Refrigeration and HVAC

HVAC Direct Digital Control

Courseware Sample

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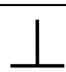
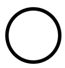
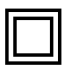
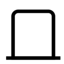
Safety and Common Symbols

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
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
	Both direct and alternating current
3∿	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	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 line of products introduces students to the basic principles of heating, ventilation, and air conditioning (HVAC) systems. It covers all components commonly used in HVAC systems today, and teaches students the skills required to work in the HVAC field. Throughout the activities of the manuals, students develop practical knowledge on how to install, maintain, and troubleshoot HVAC systems, and they become familiar with a large variety of HVAC systems as well as with their different characteristics.

The training systems in this line of products are specially designed for full modularity. This particularity allows them to be used to implement a wide variety of HVAC systems and circuits. The training systems also incorporate actual residential, industrial, and commercial devices in order to give students an experience that is as close as possible to actual work in the HVAC field.

Do you have suggestions or criticism regarding this manual?

If so, send us an e-mail at 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.

Reference material

Refer to the textbook titled *Refrigeration and Air Conditioning Technology* written by Bill Whitman, Bill Johnson, John Tomczyk, and Eugene Silberstein.

Additional information can be found on the website of the different component manufacturers.

Prerequisite

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

- Voltage, current, and power, both in 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 U.S. customary system of units followed by the units expressed in the SI 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
- Rooftop unit
  Rooftop unit controller.
- Direct digital control

DISCUSSION OF FUNDAMENTALS

What is HVAC?

HVAC stands for Heating, Ventilating, and Air Conditioning. Do not be misled by the expression *air conditioning*; the meaning of air conditioning has shifted over the years to more than just cooling. Nowadays, every aspect necessary to provide total control of air is included in what is called air conditioning: temperature and humidity regulation, fresh air supply, air filtration, and air movement.

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 also exist in a wide range of sizes. For example, 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 an American football field (Figure 1). Considering the variations in complexity and size, as well as the specifics of each application, it is easy to understand why HVAC is such a broad field.

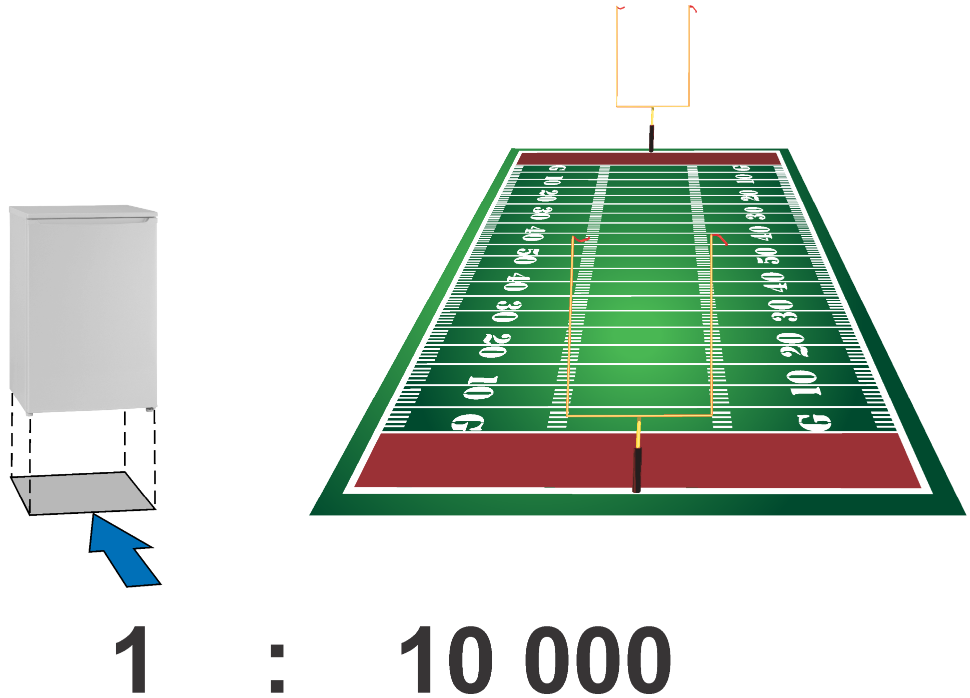

Figure 1. HVAC systems can vary greatly in size.

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

In order to configure, install, and troubleshoot HVAC equipment, it is important to understand the processes that this equipment controls. Seven processes are of main concern to achieve total control of air characteristics in an HVAC system: heating, cooling, humidifying, dehumidifying, cleaning, ventilating, and air movement. In a standard HVAC system, each of these processes is usually controlled using one or more devices. Being able to identify those devices and understand their influence on the seven main processes is essential to the understanding of 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 (**RTU**), 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 RTUs is limited to what is available on the market and maintenance must be performed no matter the outdoor conditions.

The role of the RTU 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). The unit distributes conditioned air to all controlled areas of the building via ducts. In addition to the RTU and ducts, equipment such as controllers, heaters, and dampers are also part of HVAC systems.

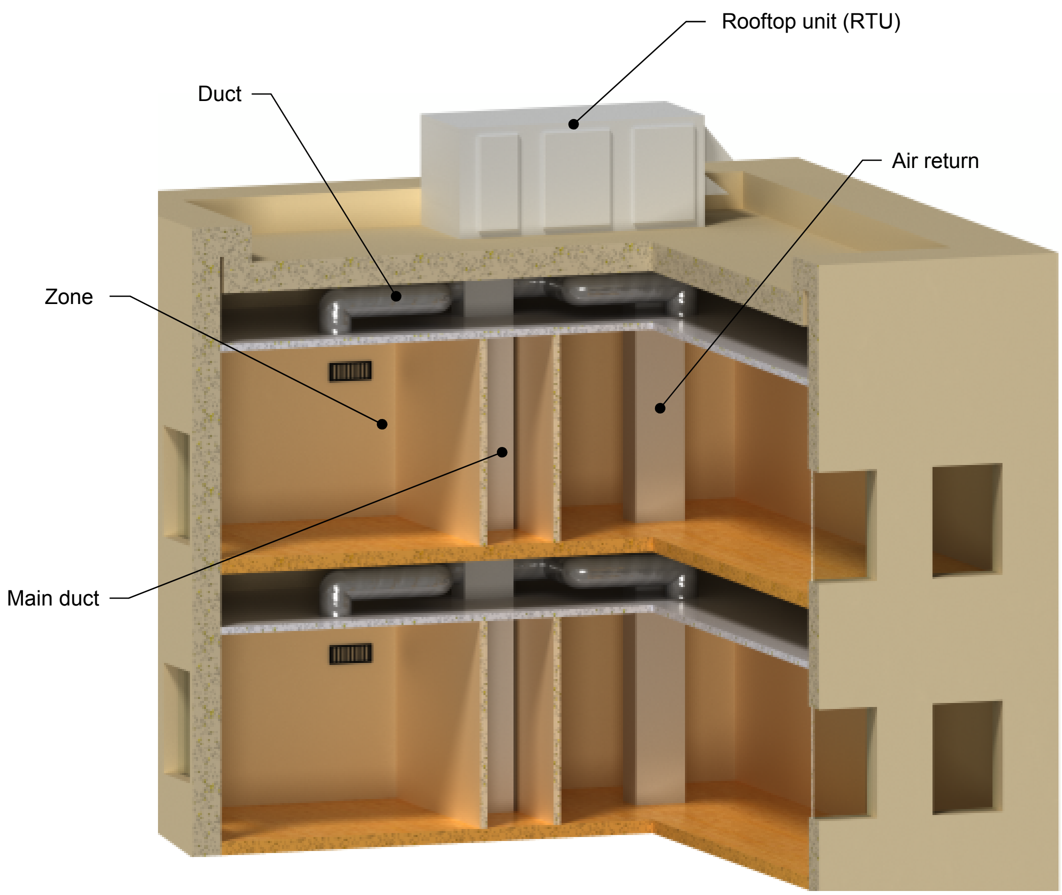

Figure 2. HVAC system.

Rooftop unit

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

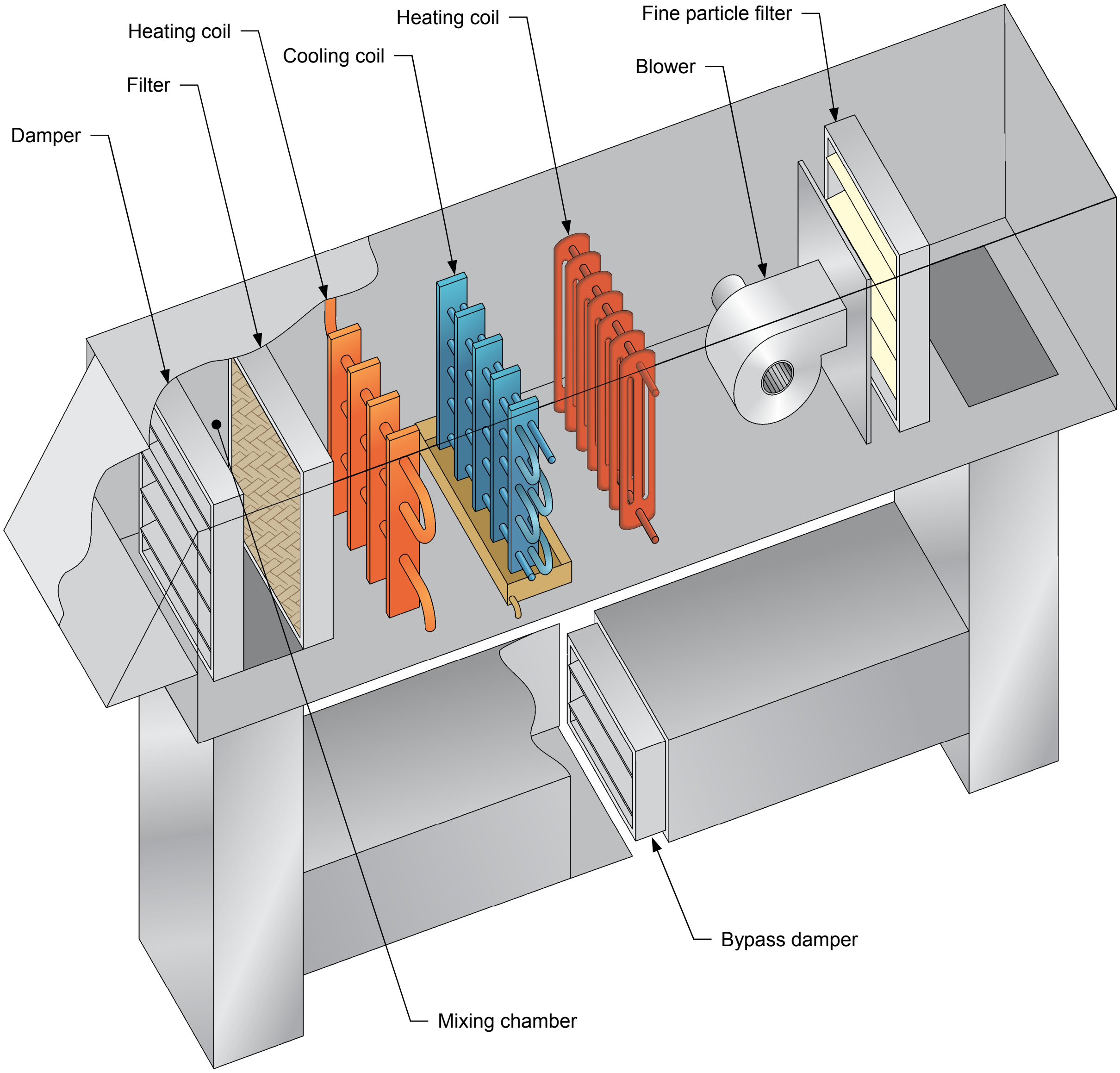

Figure 3. HVAC system.

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

A zone is an area whose temperature, humidity, pressure, and other regulated parameters are monitored and controlled by an HVAC system. 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 (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.

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

Figure 4. Typical RTU.

Figure 5. Typical RTU.

Figure 6. Dusty economizer damper.

Figure 7. Particle filters.

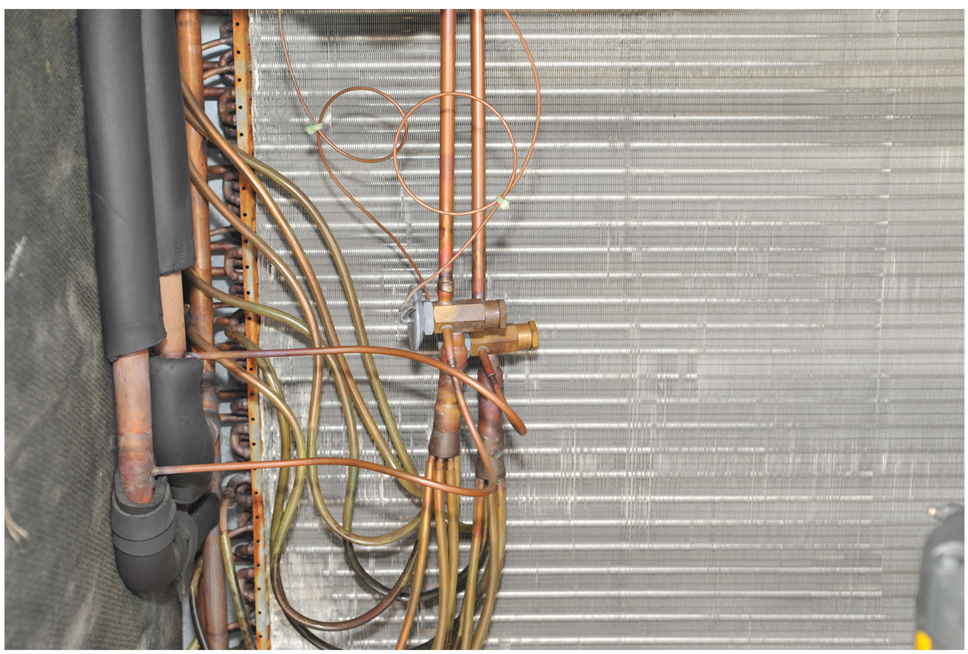

Figure 8. Cooling coil.

Figure 9. Blower.

Rooftop unit controller

The RTU has its own controller. This controller activates the various components of the unit (e.g., heater and cooler) according to the information it receives.

In the case of a multi-zone HVAC system, the RTU controller is connected to zone controllers that inform the RTU of the zone conditions and set points. A typical RTU controller also has inputs that receive information from the different sensors located elsewhere in the system. Examples of such sensors include an outdoor temperature sensor and a duct static pressure sensor.

The RTU controller outputs activate the fresh air damper, bypass damper, fan, heating coil, and cooling coil. Other types of inputs and outputs are also available to accommodate different types of installations. Figure 10 shows an RTU connected to a simplified controller. Figure 11 shows an actual RTU controller board.

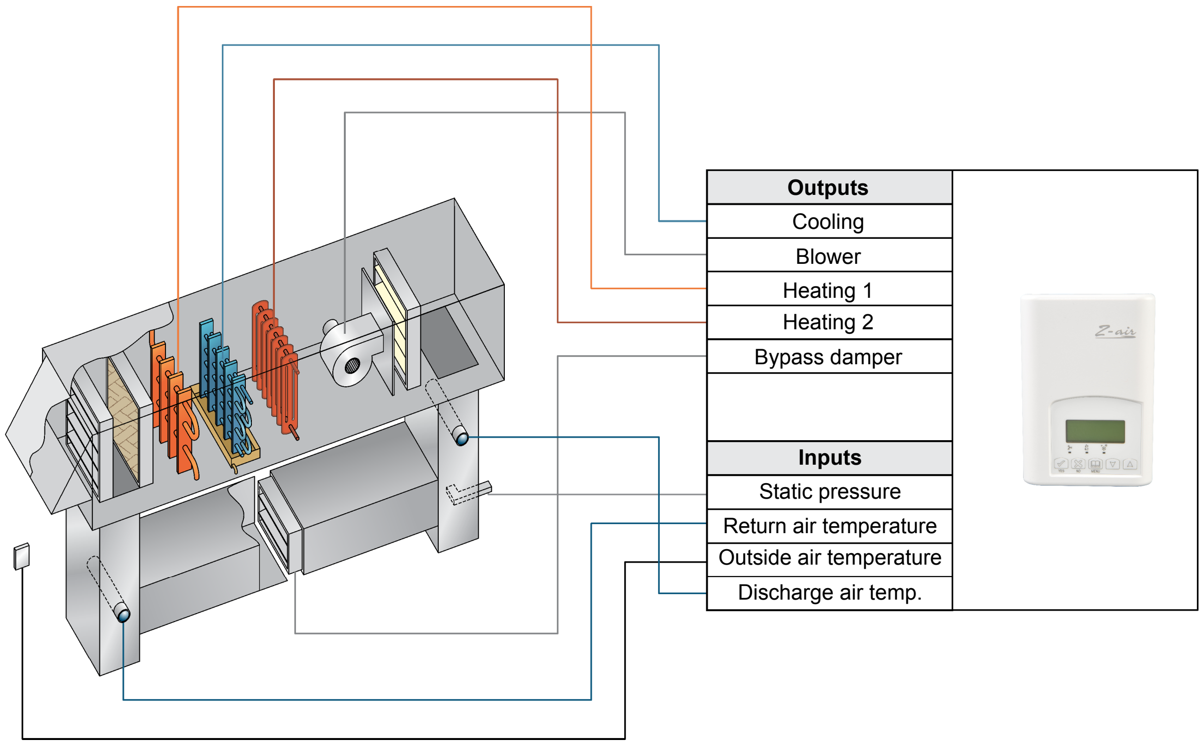

Figure 10. HVAC system.

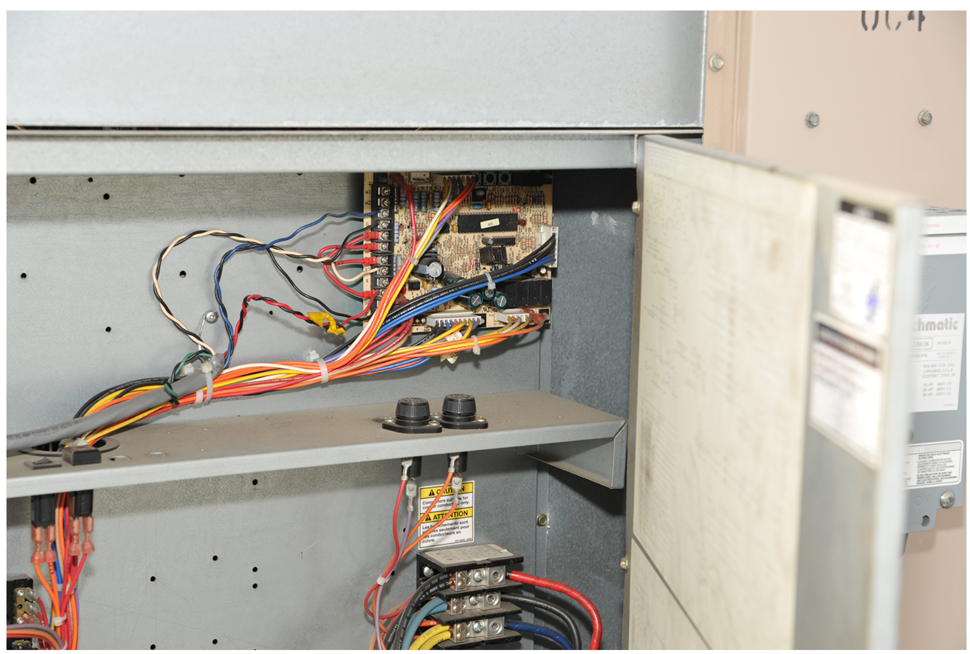

Figure 11. RTU controller board.

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.

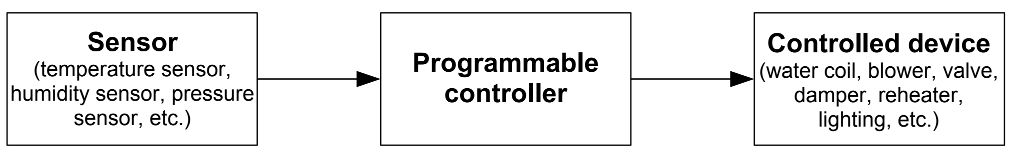

Figure 12. DDC controlled HVAC system operation.

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.

Familiarization with the Building Energy Management Training System

EXERCISE OBJECTIVE

When you have completed this exercise, you will know 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 will also know how the controller programming software manages inputs and outputs. You will be familiar with using the software in commissioning mode to test your setup, and with how this mode can be used to test a real HVAC system. You will be able to read an electrical wiring diagram and recognize the symbols of the controller terminals. Finally, you will have done troubleshooting exercises on the control transformer module.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Building Energy Management Training System
  System overview. Power source. Control transformer. Programmable controller. Temperature sensor. Supervisory controller. Main module.
- Programmable controller software

DISCUSSION

Building Energy Management 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 Energy Management 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 system main module. 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 main module, while the transformer provides 24 V ac power to the programmable controllers.

The main module 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 modules, a temperature sensor module, and a supervisory controller module. Figure 13 shows all system modules installed in a workstation.

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

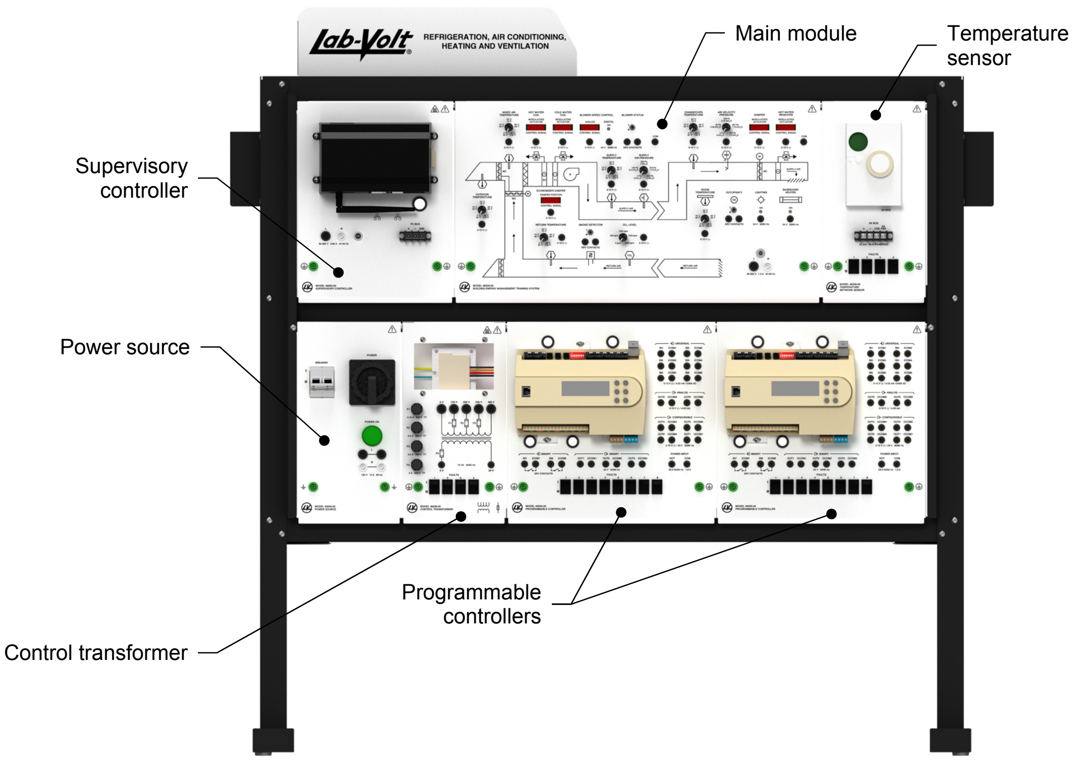

Figure 13. Building Energy Management Training System.

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 120 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 all ground (green) terminals of the modules in the training system in series with the ground (green) terminals of the power source.

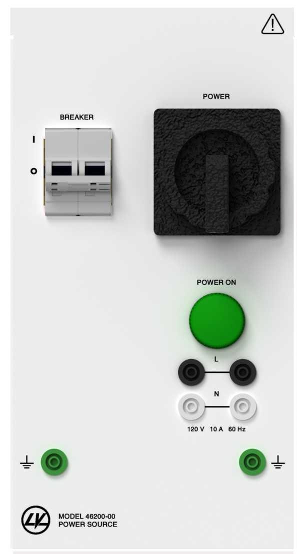

Figure 14. Power source module.

Control transformer

The control transformer module has intermediate terminals called taps on the primary winding, as shown in Figure 15. This allows variation of the ratio between the voltage at the primary of the control transformer and the voltage at the secondary. To obtain the required voltage at the secondary, be sure to connect the power supply outputs to the appropriate terminals of the primary. For example, in Figure 15, if your power supply voltage is 120 V ac, connecting the power supply outputs to the 0 V and 120 V terminals of the transformer produces a voltage of 24 V at the secondary terminals.

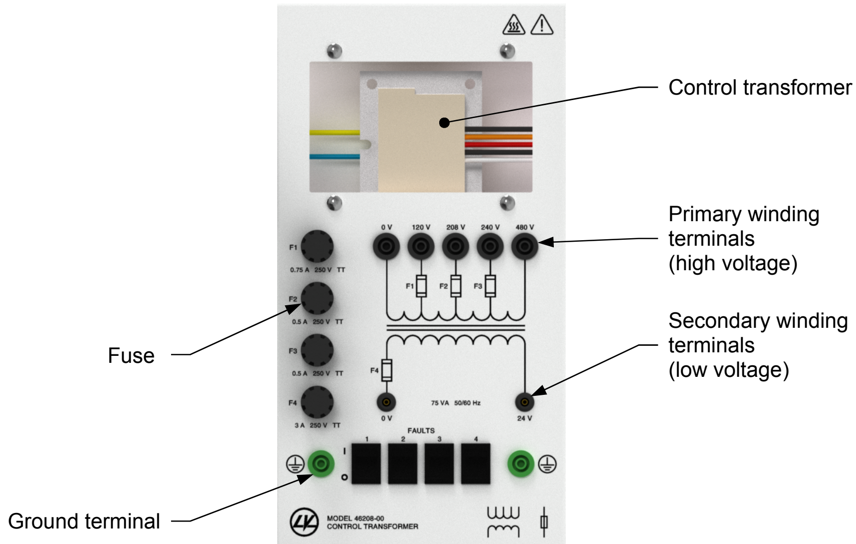

Figure 15. Control transformer module (120 V version).

CAUTION

Never apply more than the rated voltage to the transformer terminals. The maximum voltage that you can apply to the primary is 480 V and the maximum amount of power that the transformer should transfer is 75 VA. Not respecting these ratings could damage the transformer.

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). All primary winding and secondary winding terminals are fuse protected.

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

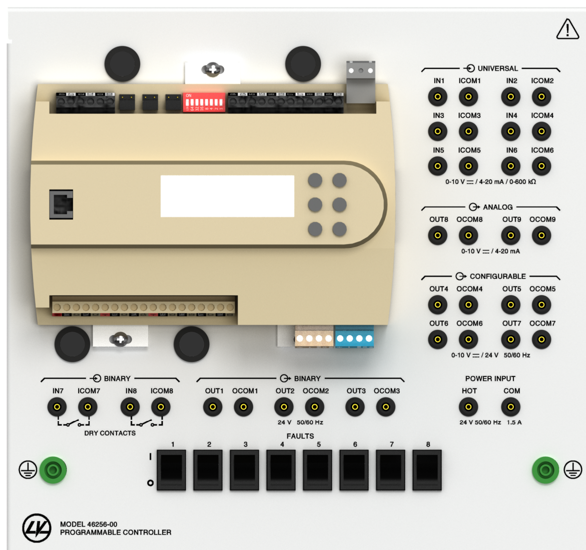

Figure 16. Programmable controller module.

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 main module. 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 through a screw terminal block and a special cable for connection to a controller.

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

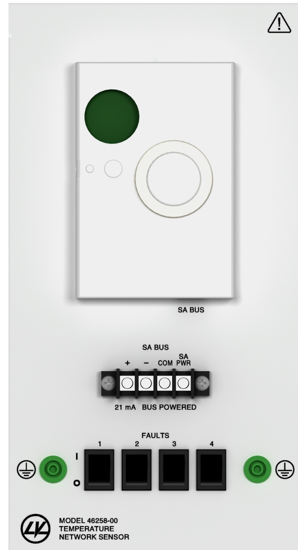

Figure 17. Temperature sensor module.

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 18 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).

The supervisory controller module must be powered using the local ac power network voltage, obtained from the power source module. The supervisory controller is equipped with a screw terminal block that allows connection through an FC bus to a programmable controller, for example.

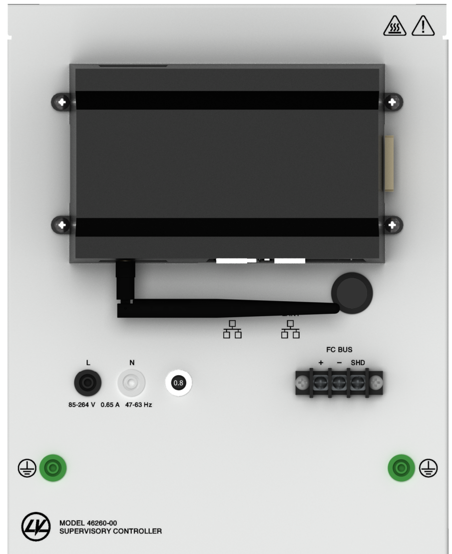

Figure 18. Supervisory controller module.

Main module

The main module of the Building Energy Management 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 19.

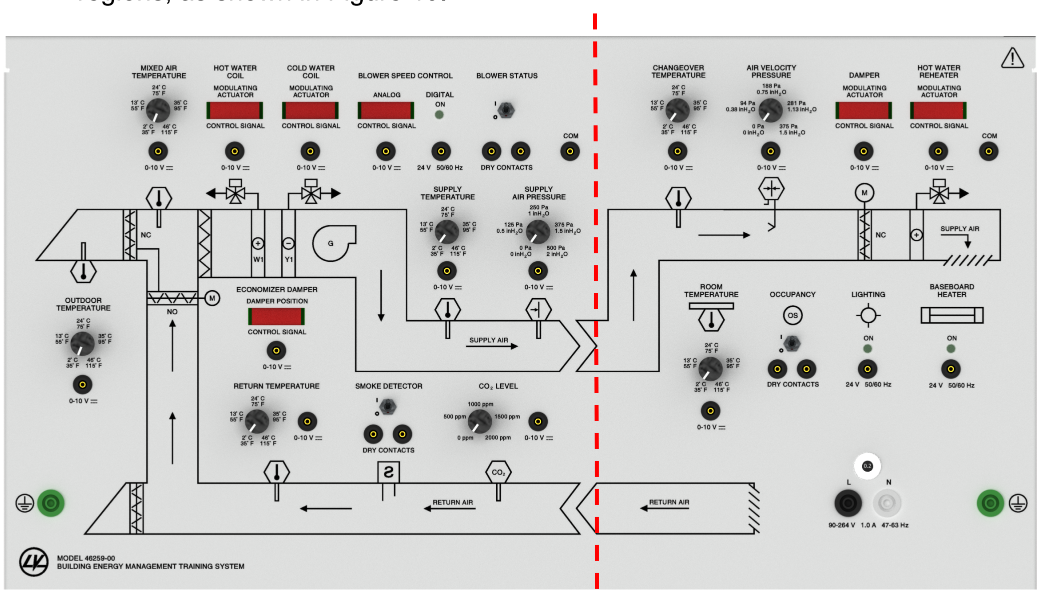

Figure 19. Main module.

The first section represents the RTU 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 20 shows the components in the first section of the main module, while Table 2 and Table 3 list the functions of the various terminals, switches, and buttons. Further information regarding the various components of the main module is provided as required by the exercises in this manual.

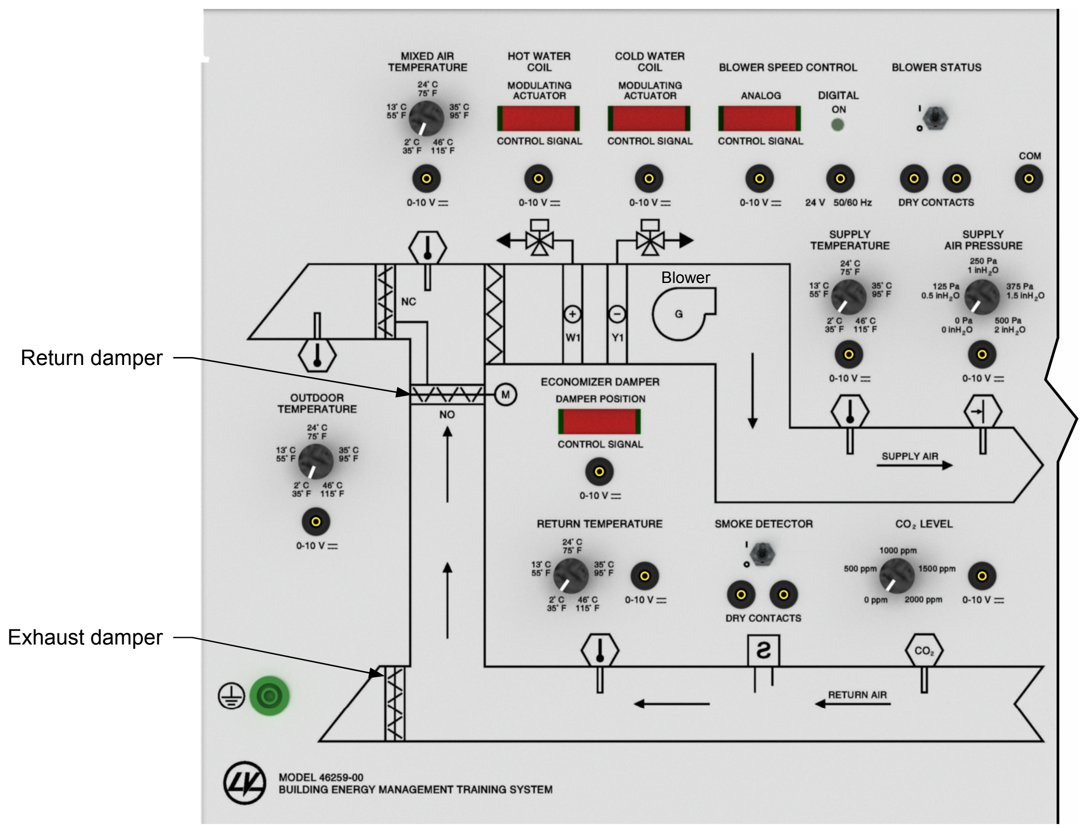

Figure 20. Main module – RTU section.

Table 2. Main module – RTU section terminals.

Terminal identification	Description
Mixed air temperature	0-10 V dc analog output for the simulated temperature sensor of the mixed air
Hot water coil	Input for the 0-10 V dc control signal of the hot water coil. A bar meter represents the level of the control signal. 10 bars indicate maximum heating, while no bar indicates no heating.
Cold water coil	Input for the 0-10 V dc control signal of the cold water coil. A bar meter represents the level of the control signal. 10 bars indicate maximum cooling, while no bar indicates no cooling.
Blower speed control (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.

Terminal identification	Description
Blower speed control (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.
Supply temperature	0-10 V dc analog output for the simulated temperature sensor of the air supply
Supply air pressure	0-10 V dc analog output for the simulated pressure sensor of the air supply
Outdoor temperature	0-10 V dc analog output for the simulated outdoor 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. Main module – RTU 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.
Supply temperature	Sets the simulated air temperature in the supply duct
Supply air pressure	Sets the simulated air pressure in the supply duct
Outdoor temperature	Sets the simulated outdoor temperature
Return 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 main module represents the infrastructure of the building, including the zone damper, hot water reheater, zone sensors, lighting system, 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 21 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.

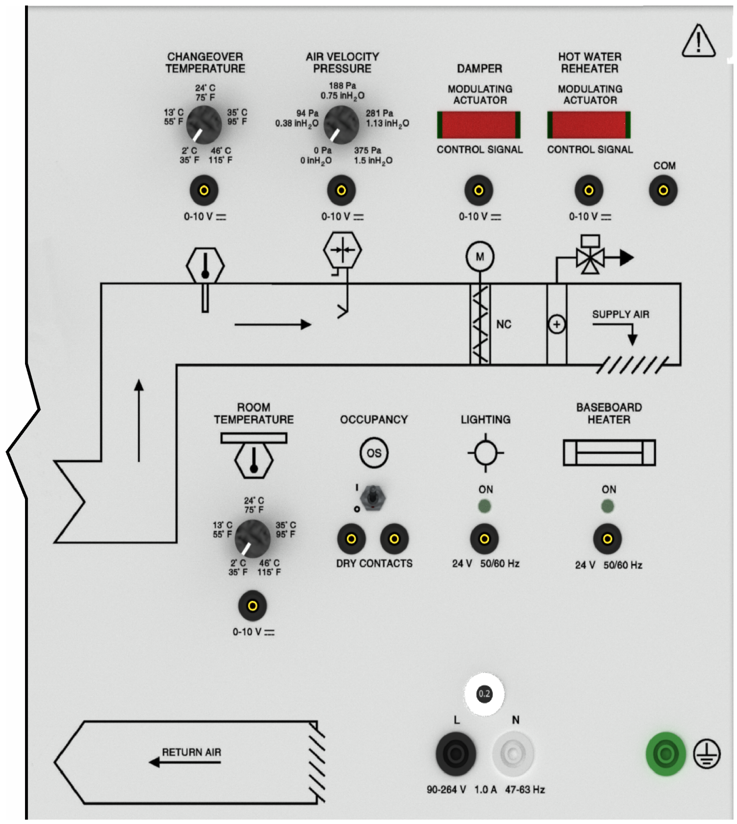

Figure 21. Main module – zone section.

Table 4. Main module – Zone section terminals.

Terminal identification	Description
Changeover temperature	0-10 V dc analog output for the simulated changeover temperature sensor
Air velocity pressure	0-10 V dc analog output for the simulated air velocity pressure sensor
Room humidity (humidity control add-on only, see Exercise 3)	0-10 V dc analog output for the simulated room 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.

Terminal identification	Description
Humidifier (humidity control add-on only, see Exercise 3)	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.
Hot water reheater	Input for the 0-10 V dc control signal of the hot water 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
Room temperature	0-10 V dc analog output for the simulated room 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 room is occupied. If the switch is set to the O position, the contact is open, thereby indicating that the room is unoccupied.
Lighting	Digital input (24 V ac) for the control signal for lighting. A green LED indicates that the lights are on.
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. Main module – RTU section switches and buttons.

Switch/button identification	Description
Changeover temperature	Sets the simulated changeover temperature
Air velocity pressure	Sets the simulated air velocity pressure (0 inH_2O to 1.5 inH_2O or 0 Pa to 375 Pa)
Room humidity (humidity control add-on only, see Exercise 3)	Sets the simulated relative humidity in the room
Room temperature	Sets the simulated temperature in the room
Occupancy sensor	Simulates an occupancy sensor. Setting it to I indicates that the room is occupied, while setting it to O indicates that the room is unoccupied.

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 Energy Management Training System is PCT, which stands for Programmable Controller Tool. Figure 22 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 would require 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.

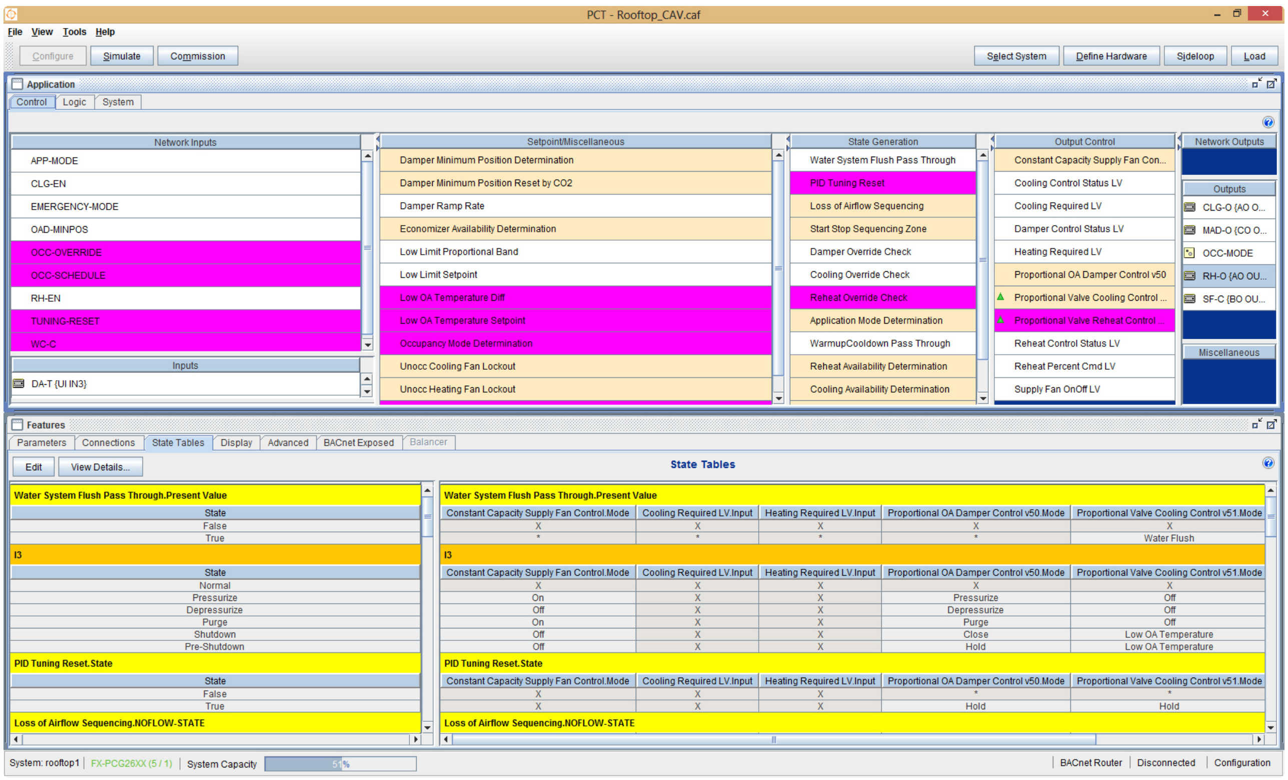

Figure 22. Programmable controller software (PCT from Johnson Controls©).

Figure 22 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.

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 23. View on the RTU unit of a local train in Switzerland (cc-by-sa-3.0|FabiBerg).

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 Energy Management Training System.

1. You will need most of the modules in the system for each exercise of this manual. Therefore, it is recommended to install all the modules in the workstation and wire only those required in the exercise.

   Install the modules in the workstation as shown in Figure 24. The supervisory controller, main module, and temperature sensor are located in the top row. The power source, control transformer, and programmable controllers are located in the bottom row.

   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.

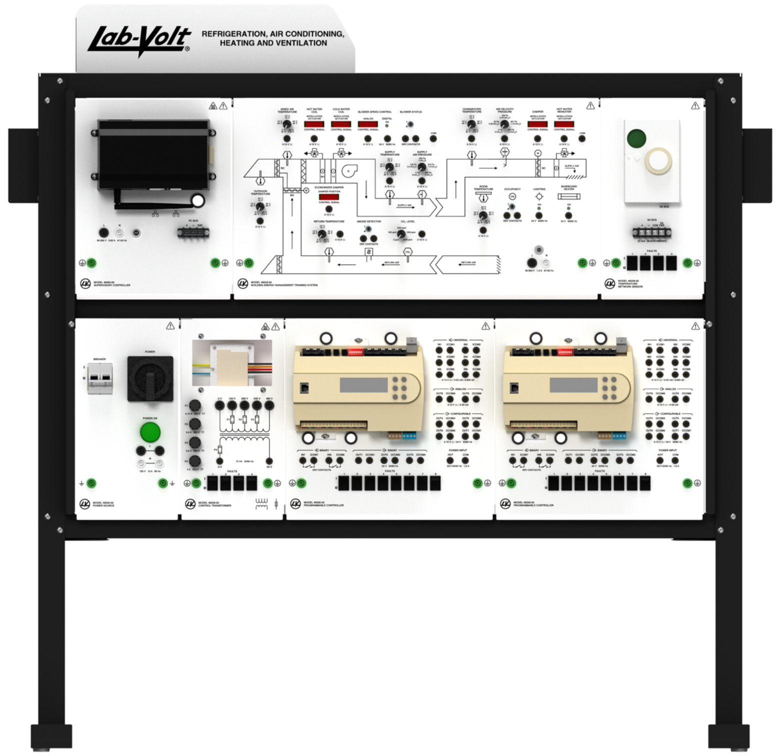

Figure 24. Building Energy Management Training System.

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 the control transformer, programmable controllers, and temperature sensor are set to the O position.

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

High-voltage connections

5. Firstly, we will connect the different devices that require power directly from the ac network (high-voltage connections). Figure 25 shows the connections required to provide power from the local ac network to the control transformer, main module, and supervisory controller. Connect these modules using 4 mm leads (i.e., the large-diameter leads).

   The control transformer module converts the power it receives from the local ac network into 24 V ac power. The connections between the ac power source and the control transformer depend on the voltage of your local ac network. Make sure to connect the line terminal (L) of the power source to the control transformer terminal whose specified voltage is equal to the voltage of your local ac network. Figure 25 shows how to connect a 120 V ac power source to the control transformer.

CAUTION

Always connect the line terminal (L) of the power source to the control transformer terminal whose specified voltage is equal to the voltage of your local ac network. For example, if the local ac network voltage is 120 V, connect the power source L terminal to the 120 V terminal of the transformer primary winding.

6. Connect all ground (green) terminals of the modules in the training system in series with the ground (green) terminals of the power source. Grounding connections are shown in green in Figure 25.

Do not turn the power source on for the moment.

7. In the following exercises of this manual, we will not use figures such as Figure 25 to represent the system connections. Instead, we will use wiring diagrams similar to the one shown in Figure 26. 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 26 and compare it to Figure 25. Make sure you understand each connection shown in this diagram. Notice that the ground connections are not shown on the figure and that new connections are shown in red.

Table 6 lists the different identifiers used in the wiring diagrams with their corresponding name on the main module. Most of the time, the identifier is created after the first letter of each word in the name of the component. For example, HWC stands for Hot Water Coil.

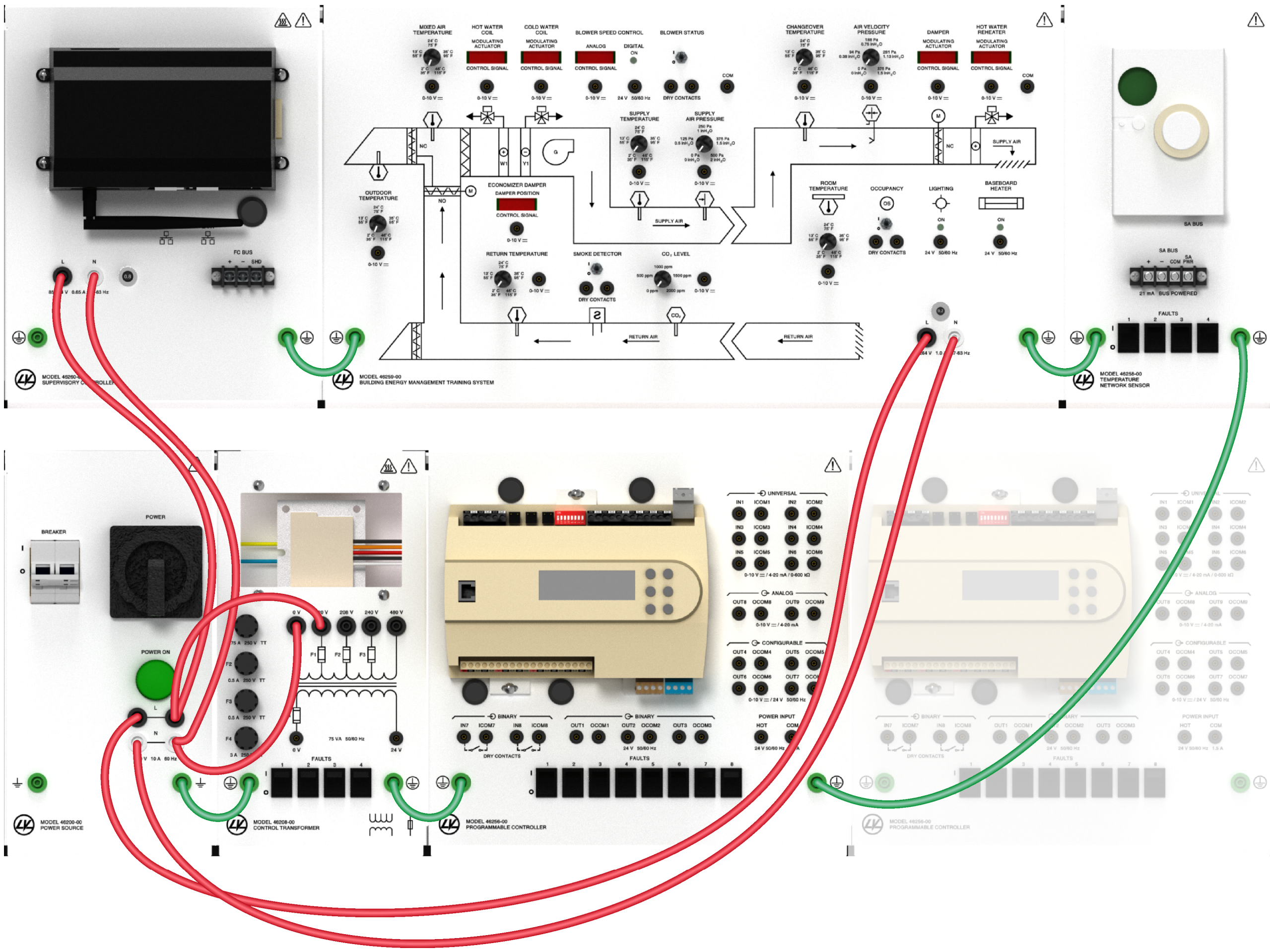

Figure 25. High-voltage connections.

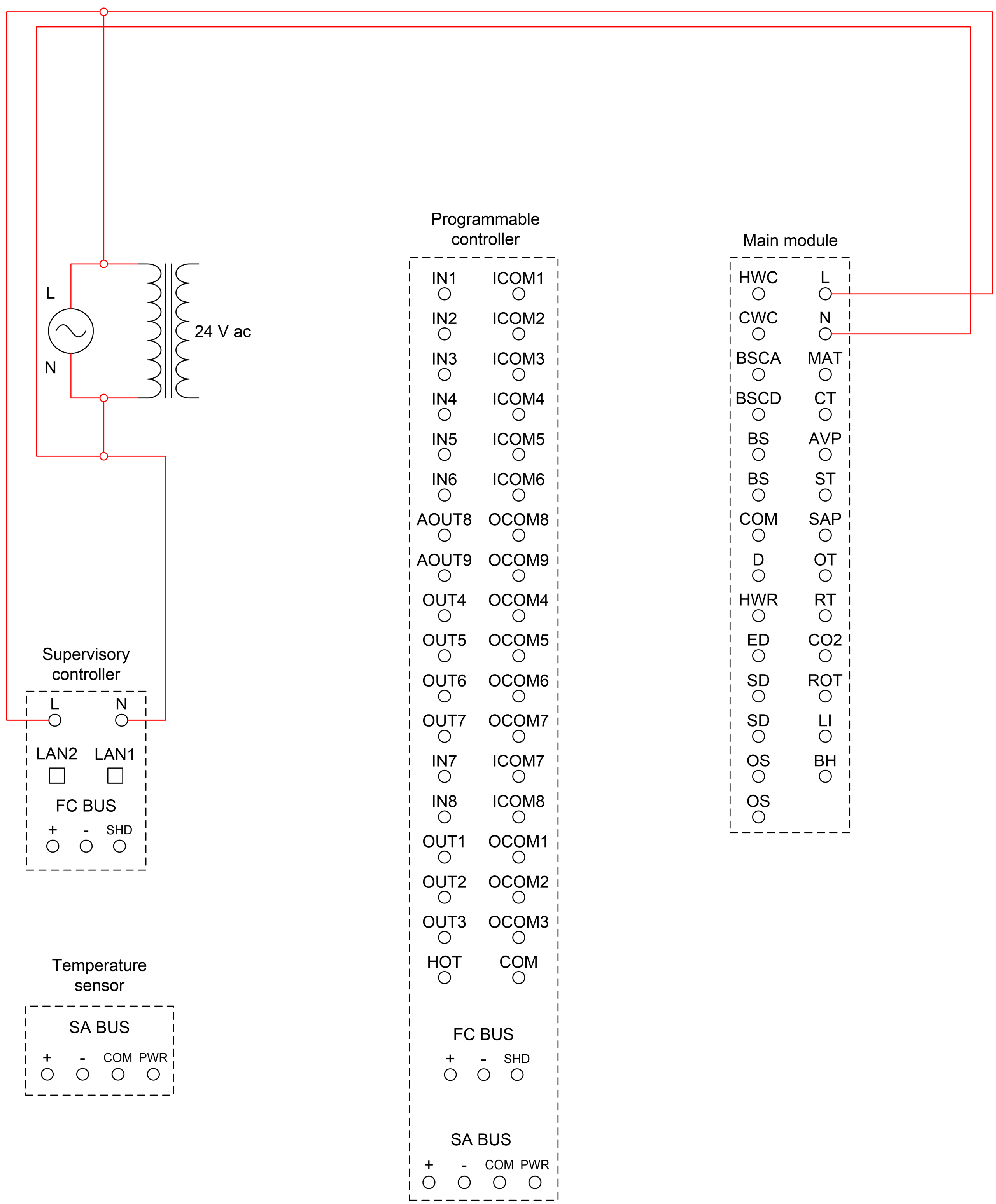

Figure 26. High-voltage connections - wiring diagram.

Table 6. Identifiers in the wiring diagrams and their corresponding name on the main module.

identifier	Name on the main module
HWC	Hot water coil
CWC	Cold water coil
BSCA	Blower speed control analog
BSCD	Blower speed control digital
BS	Blower status
COM	COM (common connector)
D	Damper
HWR	Hot water reheater
ED	Economizer damper
SD	Smoke detector
OS	Occupancy sensor
L	L (line connector)
N	N (neutral connector)
MAT	Mixed air temperature
CT	Changeover temperature
AVP	Air velocity pressure
ST	Supply temperature
SAP	Supply air pressure
OT	Outdoor temperature
RT	Return temperature
CO2	CO_2 level
ROT	Room temperature
LI	Lighting
BH	Baseboard heater

Controller low-voltage connections

8. The programmable controllers require 24 V ac power for operation. Once you have connected the control transformer and the other devices requiring power from the local ac network, use 2 mm leads (small-diameter leads) to connect one of the controllers to the transformer, as shown in Figure 27. Figure 28 shows the corresponding wiring diagram.

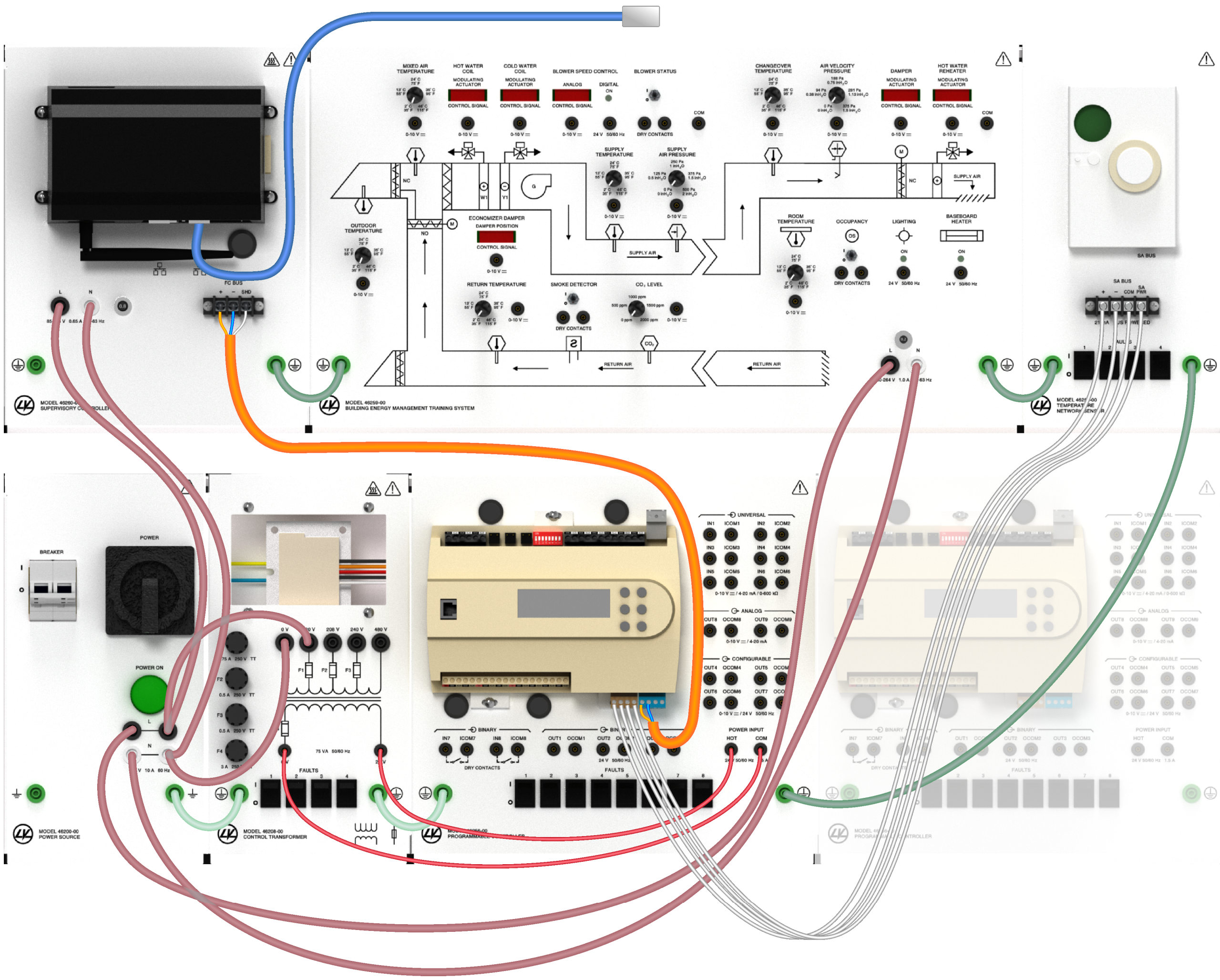

Figure 27. Controller low-voltage connections and network connections.

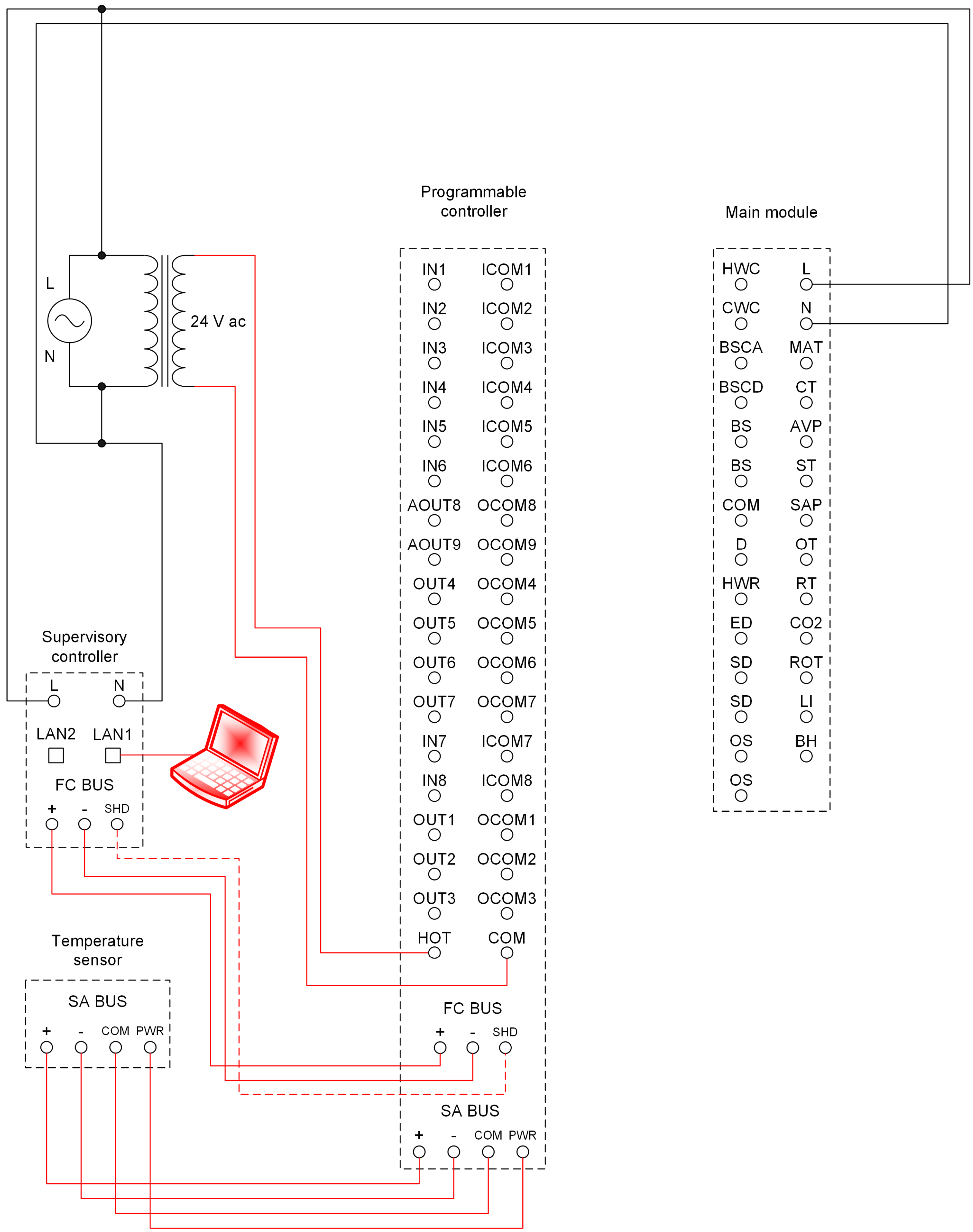

Figure 28. Controller low-voltage connections and network connections - wiring diagram.

Network connections

9. Figure 27 and Figure 28 also show the required network connections. There are three different types of network connections in this setup:

- a standard Ethernet connection between the supervisory controller and a computer,
- a network 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.

The connections required for each type of network are covered in the following steps. Be absolutely sure to make each connection properly as they are vital to ensure proper network communications. If one of the networks is not correctly set up, the HVAC system will not operate properly.

10. Use an Ethernet cable for the Ethernet connection between the supervisory controller and a computer. Connect the Ethernet cable to both the LAN1 Ethernet port of the supervisory controller and the Ethernet port of the computer.

11. Use the orange cable for the network connection in the FC bus protocol between the supervisory controller and the programmable controller. Figure 29 shows how to connect the wires in the orange cable to the supervisory controller, while Figure 30 shows how to connect them to the programmable controller. As you can see, the shielding wire (SHD) in the orange cable is only connected to the supervisory controller and not to the programmable controller. This is why the orange cable has three wires on one end and only two wires on the other end.

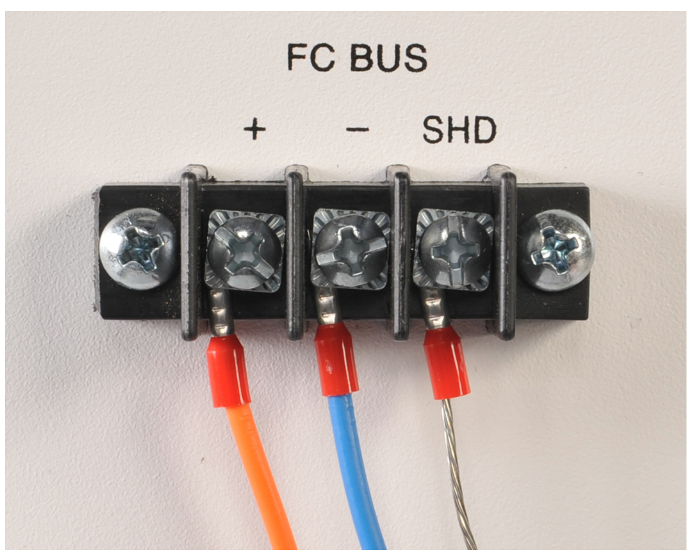

Figure 29. FC bus connections on the supervisory controller.

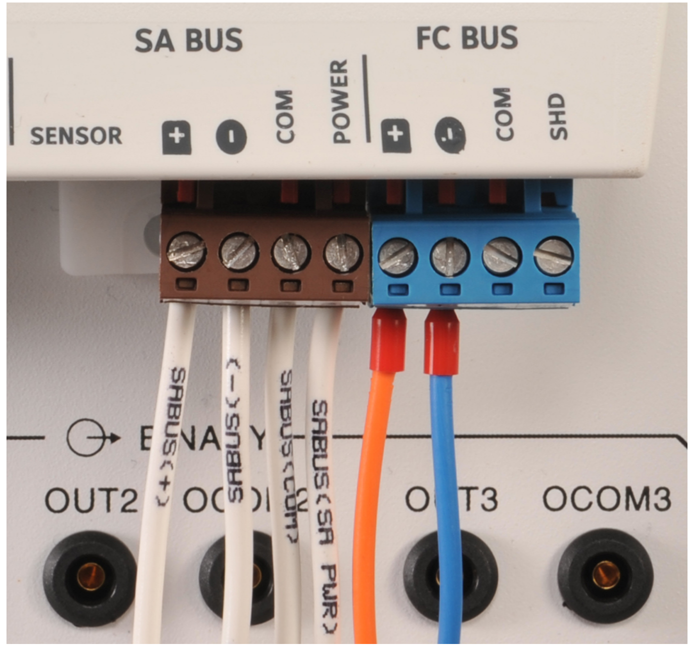

Figure 30. Bus connections on the programmable controller.

12. Use the white wires for the network connection in the SA bus protocol between the programmable controller and the temperature sensor. Figure 30 shows how to connect the white wires to the programmable controller. Figure 31 shows how to connect the white wires to the temperature sensor. As you can see, each white wire has an identification printed on it. Be sure to match the identification on each wire with the identification on the device.

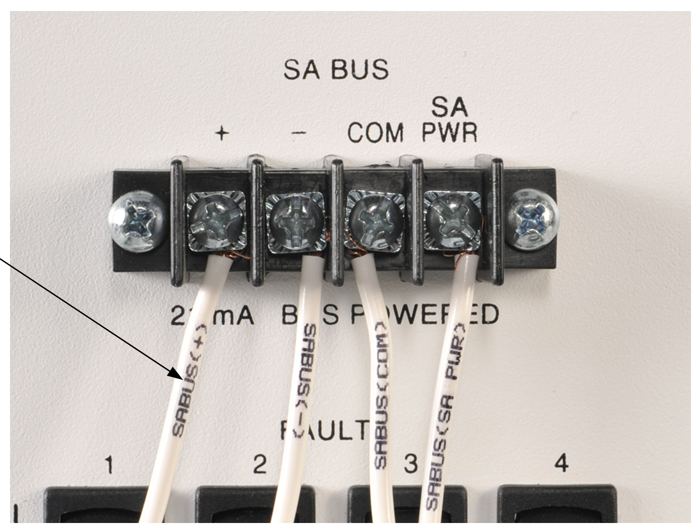

Figure 31. SA bus connections on the temperature sensor.

Input and output connections

In this familiarization exercise, you will connect only some of the inputs and outputs of the programmable controller to the main module. This does not correspond to a fully functional HVAC setup. Several components such as the economizer damper, the hot water coil, and several sensors will not be connected. You will connect a complete setup in the following exercise.

13. The programmable controller has different types of inputs and outputs requiring different connection strategies. Use Figure 32 and Figure 33 to connect some of the inputs and outputs of the programmable controller to the main module. Be careful to connect the modules as shown in the figures. The following exercises of this manual cover in detail the different types of inputs and outputs of the controller.

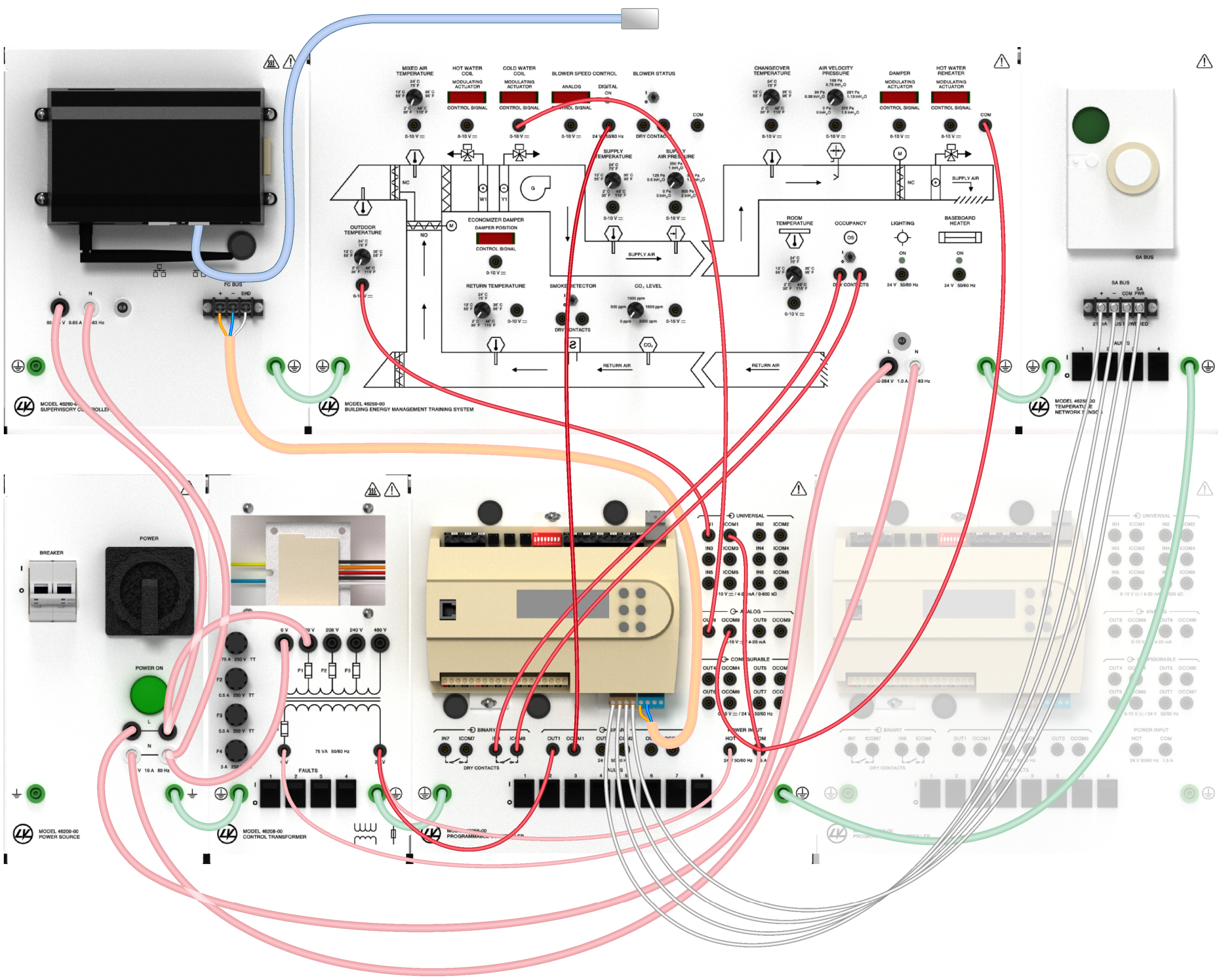

Figure 32. Input and output connections.

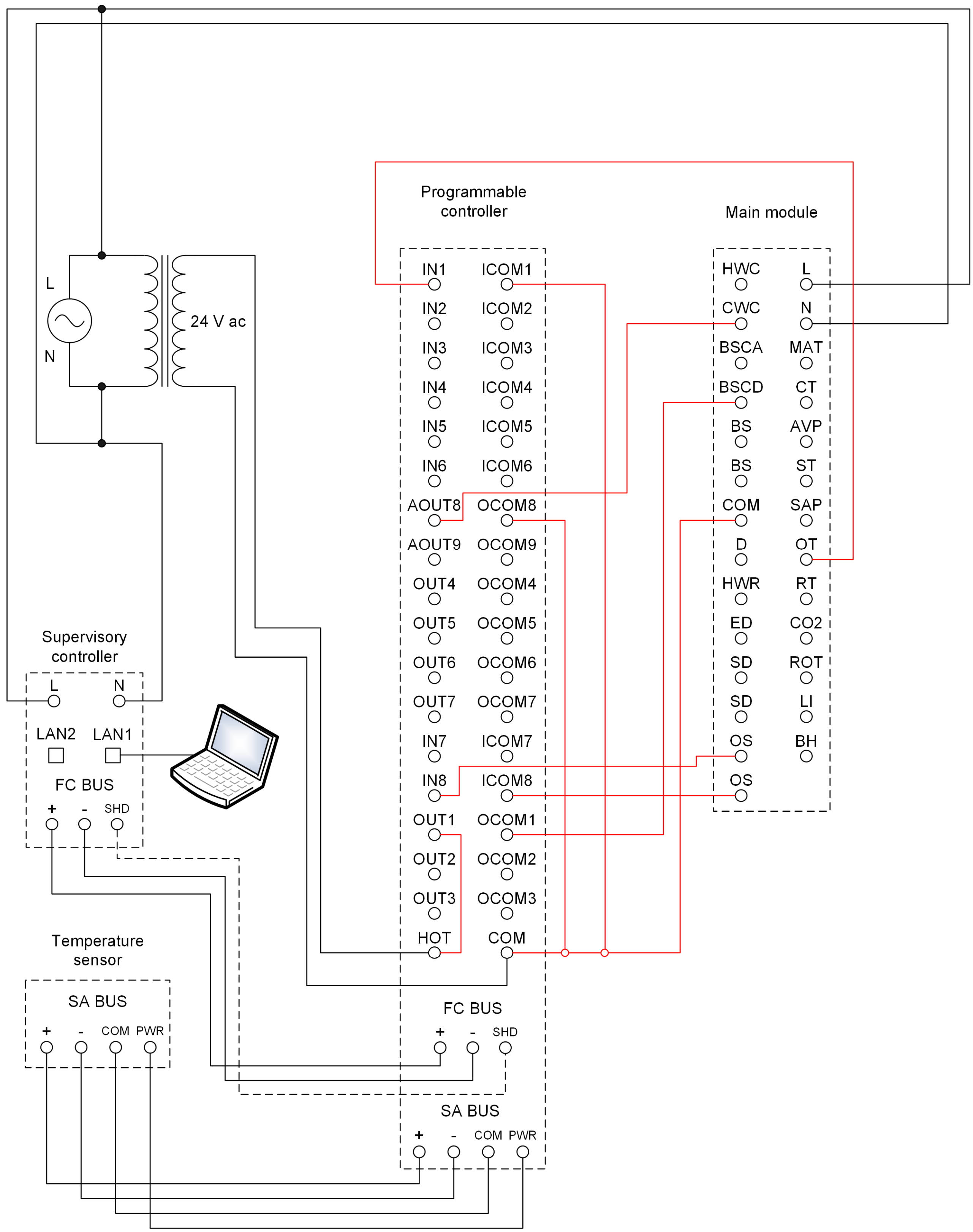

Figure 33. Input and output connections - wiring diagram.

14. 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

15. 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 Energy Management 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.

16. 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

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

18. 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, open the Control Panel, then go to Network and Sharing Center ► Ethernet ► 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)

19. (Optional) To test if the connection with the supervisory controller is established, open the Command Prompt window and type "ping" followed by the IP address of the controller (192.168.1.149).

20. Once you have established communication between the computer and the supervisory controller, start the *Programmable Controller Tool (PCT)* software.

21. In the PCT software, click File ▶ Open, then select the *Rooftop_CAV[revision_date].caf* file from the system's resource disk.

22. Once the program is opened, the software should display a series of tables and tabs similar to what is shown in Figure 34.

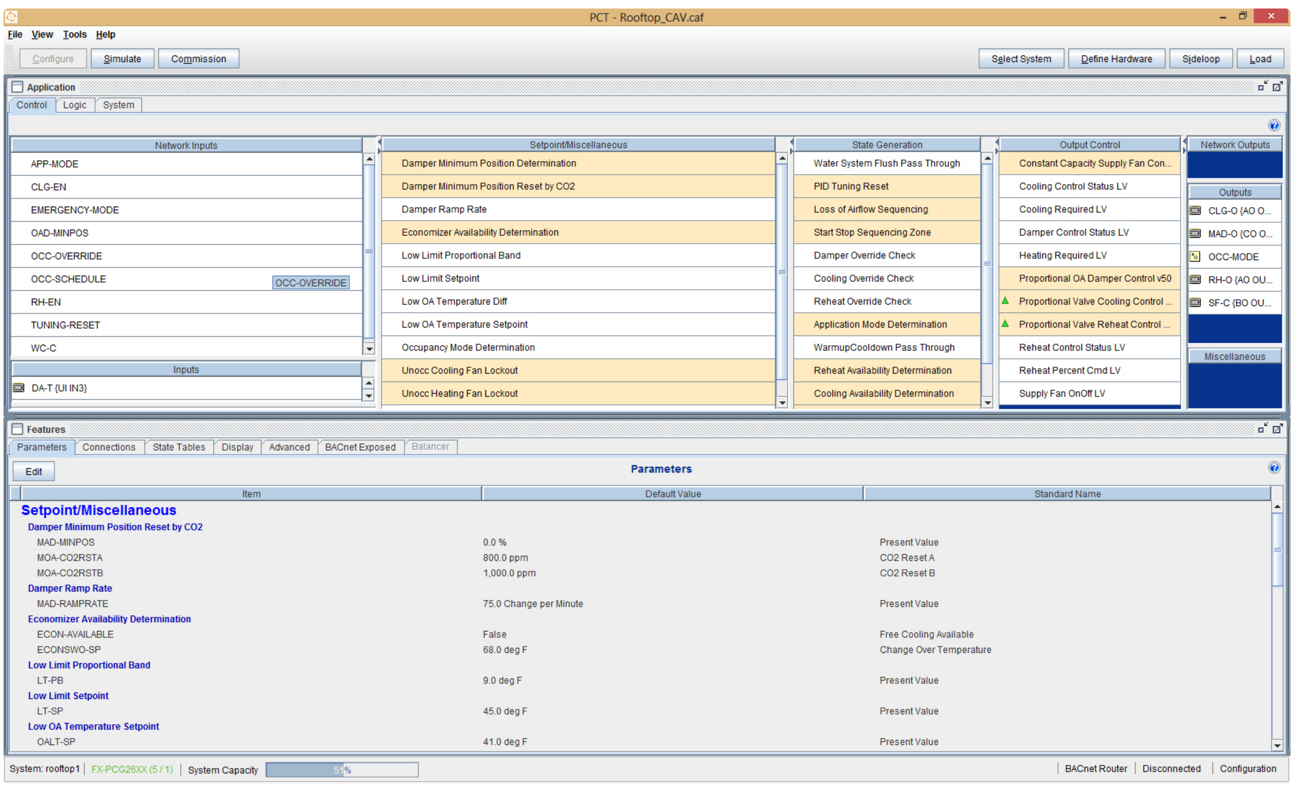

Figure 34. Opened DDC program file.

23. To load the program into the controller, click on Load located in the upper right corner of the software window. This opens the Load Device window shown in Figure 35.

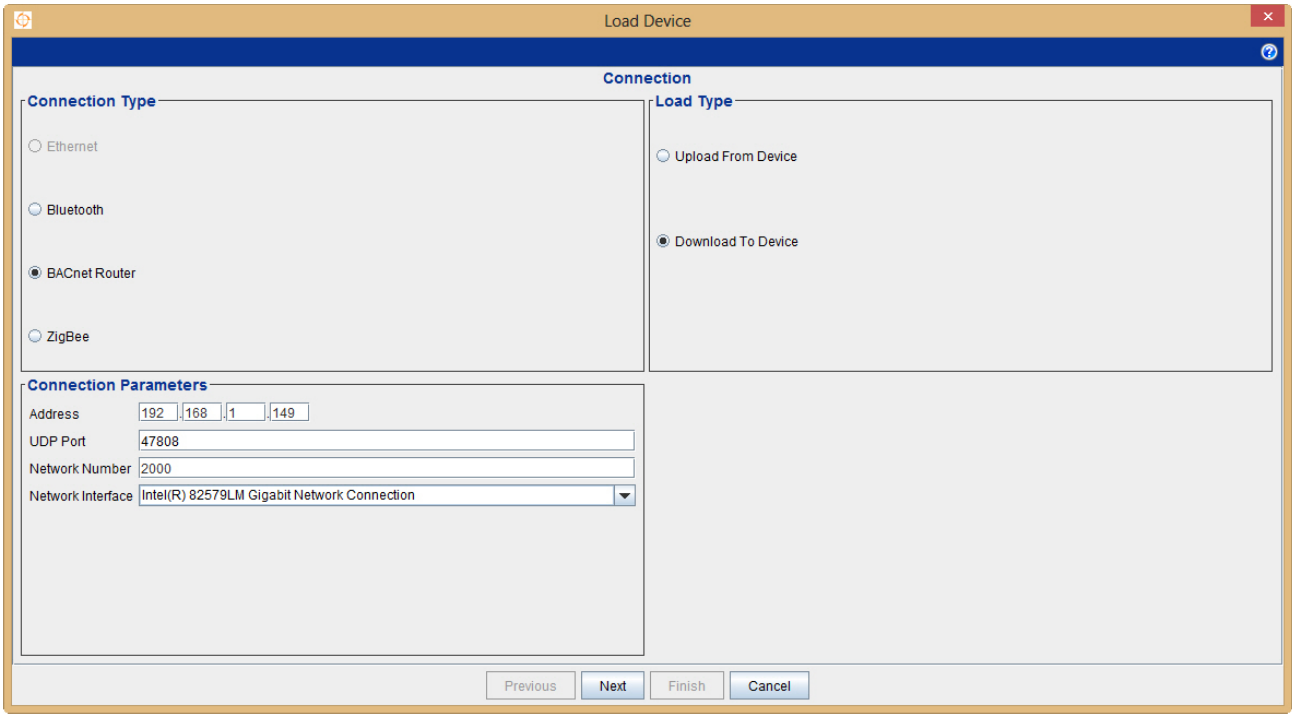

Figure 35. Setting the connection parameters.

24. Set the parameters as shown in Figure 35. 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.

25. Click Next to display the window shown in Figure 36, which presents a list of all devices available for connection with the current DDC program. Note that a device may appear in the list without being available for connection and without being connected to the computer.

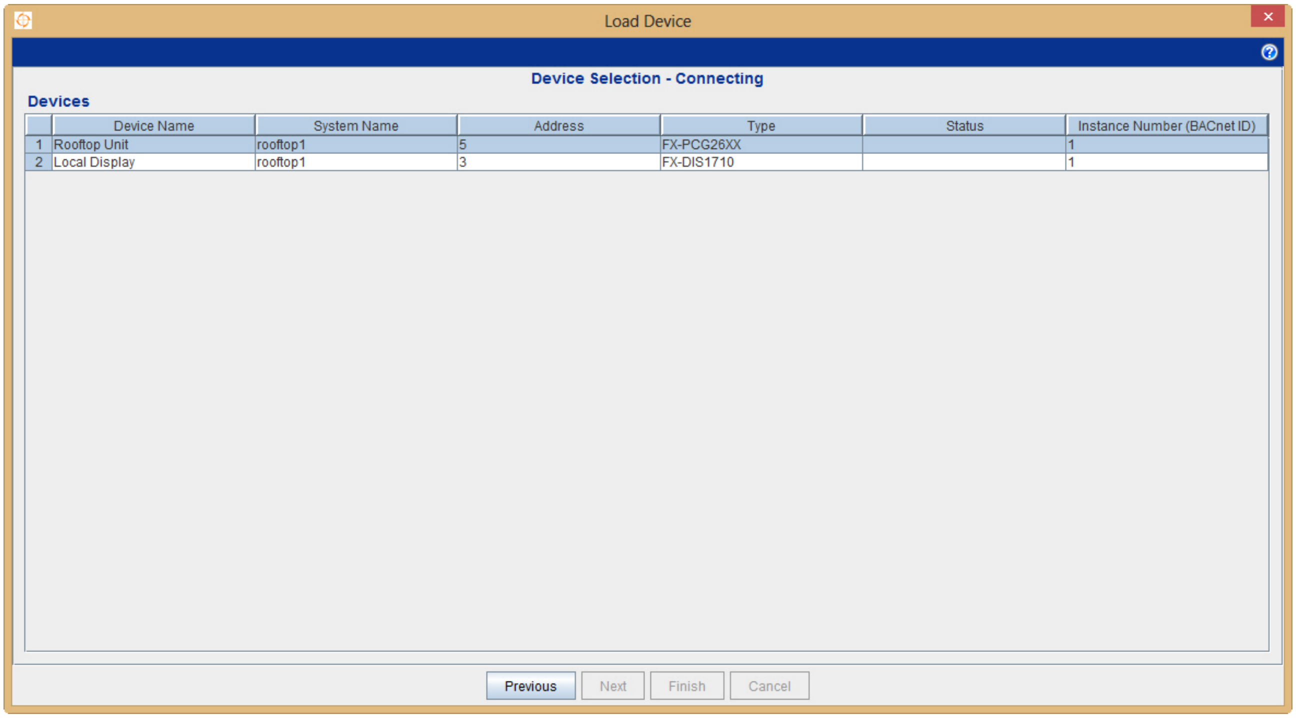

Figure 36. Device selection.

26. From the device list, select Rooftop Unit (this is the programmable controller that is connected to the main module). On the controller module, set the DIP address switches so that they match the number indicated in the address column of the device list. Figure 37 shows how to set the DIP address switches for this exercise (i.e., to address 5).

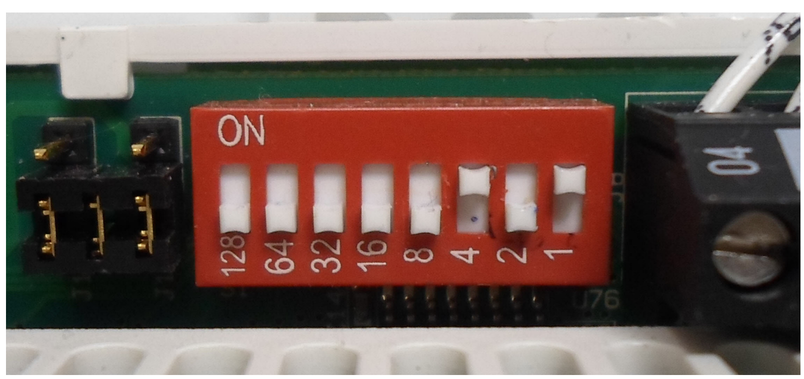

Figure 37. Controller DIP address switches.

27. When all parameters are set correctly, click Next. If the connections are correct, the software displays a load summary, as shown in Figure 38. 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.

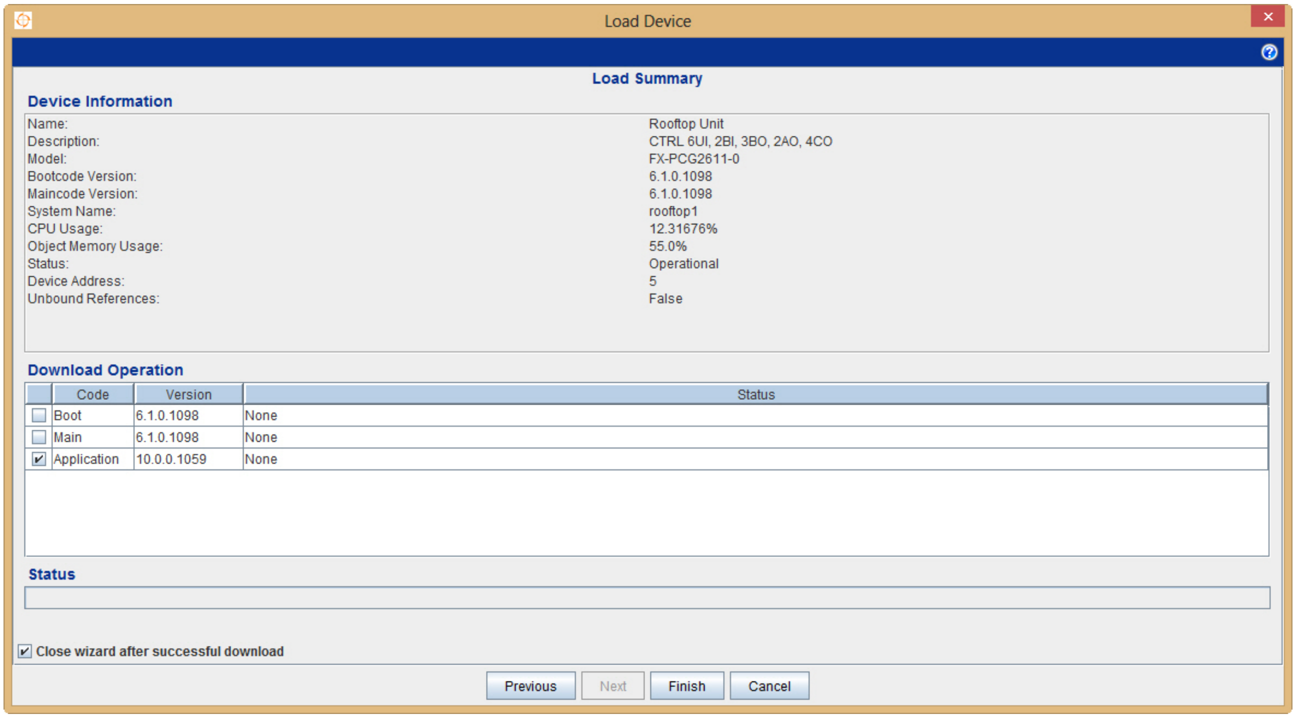

Figure 38. Load summary.

28. Once the program is loaded into the programmable controller, you are returned to the window in Figure 34. In this window, click Commission to display the connection window. Set the parameters as shown in Figure 39.

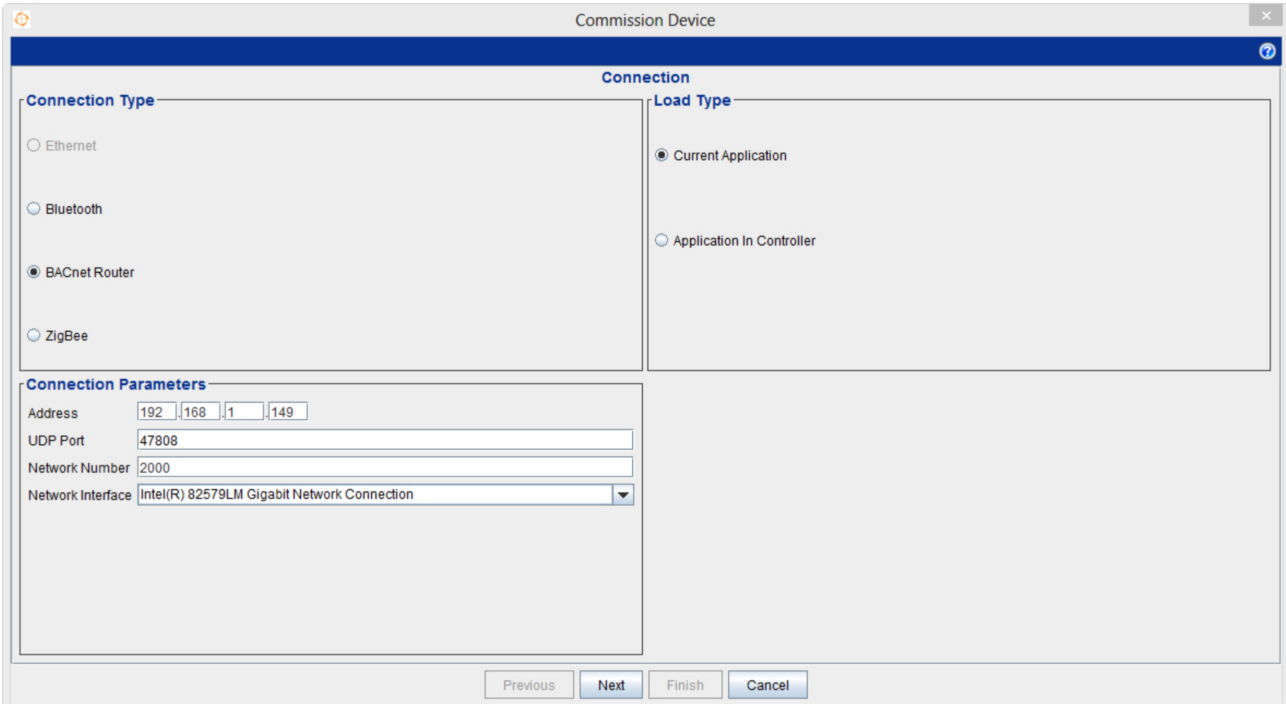

Figure 39. Setting the connection parameters.

29. Click Next to display the window shown in Figure 40. Select Rooftop Unit and click Next.

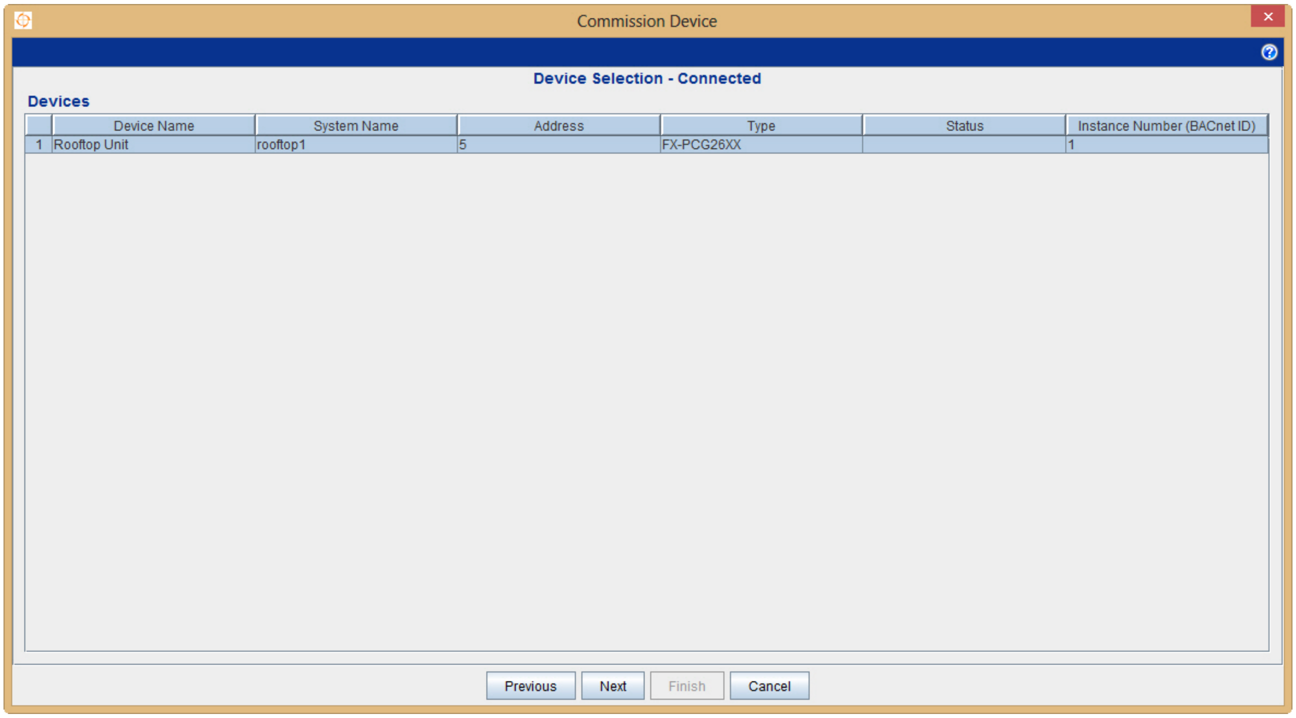

Figure 40. Device selection.

30. If you have set all parameters properly and if the connections are correct, the software displays a load summary, as shown in Figure 41. Click Finish to establish communication with the controller for commissioning.

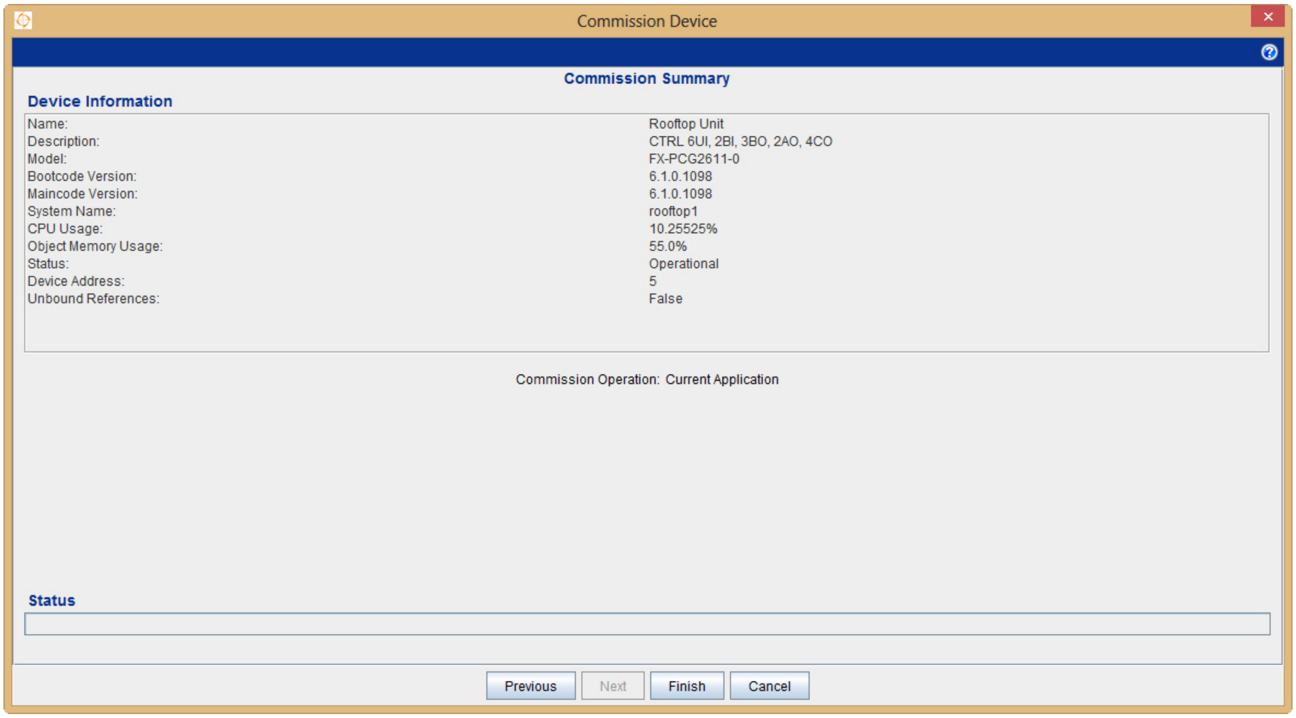

Figure 41. Load summary.

Testing the controller in the commission mode

31. The connection status and the current mode of the software are displayed in the lower right corner of the software window (Figure 42). Make sure the software status is *Connected* and the mode is *Commissioning* before proceeding further.

32. 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 42 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.

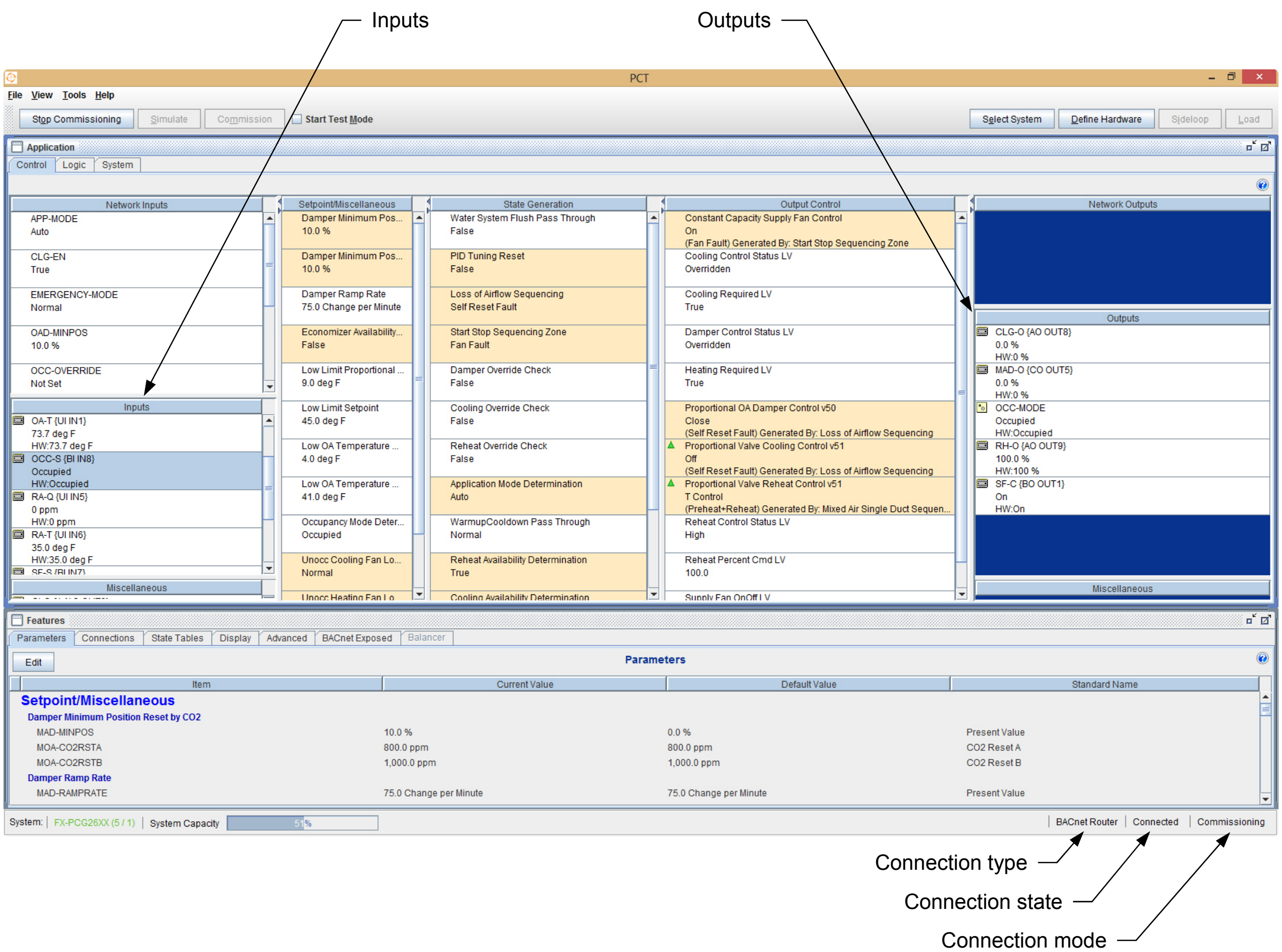

Figure 42. The programmable controller inputs and outputs are listed in the leftmost and rightmost columns of the PCT software, respectively.

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

Input/output identifier	Input/output type	Description
		Reheat: activation level of the hot water coil in the RTU
DA-T {UI IN3}		Discharge air temperature: air temperature inside the supply 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}		

Input/output identifier	Input/output type	Description
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 RTU
	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 RTU, 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 hot water coil in the RTU
DA-T {UI IN3}	Universal input	Discharge air temperature: air temperature inside the supply 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 RTU
ZN-T {UI IN4}	Universal input	Zone temperature: air temperature inside the zone

Input/output identifier	Input/output type	Description
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 cold water coil in the RTU
SF-C {BO OUT1}	Binary output	Supply fan control: controls the operation of the blower in the RTU
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 RTU, on or off

33. 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 main module. 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 43. This would indicate that the input is not properly connected. If it is the case, check all electrical connections.

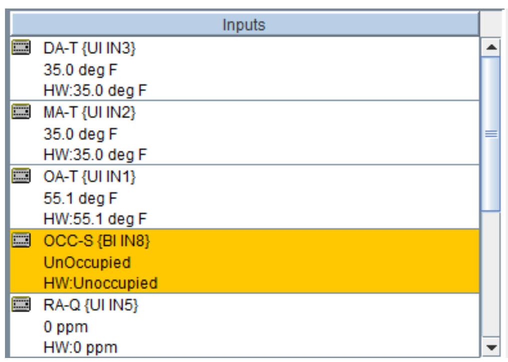

Figure 43. Inputs highlighted in orange are not properly connected.

34. On the main module, 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 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 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

35. In the inputs column of the 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 44.

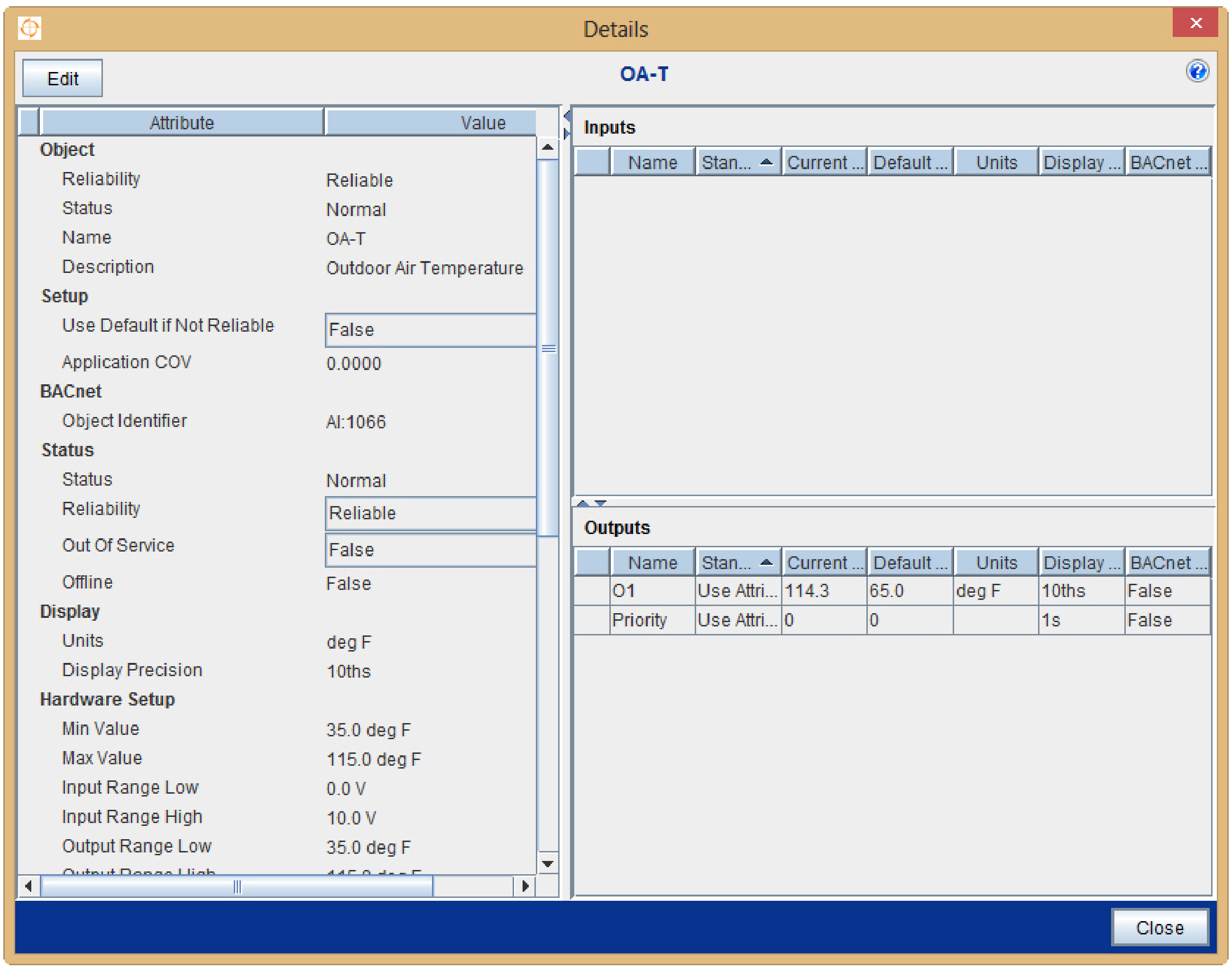

Figure 44. Details window of the OA-T (outside temperature) input.

36. Figure 44 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.

37. On the main module, adjust the outdoor temperature knob to approximately 75°F (24°C). 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 temperature knob?

❑ Yes ❑ No

Yes

38. In the inputs column of the 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.

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

It can take a few seconds before any change happens.

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

❑ Yes ❑ No

Yes

40. 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 damper output signal to a certain value to ensure that the damper reacts accordingly.

To do so, in the Outputs column on the 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 45, which allows a command to be sent to the CLG-O output.

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

On the main module, does the modulating actuator bar meter of the cold water coil currently display approximately 75%, indicating that the override command is in effect?

❑ Yes ❑ No

Yes

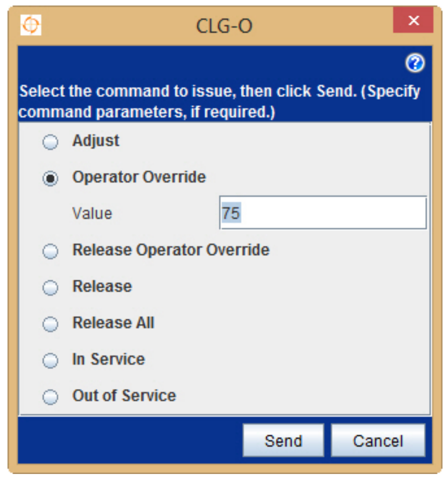

Figure 45. Operator override of the CLG-O output value.

41. 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 46.

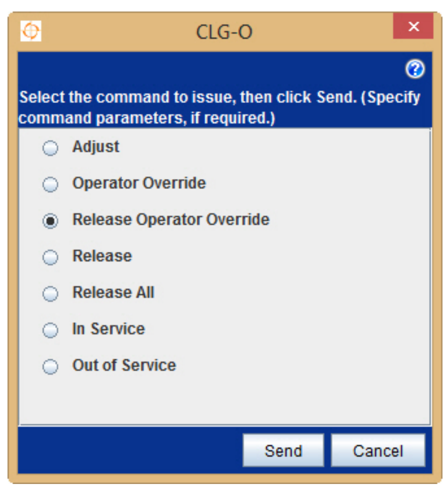

Figure 46. Releasing the cooling output override.

42. Continue experimenting with the system. When you feel you have become familiar enough with it, click Stop Commissioning in the upper left corner of the software window 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.

43. 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, the display of the programmable controller turns 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.

44. Using a voltmeter, measure the voltage across the primary windings of the control transformer, as well as the voltage across the secondary windings. Record the values below.

Primary windings voltage = _______ V

Secondary windings voltage = _______ V

Primary windings voltage = local ac power network voltage

Secondary windings voltage = 0 V

45. Turn the power source off.

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 = 0.8 Ω

46. What can you conclude about the nature of fault 1 from the voltage and current measurements you just made? Explain briefly.

The secondary windings voltage is equal to 0 V, while the primary windings voltage is normal, indicating that the fault is located before the secondary windings in the circuit. The resistance measurements, on the other hand, indicate that the primary windings circuit is open, due to its resistance being infinite. Therefore, it is possible to conclude that fault 1 causes the circuit of the transformer primary windings to be open (either across the 0 V terminal or across the ac power network voltage terminal), just as if fuse 1, 2, or 3 was blown.

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

48. You can add other faults on the control transformer module and troubleshoot them using the same procedure described in this section. When you are finished troubleshooting the module, proceed to the next step.

49. 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 RTU in an HVAC system?

The role of the RTU 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 RTU controller in an HVAC system? Explain briefly.

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

5. What is the role of the control transformer in the Building Energy Management Training System?

In the Building Energy Management Training System, the control transformer is used to convert the local ac power network voltage (e.g., 120 V, 220 V, 240 V) to a voltage of 24 V ac that is suitable for the devices in the system, such as the programmable controllers, for example.

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