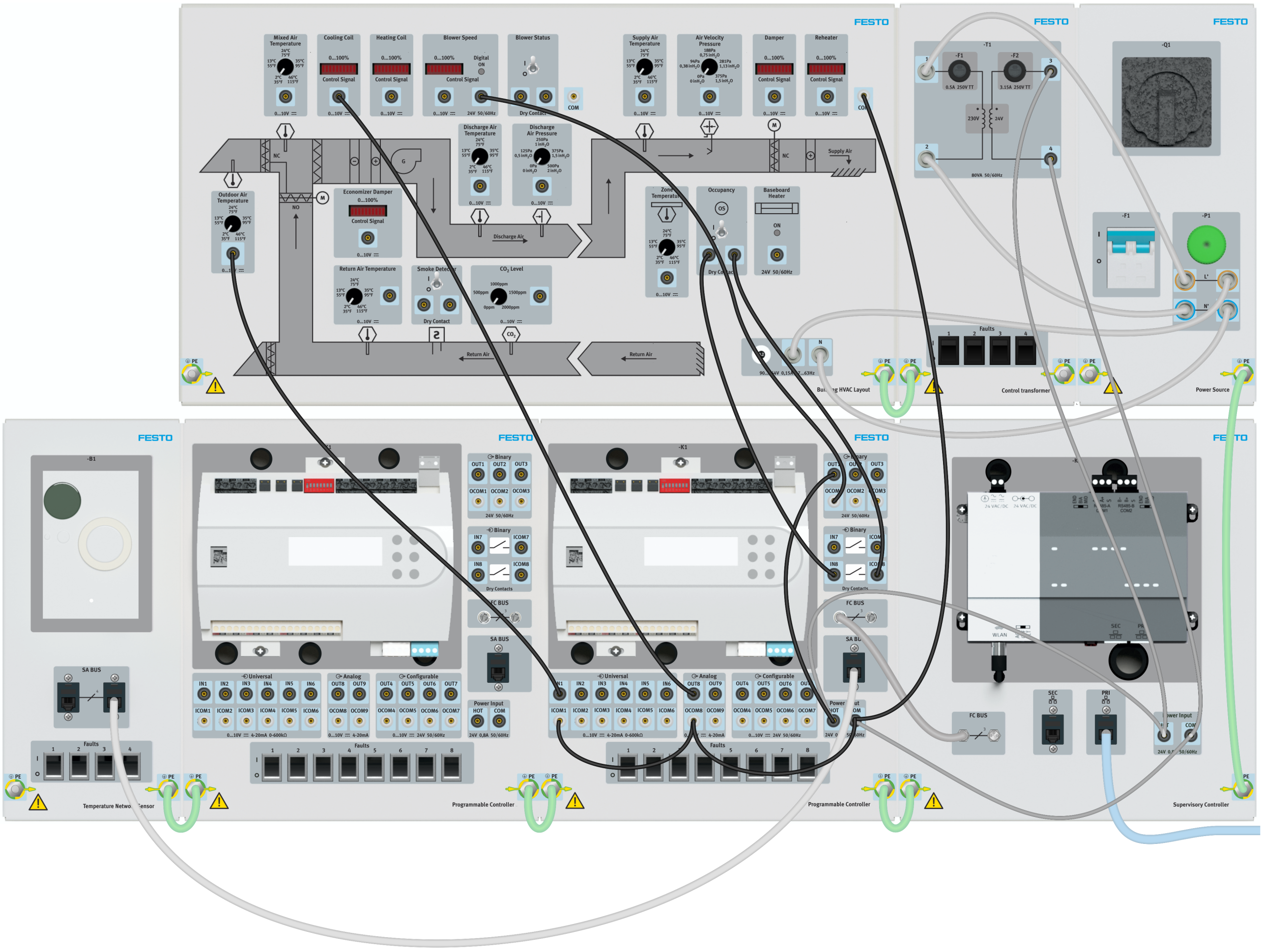

Figure 33. Input and output connections.

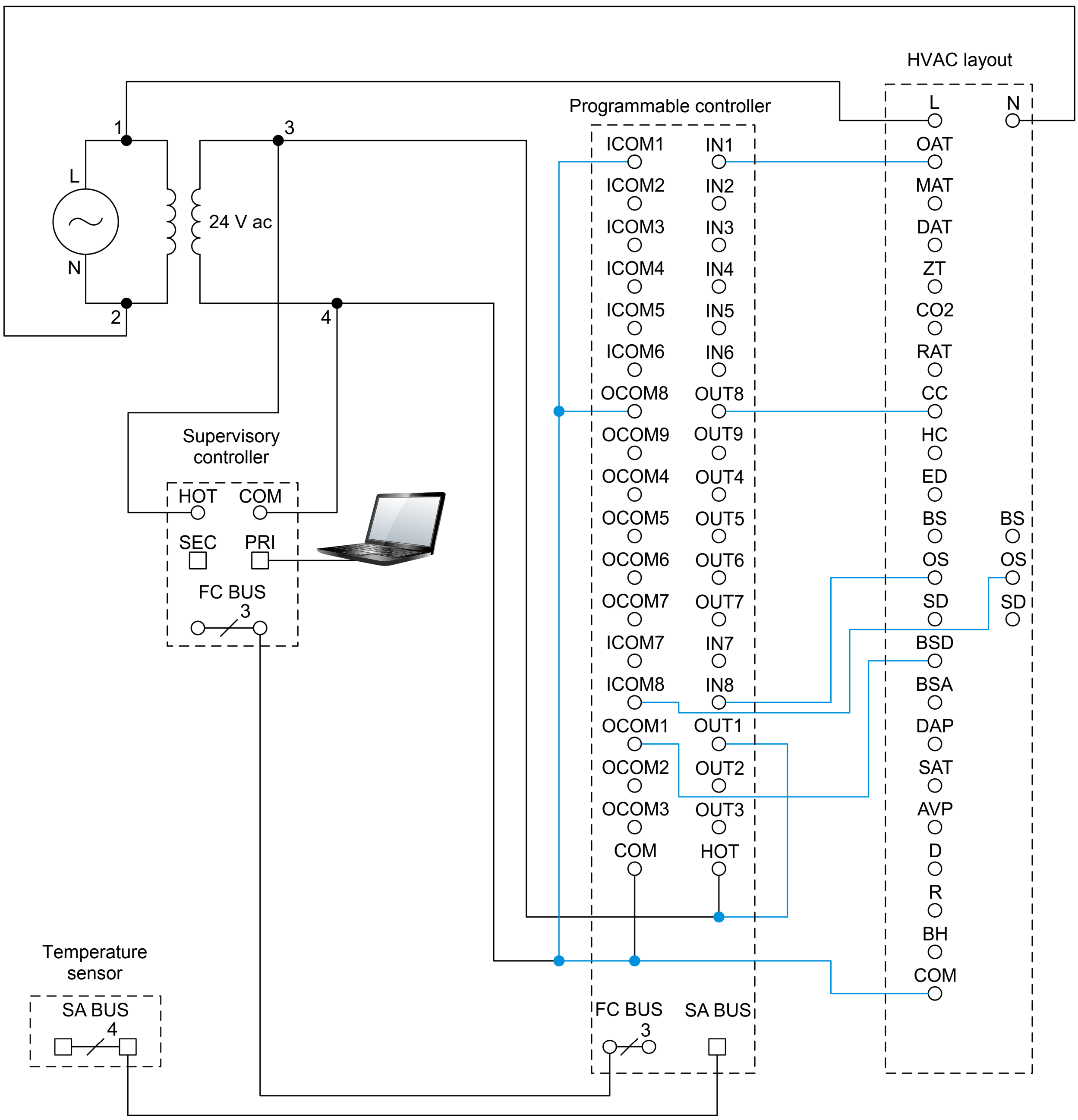

Figure 34. Input and output connections – wiring diagram.

12. When all connections are made, turn the power source on. The controller display, the LEDs on the supervisory controller, and the temperature sensor display should light up.

Loading the program into the controller

13. Before you can use a programmable controller to control the HVAC system of a building, the controller must be properly programmed with respect to the building hardware.

The Building HVAC Controls Training System includes several programs that allow you to use the controllers in different HVAC control schemes. To test your connections, you will download one of these programs into the programmable controller.

To do so, you must first establish a connection between the programmable controller and a computer on which the *Programmable Controller Tool* software is installed.

If the Programmable Controller Tool software is not installed on your computer, install it by running the \FX-PCT\setup.exe file on the Facility Explorer Programmable Controller Tool DVD provided with the system. Note that the installation process may require that you restart your computer several times.

14. To establish a connection between the programmable controller and the computer, configure the computer Ethernet card so that it connects to the supervisory controller. To establish communication, the network adapters of the two devices must operate on the same IP subnetwork. The steps below detail how to configure your computer network card with the proper IP address.

All communications between the computer and the programmable controller(s) transit via the supervisory controller.

Changing the IP address

15. Turn your computer on. If you have a Wi-Fi Internet connection, turn it off.

16. Set the IP address of your PC network adapter to "192.168.1.150" and the Subnet mask to "255.255.255.0". To do so, type “View network connections” in the windows search box and select “View network connections” from the search results. Go to Local Area Connection ► Properties ► Internet Protocol Version 4 (TCP/IPv4) ► Properties. Then, click on Use the following IP address and enter the following values:

IP address: 192.168.1.150

Subnet mask: 255.255.255.0

Default gateway: (leave blank)

17. (Optional) To test if the connection with the supervisory controller works, open the Command Prompt (All Programs ► Accessories ► Command Prompt) and type "ping 192.168.1.149”. This tests the reachability of the controller. If the controller is unreachable, check your connection and network configuration.

18. Once the computer can reach the supervisory controller, start the *Programmable Controller Tool (PCT)* software.

19. In the PCT software, click File ► Open, then select the *AHU_CAV_Festo_revision_date].caf* file from the system’s resource disk.

20. Once the program is open, the software should display a series of tables and tabs similar to what is shown in Figure 35.

You can change the software language from Settings ▶ Localization.

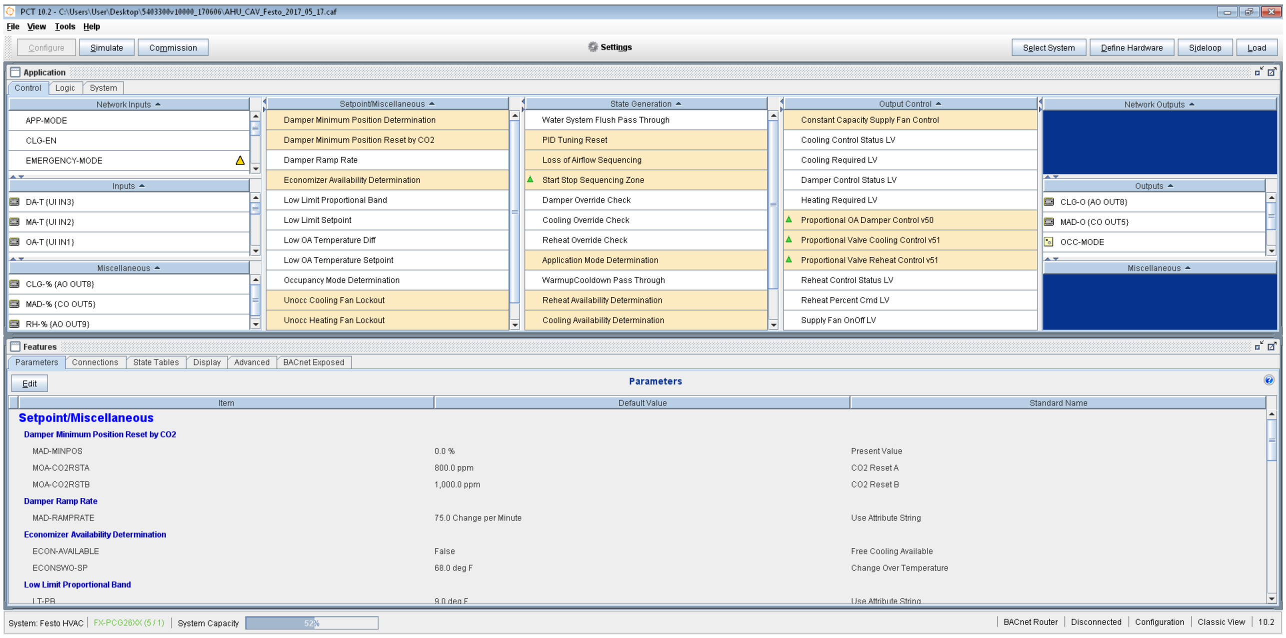

Figure 35. Direct digital control program.

21. To load the program into the controller, click on Load in the upper right corner of the PCT software window; this opens the Load Device window shown in Figure 36.

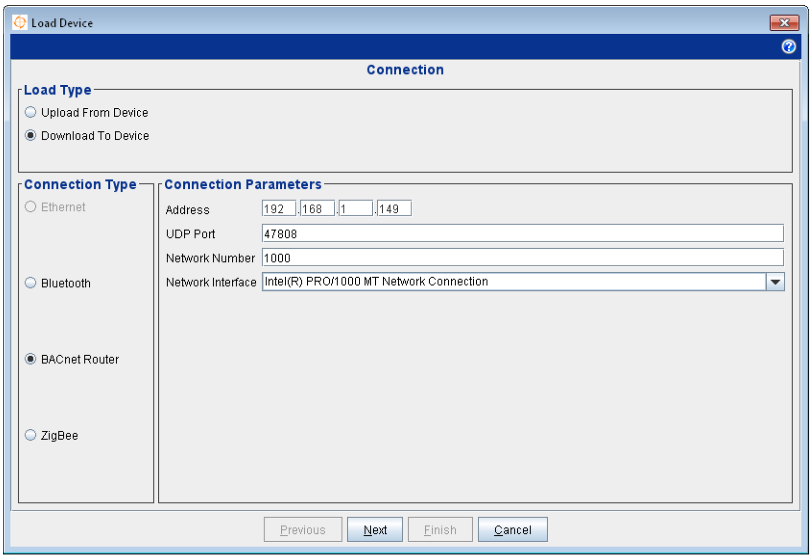

Figure 36. Setting the connection parameters.

22. Set the parameters as shown in Figure 36. Note that the name of the network interface may be different from the name shown in this figure. Be sure to select your computer network card from the network interface dropdown list.

23. Click Next to display the window shown in Figure 37, which presents a list of all devices available for connection with the current program. Note that a device may appear in the list without being available for connection.

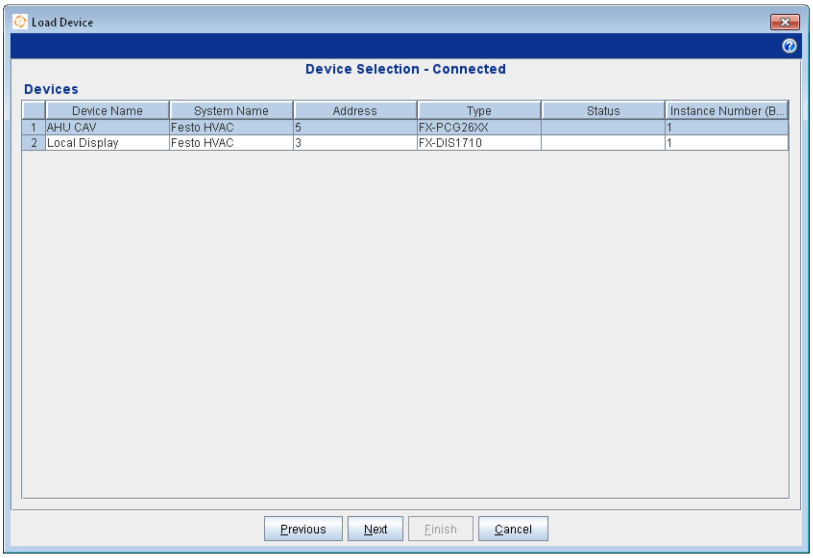

Figure 37. Device selection.

24. From the device list, select AHU CAV (this is the programmable controller that is connected to the HVAC layout). On the controller module, set the DIP address switches so that they match the number indicated in the address column of the devices list. Figure 38 shows how to set the DIP address switches to address 5 for this exercise.

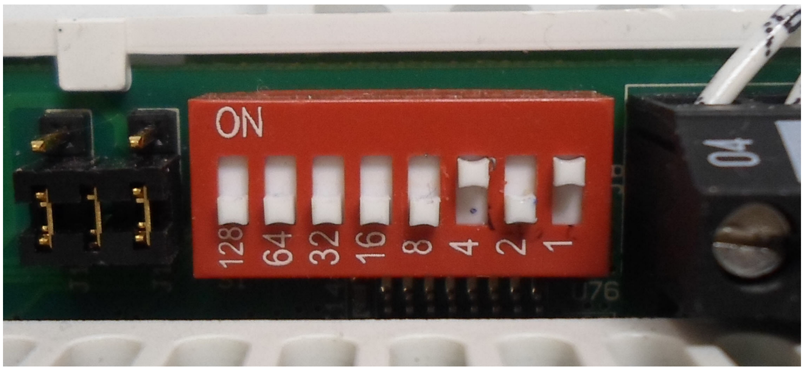

Figure 38. Controller DIP address switches.

25. Click Next, if the connection and parameters are correct, the software displays a load summary, as shown in Figure 39. Check only the application box and click Finish to load the program into the controller. This could take a couple of minutes. Various messages will inform you of the status of the loading process.

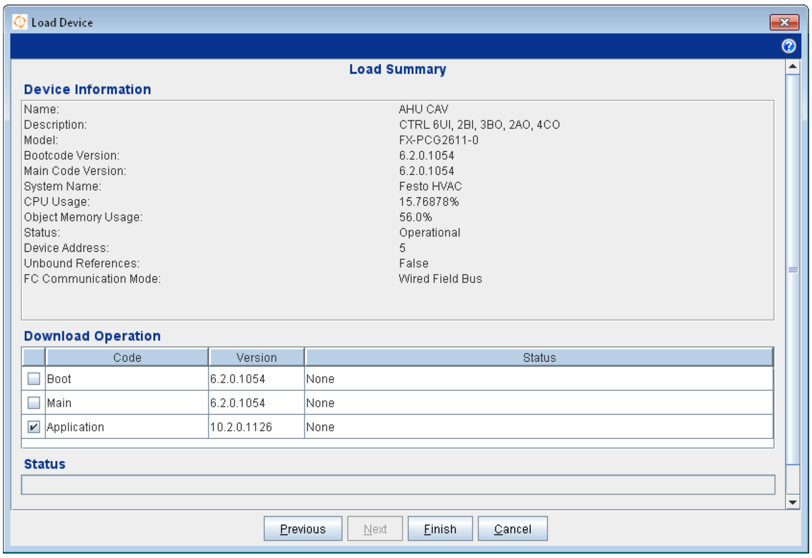

Figure 39. Load summary.

26. Once the program is loaded into the programmable controller, the software returns to the main window show in Figure 35. In this window, click Commission (upper left) to display the connection window. Set the parameters as shown in Figure 40.

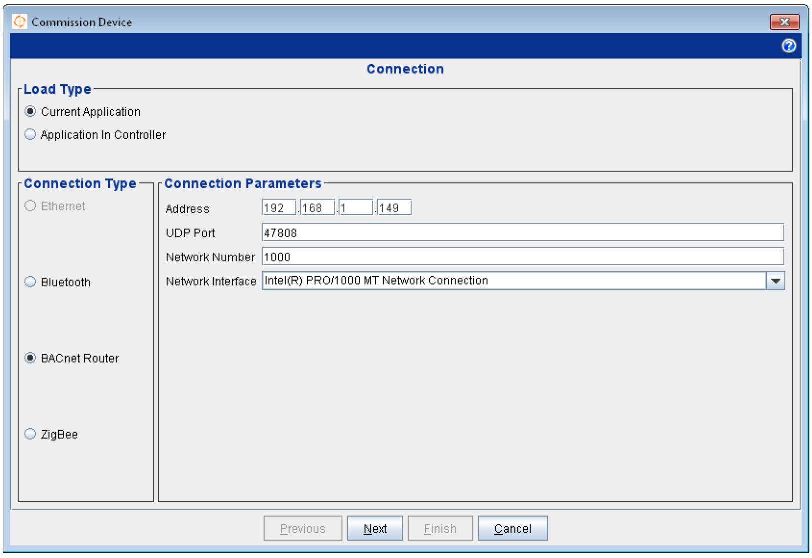

Figure 40. Setting the connection parameters.

27. Click Next to display the window shown in Figure 41. Select AHU CAV and click Next.

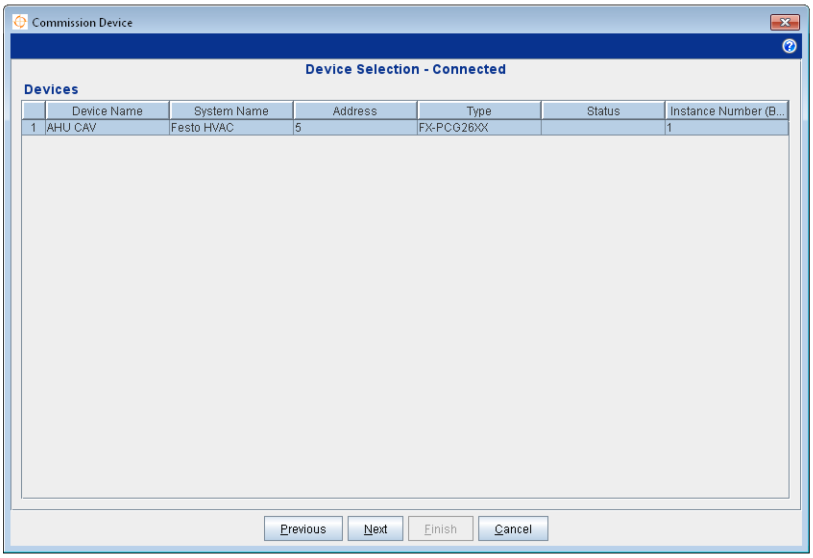

Figure 41. Device selection.

28. If you have set all parameters properly and if the connections are correct, the software displays a commission summary, as shown in Figure 42. Click Finish to establish communication with the controller for commissioning.

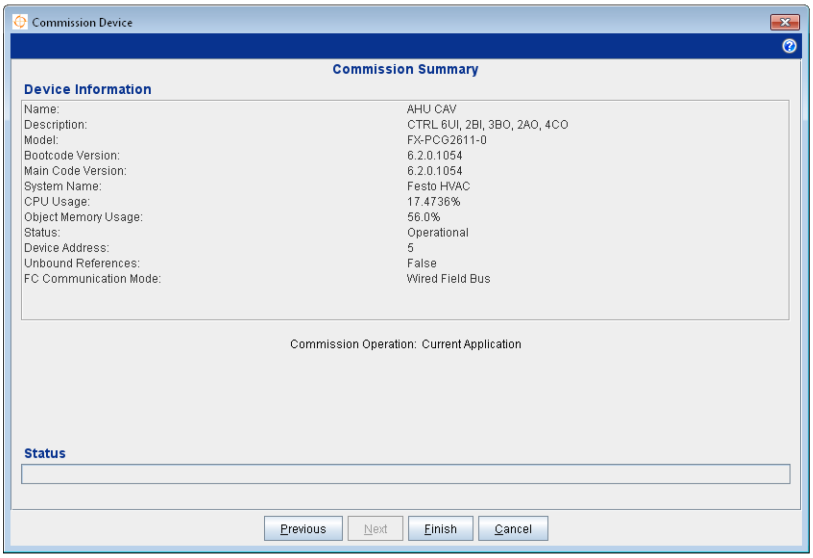

Figure 42. Commission summary.

Testing the controller in the commission mode

29. The connection status and the current mode of the software are displayed in the lower right corner of the PCT software window (Figure 43). Make sure the software status is *Connected* and the mode is *Commissioning* before proceeding further.

30. The commissioning mode allows real-time monitoring of the different inputs and outputs of the programmable controller. In the following steps, you will observe the input and output values using the PCT software.

Figure 43 shows the software in commissioning mode. The leftmost column lists the controller inputs available in the current program. The three columns at the center of the window show parameters and settings such as set points, states, and output controls. The information in these three columns is used by the controller to establish the control logic for the HVAC system. The rightmost column lists the controller outputs available in the current program. For the moment, we will focus only on the inputs and outputs columns. Browse the inputs and outputs lists and, from the information available, complete Table 7.

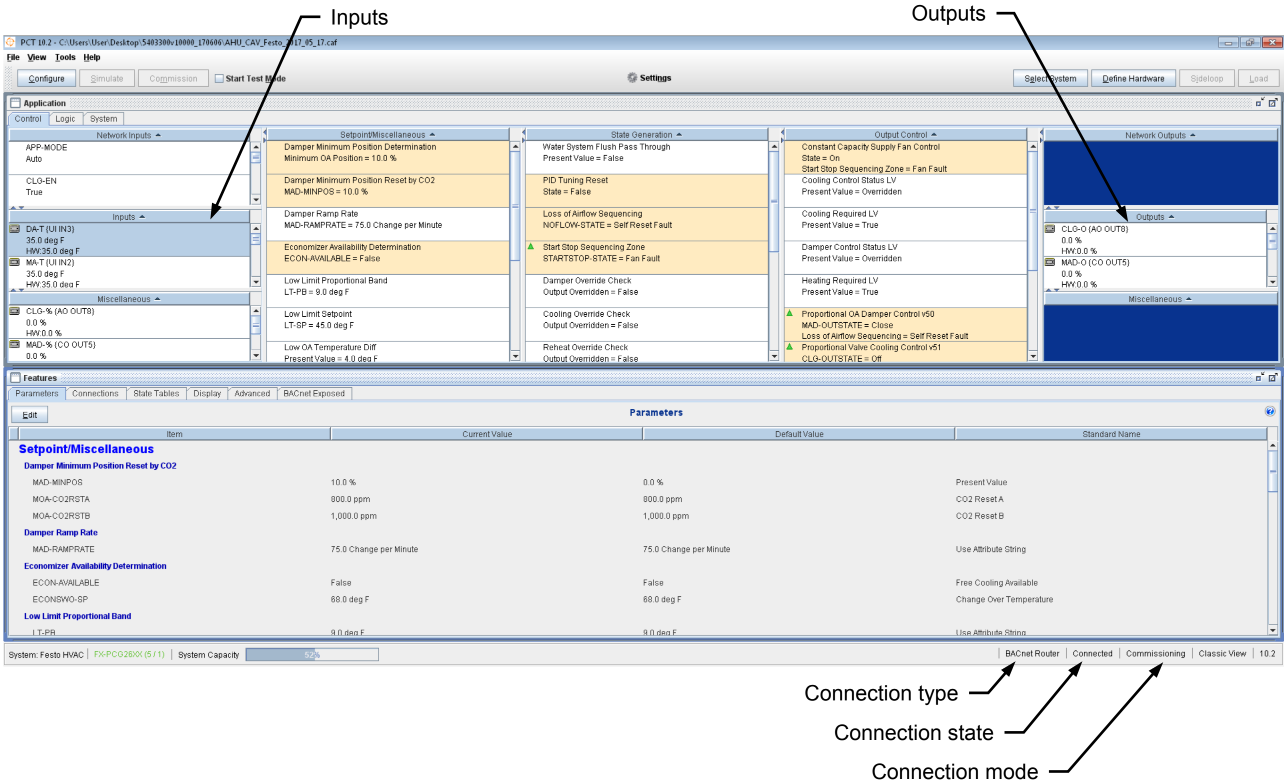

Figure 43. The programmable controller inputs and outputs are listed in the leftmost and rightmost columns of the PCT software, respectively.

Table 7. Controller inputs and outputs identifiers, types, and descriptions.

Input/output identifier	Input/output type	Description
		Reheat: activation level of the heating coil in the air-handling unit
DA-T {UI IN3}		Discharge air temperature: air temperature inside the discharge air duct
		Return air quality: level of CO_2 in the air inside the return duct
	Universal input	Mixed air temperature: air temperature in the section after the economizer damper and the mixed air damper, but before the air filters
RA-T {UI IN6}		
OA-T {UI IN1}		
ZN-T {UI IN4}		Zone temperature: air temperature inside the zone
	Binary input	Zone occupancy status: indicates the presence of occupants in the zone
CLG-O {AO OUT8}		
	Binary output	Supply fan control: controls the operation of the blower in the air-handling unit
	Configurable output	Mixed air damper: controls both the normally closed economizer damper and the normally open mixed air damper
ZN-SP	SA-BUS	Zone temperature set point: determines the set point of the air temperature in the zone
		Supply fan status: indicates the status of the blower in the air-handling unit, on or off

The complete table is presented below.

Controller inputs and outputs identifiers, types, and descriptions.

Input/output identifier	Input/output type	Description
RH-O {AO OUT9}	Analog output	Reheat: activation level of the heating coil in the air-handling unit
DA-T {UI IN3}	Universal input	Discharge air temperature: air temperature inside the discharge air duct
RA-Q {UI IN5}	Universal input	Return air quality: level of CO_2 in the air inside the return duct
MA-T {UI IN2}	Universal input	Mixed air temperature: air temperature in the section after the economizer damper and the mixed air damper, but before the air filters
RA-T {UI IN6}	Universal input	Return air temperature: air temperature inside the return duct
OA-T {UI IN1}	Universal input	Outdoor air temperature: air temperature at the input of the air-handling unit
ZN-T {UI IN4}	Universal input	Zone temperature: air temperature inside the zone
OCC-S {BI IN8}	Binary input	Zone occupancy status: indicates the presence of occupants in the zone
CLG-O {AO OUT8}	Analog output	Cooling: activation level of the cooling coil in the air-handling unit
SF-C {BO OUT1}	Binary output	Supply fan control: controls the operation of the blower in the air-handling unit
MAD-O {CO OUT5}	Configurable output	Mixed air damper: controls both the normally closed economizer damper and the normally open mixed air damper
ZN-SP	SA-BUS	Zone temperature set point: determines the set point of the air temperature in the zone
SF-S {BI IN7}	Binary input	Supply fan status: indicates the status of the blower in the air-handling unit, on or off

31. When you are familiar with the different inputs and outputs of the controller, observe the OCC-S input. In actual HVAC systems, the occupancy sensor would be connected to this input. In the current system, the occupancy sensor is replaced by the occupancy switch on the HVAC layout. This switch can send only one of two signals: occupied and unoccupied.

Before going further, make sure that the OCC-S input is not highlighted in orange, as shown in Figure 44. This would indicate that the input is not properly connected. If it is the case, check all electrical connections.

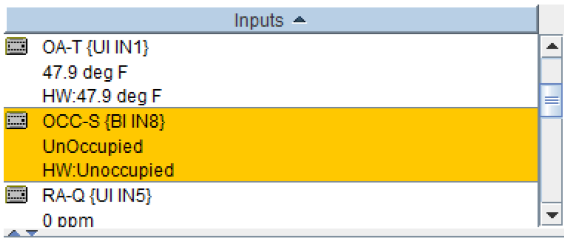

Figure 44. Inputs highlighted in orange are not properly connected.

32. On the HVAC layout, toggle the occupancy switch between occupied (I) and unoccupied (O). As you do so, observe the occupancy status of the OCC-S input change (after a delay of a few seconds) in the PCT software window.

If the OCC-S input status does not change when you toggle the switch, first, make sure that the connection status in the lower right corner of the PCT software window indicates Connected. Then, verify all of your electrical and network connections.

Is the occupancy status of the OCC-S input occupied when the occupancy switch is set to I and unoccupied when the occupancy switch is set to O?

❑ Yes ❑ No

Yes

33. In the inputs column of the PCT software window, locate and select the OA-T input. Right-click on this input to display the associated context menu and select View Details; this opens the Details window shown in Figure 45.

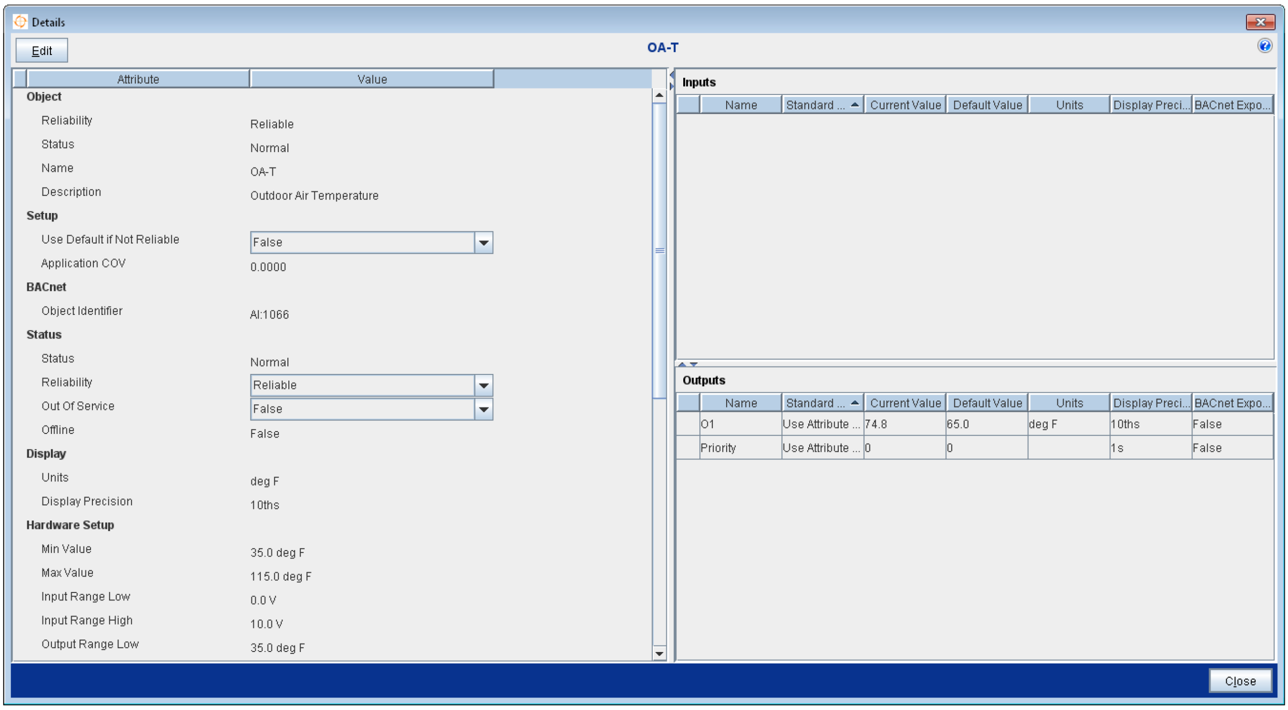

Figure 45. Details window of the OA-T (outside temperature) input.

34. Figure 45 shows all the information associated with the input. The object description may help you to identify an input or output for which you cannot deduce the function from the identifier alone (e.g., DA-T {UI IN3}). The hardware section of this window gives information on the various ranges associated with the input. Take time to look at the available information for the different inputs and outputs. Use this information to complete or correct what you have entered in Table 7.

35. On the HVAC layout, adjust the outdoor air temperature knob to approximately 24°C (75°F). As you do so, observe what happens in the details window of the OA-T input.

It can take a few seconds before any change happens.

Is the outdoor air temperature indicated in the details window of the OA-T input approximately equal to the temperature at which you set the outdoor air temperature knob?

❑ Yes ❑ No

Yes

36. In the inputs column of the PCT software window, locate and select the ZN-SP (zone set point) input. This input is connected to the temperature sensor module and indicates the current set point. Notice that the icon on the left of the ZN-SP input is different from the other icons. This is because the controller communicates with the temperature sensor module via the SA (Sensor/Actuator) bus protocol.

37. On the temperature sensor module, adjust the dial of the sensor so that the display indicates 24°C (75°F). As you do so, observe what happens to the ZN-SP input value indicated in the Inputs column of the PCT software window.

It can take a few seconds before any change happens.

Is the zone temperature set point indicated in the PCT software window equal to the temperature indicated on the temperature sensor?

❑ Yes ❑ No

Yes

38. Using the PCT software in commissioning mode enables the user to force the value of certain parameters, a useful feature for performing tests. As an example, we will force the cooling output signal to a certain value.

To do so, in the Outputs column on the PCT software window, right-click on the CLG-O (cooling) output to display the associated context menu, then select Hardware Commands; this opens the CLG-O window shown in Figure 46, which allows a command to be sent to the CLG-O output.

In this window, select Operator Override, set the value to 75, and then click send. This overrides any output signal that was being sent through this output and replaces it with a signal of 75% (after a few seconds).

On the HVAC layout, does the modulating actuator bar meter of the cooling coil currently display approximately 75%, indicating that the override command is in effect?

❑ Yes ❑ No

Yes

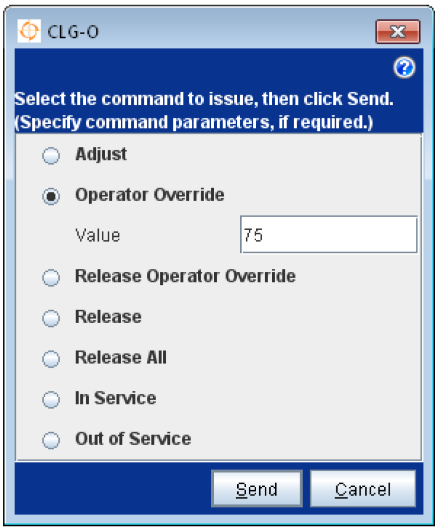

Figure 46. Operator override of the CLG-O output value.

39. To return the control of the CLG-O output to normal, right-click on the CLG-O output, then select Hardware Commands. In this window, select Release Operator Override, then click send, as shown in Figure 47.

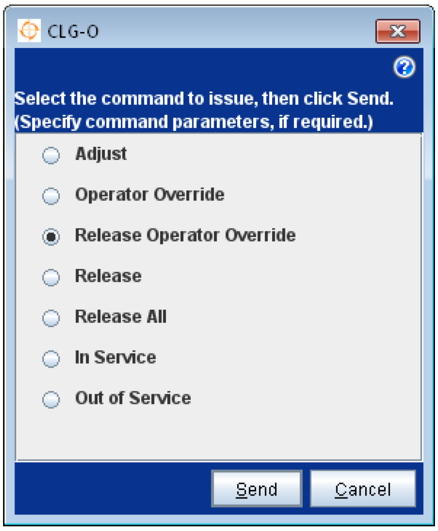

Figure 47. Releasing the cooling output override.

40. Continue experimenting with the system. When you feel you have become familiar enough with it, click Configure to disconnect the computer from the controller. Then, proceed to the next section concerning troubleshooting.

Troubleshooting the control transformer module

In this section, you will insert a fault in the control transformer module and try to determine the nature of this fault.

41. On the control transformer module, set the toggle switch for fault 1 to the I position. As you do so, observe what happens. Note your observations below.

When fault 1 is activated, both the programmable controller and the supervisory controller turn off.

What could be the cause of this problem? Explain briefly.

The observed problem is probably due to the fact that the control transformer no longer supplies power to the programmable controller.

42. Turn the power source off.

43. On the control transformer, disconnect the leads connected to the primary and secondary windings.

Using an ohmmeter, measure the resistance of the primary windings of the control transformer, as well as the resistance of the secondary windings. Record the values below.

Primary windings resistance = _______ Ω

Secondary windings resistance = _______ Ω

Primary windings resistance = ∞

Secondary windings resistance = 0.5 Ω

44. What can you conclude about the nature of fault 1 from the measurements you just made? Explain briefly.

The resistance measurements indicate that the primary windings circuit is open, since its resistance is infinite. Therefore, we can conclude that fault 1 opens the circuit of the transformer primary windings, either across the N terminal or the L terminal.

45. On the control transformer module, set the toggle switch for fault 1 back to the O position.

You can ask the student to add other faults on the control transformer module and troubleshoot them.

46. Turn the power source off and remove all connection leads.

Conclusion

In this exercise, you learned how to configure your computer and software for downloading a program to a programmable controller and thus how to implement direct digital control (DDC) on a building HVAC system. You learned how the controller programming software manages inputs and outputs. You used the software in commissioning mode to test your setup, and learned how this mode can be used to test a real HVAC system. You also learned how to read an electrical wiring diagram and recognize the symbols of the controller terminals. Finally, you did troubleshooting exercises on the control transformer module.

Review Questions

1. What does HVAC stand for?

   HVAC stands for heating, ventilating, and air conditioning.

2. What is the role of the air-handling unit in an HVAC system?

   The role of the air-handling unit is to take air from outside as well as, in some cases, return air from inside, and condition it according to the desired requirements (e.g., temperature, relative humidity, pressure, quality).

3. Briefly define what a zone is in the context of HVAC systems.

   In the context of HVAC systems, a zone is an area whose temperature, humidity, and other regulated parameters are monitored and controlled by an HVAC system. Typically, each zone in an HVAC system contains a thermostat (for temperature control), a humidistat (for humidity control), or any other control device enabling occupants to adjust the different parameters regulated in the zone. Zones can be separated by walls, doors, windows, or simply be different areas of a larger room.

4. What is the role of an air-handling unit controller in an HVAC system? Explain briefly.

   The role of an air-handling unit controller in an HVAC system is to activate the various components of the air-handling unit (e.g., heater and cooler) according to the information it receives.

5. What is the role of the control transformer in the Building HVAC Controls Training System?

   In the Building HVAC Controls Training System, the control transformer is used to convert the local ac power network voltage to a voltage of 24 V ac that is suitable for the devices in the system, such as the programmable controllers.

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