Signals and Communication Technology

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Christof Hübner

# Building Automation

## Communication Systems with EIB/KNX, LON and BACnet

*Second Edition*

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# Foreword 2nd Edition

An ever-increasing number of processes are being automated in our modern industrial society. The level of automation in residential and commercial buildings is also steadily increasing due to the demand for more comfort, convenience, security and efficiency. Building automation has become an integral part of automation engineering and offers customized solutions for all types of buildings. In order to process their sometimes very complex functions, the employed sensors, actuators, controllers/regulators and visualizations require suitable industrial communication systems to exchange data among themselves or with external systems. Therefor field buses and computer networks are employed. This book will provide you with an introduction to building automation and building systems engineering and a detailed insight into the following topics:

- Usage of DDC automation devices and energy management functions
- The basics of industrial communication technology
- European Installation Bus (KNX)
- Local Operating Network (LON)
- TCP/IP computer networks and the communication protocol BACnet

We would like to thank all readers for their constructive feedback on the 1. edition of this book. That way, we had the chance to learn that many schools, trade schools, universities of applied science and other universities use our book. We appreciate that a lot. In the present 2. edition many illustrations were updated, a subchapter on usage and planning dimensioning of DDC automation devices was added to chapter 1 and chapter 3 was adjusted to the commissioning software ETS 5.

Solutions to the exercises in this book are available.

Mannheim, Germany
March 2018

Thomas Hansemann
Christof Hübner
Hermann Merz

# Contents

# Chapter 1
# Introduction to Building Automation

## 1.1 What Is Building Automation?

The level of automation in residential and commercial buildings has risen steadily over the years. This is not only due to the increasing demand for more comfort and convenience, but also the benefits building automation brings with regard to saving and managing energy. Security is another important factor, particularly in residential buildings. Whereas in commercial buildings flexibility is high on the agenda—offices buildings, for example, should be designed in such way that they can be easily adapted to meet any change in use or requirements.

### *1.1.1 Building Automation in Private Residential Buildings*

A variety of automated functions are commonplace in many modern residential buildings. One of the most obvious examples is the use of control functions in heating systems for the optimal regulation of energy consumption. Today all new installations have sophisticated combustion controllers and room temperature regulators (thermostats). These thermostats usually come with an in-built timer-switch program for automatically reducing the room temperature at night. These programs have become standard features because they are compatible with a large number of applications, and therefore operate from the word go without the need for any additional programming or configuration.

Automatic lighting control is another example of automation in residential buildings. Exterior lights are often connected to motion detectors, so that they come on automatically should someone approach. Motion detectors detect the heat radiation of an approaching person. Combined with a brightness sensor, this ensures that the light only comes on if it is dark enough. Even though this is a comparatively simple automation function, it nevertheless illustrates the



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combination of event control and logical connections. This example focuses on comfort and ease of use.

A more complex example of automation involves being able to turn all the lights in a house on or off from one central point-particularly useful if you hear an intruder at night. To achieve this with a conventional electrical installation requires an immense amount of wiring, because each lamp needs to have its own wire connecting it directly to the one switch. By connecting all the light switch components to a bus system over which they can communicate, you do not need as much wiring, making it easier and more affordable to implement this panic button function. The focus here is on security.

In summary, automation in private residential buildings focuses on:

- Cost effectiveness/saving energy
- Comfort and convenience
- Security

### *1.1.2 Building Automation in Commercial Buildings*

Commercial buildings within the context of building automation are buildings that serve a purely functional purpose, for example, offices, shopping centers, hospitals, railway stations, airport terminals and underground car parks.

In modern buildings there are a variety of automation systems for heating, ventilating and air conditioning (see Fig. 1.1). To ensure these systems run smoothly and economically, they are fitted with sophisticated controllers, which are often interconnected with each other and to a control center via field buses and networks. These control systems optimize energy consumption and enable support and maintenance personnel to carry out their jobs more efficiently.

Studies carried out on the workplace have shown that staff performance and productivity is at its highest in a comfortable environment and drops considerably if, for example, the temperature in an office is too high during the summer. This has led to the installation of air-conditioning systems in an increasing number of offices in new commercial buildings. Even the way we operate these systems has changed. Today blinds and lights can be controlled from office computers, increasing comfort and usability and, in so doing, optimizing employee productivity and performance [10].

Systems in commercial buildings must be flexible. If a company wants to restructure the layout of an office by converting a large conference room into a number of smaller offices, the layout and set up of the building's operational equipment must enable these changes. Building automation systems enable you to connect a light switch to a light by simply reprogramming the intelligent components, rather than rewiring the electrics. The focus here is on flexibility.

**Fig. 1.1** A ventilation system in a commercial building [1]

In summary, automation in commercial buildings focuses on:

- Cost-effectiveness/saving energy
- Communication via bus systems and networks
- Comfort and convenience
- Flexibility.

## 1.2 The Difference Between Building Automation and Building Control

When we talk about automated functions in buildings, the terms “building automation” and “building control” are often used. At first glance these terms appear synonymous. For clarification the Association of German Engineers (*Verein Deutscher Ingenieure*) defines building automation as follows:

Building automation is the computerized measurement, control and management of building services [11].

From this definition we can deduce that building control is a part of building automation. Building automation was first implemented in commercial buildings to enable functions to run automatically. This also included the first use of direct digital controllers (DDCs) (Fig. 1.2) in heating, ventilation and air-conditioning systems (HVACs). Furthermore, by using a control center you can operate and monitor the systems more effectively, and also create a cross-system network.

Building control is a specific subdivision of building automation that focuses mainly on electrical installations.

Building control refers to the use of an installation bus to connect system components and devices to a system designed for a specific electrical installation that controls and connects all the functions and processes in a building. All of the components have their own "intelligence" and exchange information directly with each other [4].

Building control components, such as four-gang blind actuators (see Fig. 1.3), are usually mounted in a control cabinet or next to the device to be controlled (for example, a blind). Building control systems do not require central DDCs to process control or regulation functions.


**Fig. 1.2** A direct digital controller (DDC) [5]


**Fig. 1.3** A 4-gang blind actuator for mounting in a control cabinet [Busch-Jaeger Elektro]

### *1.2.1 Systems in Building Automation*

Building service equipment includes all the systems necessary for a building to operate, the most important of which are the heating, ventilation, air conditioning, water and electrical energy supply, and sanitation systems such as sewage pumping stations.

DDCs are now essential because the operational processes in a building must operate automatically if they are to be cost effective. The vendor who supplies the DDCs for specific systems is responsible for measuring and controlling (MC) these systems-primarily HVAC. Table 1.1 summarizes the systems in building automation.

Building automation involves coordinating and connecting all the systems in a building, so that they can communicate with each other. This can be achieved in three ways:

- Systems can be connected via DDCs and building control components. This is common in heating, ventilation, air-conditioning, lighting and shade control systems.
- Systems can also be connected via special DDCs that perform only input and output functions. This is common in sanitation and power supply systems that have their own in-built automation mechanisms.

**Table 1.1** Systems in building automation

| System | Usually integrated into building automation | Increasingly integrated into building automation | Systems that are controlled by DDCs or other building automation components |
|---|---|---|---|
| Heating | × | | × |
| Cooling | × | | × |
| Ventilation | × | | × |
| Power supply | × | | |
| Lighting control | × | | × |
| Blinds | × | | × |
| Sanitation | × | | |
| Central fire alarm | × | | |
| Burglar alarm | | × | |
| Access control | | × | |
| Video surveillance (CCTV) | | × | |
| Network engineering | | × | |
| Multimedia | | × | |
| Elevators | | × | |
| Telephones | | × | |
| Maintenance management | | × | |
| Payroll/ accounting | | × | |
| Facility management | | × | |

- If a system needs to transfer a large amount of information or has its own computer, then it can be directly connected to the building automation control computer. Data is then transferred via a bus system or network as opposed to over individual wires. This is common in subordinate video or superordinate accounting systems.

The interfaces between the individual operational systems of each facility must always be clearly defined in terms of data exchange and logistics.

In building automation, information technology is used to link all the systems in a building, enabling them to be centrally monitored by a control computer at the management level (see Fig. 1.4). In older systems, the control computer also processes regulation functions. This is called building management system BMS.

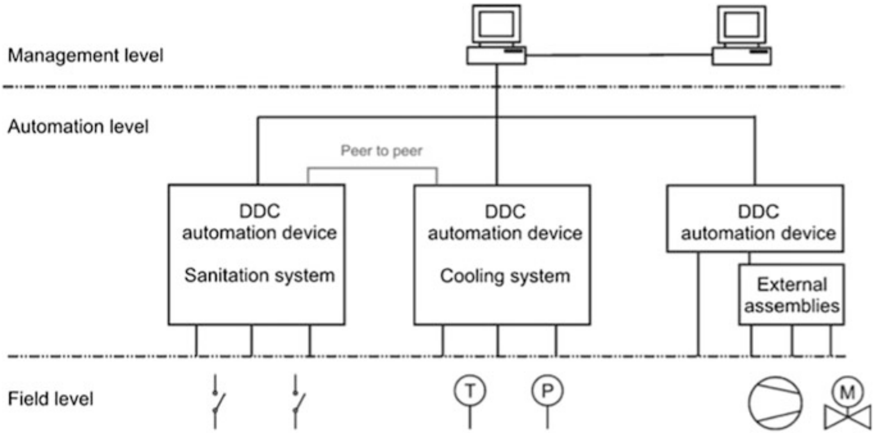


**Fig. 1.4** The IT network of systems in building automation

Information exchange between the individual systems generally occurs at the automation level. Information is transferred over so-called peer-to-peer connections, which are logical pathways that use physical bus or network connections.

Another feature is the external assembly seen at the bottom right. In this case the regulation functions remain in the DDC automation device but the connected assembly processes certain parts of the function individually. Examples for this are frequency inverters for large fans used to control the rate of rotation or electronic meters used to measure energy consumption. In any case the external assembly is connected to the DDC automation device by bus.

### *1.2.2 Systems in Building Control*

Building control represents a small subsection of building automation and involves the localized automation of components in an individual room—known as single room control or room automation (see Table 1.2). The building control components combine all the functions that are needed to provide a comfortable and energy-saving environment. DDCs are not used because the functions are distributed across the intelligent building control components.

**Table 1.2** Systems in building control

| System | Room automation possible with building control components |
|---|---|
| Heating, cooling, and ventilation | × |
| Lighting control | × |
| Shade/blinds | × |


**Fig. 1.5** A building control switch actuator [3]

The individual components for each application are pre-programmed for specific tasks. For example, an intelligent processor-controlled push button directly connected to the bus is used to send the signal to turn on a light. Another component is then used as an intelligent processor-controlled switch actuator to execute the command (see Fig. 1.5). This actuator is either mounted directly next to the light or in a control cabinet.

These types of components are also used to control and regulate radiators. An electronic actuator is installed in the radiator and is connected, via the bus, to a temperature sensor near the door. The beauty of this solution is that it enables you to easily connect the various systems in the room. For example, by installing a presence sensor near the door, you can ensure that as the last person leaves the room, the lights are automatically switched off and the radiator is turned down or off. The automated functions are processed by the building control components and not by a central DDC.

Figure 1.6 gives you an idea of the building control systems found in a room.

## 1.3 The Structure of Building Automation and Control Networks

### *1.3.1 The Hierarchical Structure of Building Automation*

The components required for processing control functions in automated systems are organized hierarchically. Figure 1.7 shows the typical architecture found in building automation.

Right next to the process are the sensors necessary for recording system information in building automation. These include temperature sensors, flow meters and status registration devices (e.g. frost detectors). You will also find actuators for controlling output commands to the operational system interface.

Ventilation systems have valves that regulate the flow rate of the heating circuit, or drives that control the flaps to regulate the amount of air drawn in from outside. Figure 1.8 shows the sensors and actuators (so-called assemblies) in a ventilation system.

Wires connect the sensors and actuators to the DDCs that control and regulate the system(s). For each information such as status messages or sensor signals one

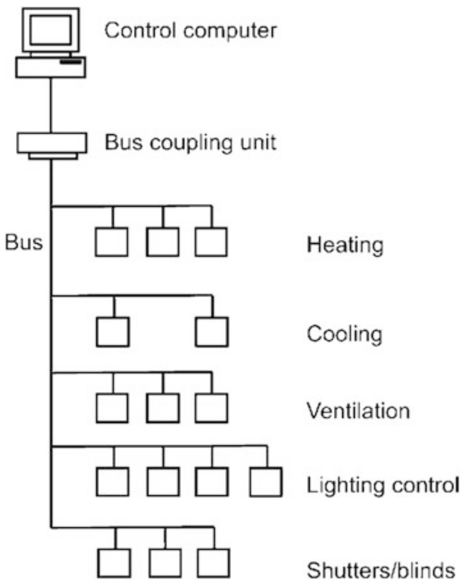


**Fig. 1.6** Building control systems in a room

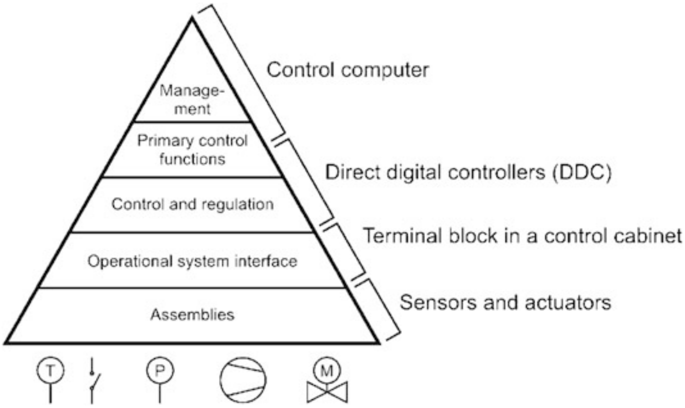


**Fig. 1.7** The hierarchical structure in building automation

pair of wires is used. The DDCs are mounted in a control cabinet (see Fig. 1.9), which is positioned next to the technical system. The close proximity of the control cabinet to the technical system reduces the amount of cabling required. Even a standard ventilation system installed in a commercial building needs ~1.2 km of cable to send and receive 40 information messages. A terminal block is housed in the control cabinet and is used to connect the cables to the technical system, which is why it is called the system interface.

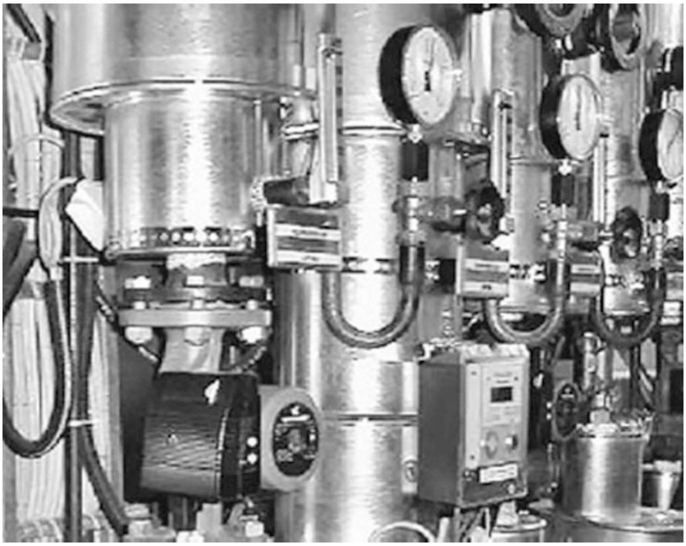

**Fig. 1.8** Sensors and actuators in a ventilation system [1]

**Fig. 1.9** The terminal block and DDCs mounted in a control cabinet [1]

The DDCs housed in the control cabinet process all control functions and, therefore, enable the whole system to operate automatically. The DDCs do not need to be connected to a central control computer. Even at the automation level the

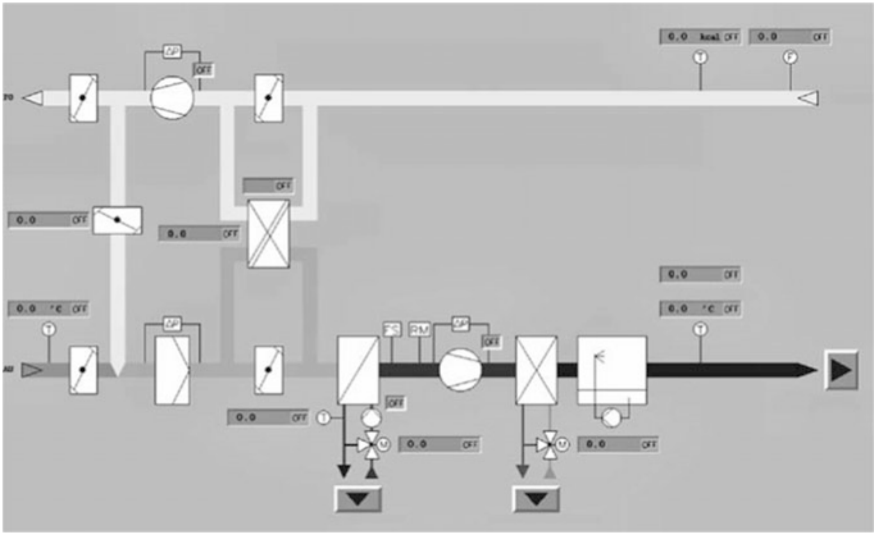

**Fig. 1.10** A ventilation system displayed on a control computer

DDCs have energy-saving programs integrated into their software, for example, for controlling the position of the ventilation flaps to let in the desired amount air from the outside based on the temperature in the room.

If all the systems are in close proximity to each other and the building operator does not have to make constant adjustments, then specially optimized DDC can be used to implement high-level control functions. Alternatively, these high-level control functions can be managed by a control computer (see Fig. 1.10).

Control computers can also execute cross-system functions, because the systems transfer all information over the same transmission medium. An excellent example of this is a timer-switch program set to the times the building is in use. This program automatically shuts down all non-essential systems in the evening and starts them up again in the morning.

The control computer also runs all the necessary building management programs, including logging all events and alarms, archiving all measured readings, and graphically displaying the status of the operational systems. It also forwards information to other computer systems, for example, energy and load meter readings to a main accounting system.

## *1.3.2 The Hierarchical Structure in Building Control*

By housing the sensor together with an in-built processor and a bus connector, you can combine different levels into one (see Fig. 1.11).

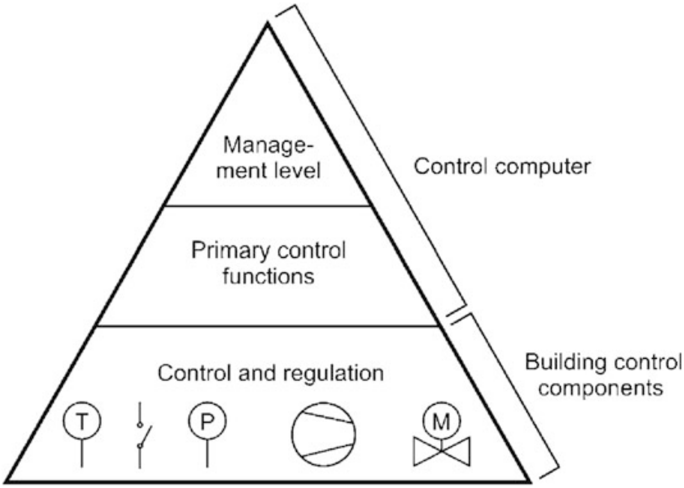


**Fig. 1.11** The special hierarchical structure found in building control systems

**Fig. 1.12** A building control temperature sensor with a setpoint adjuster and control program (a Busch-triton® 5-gang switch sensor with thermostat) [Busch-Jaeger Elektro]

Figure 1.12 shows a device comprising a five-gang switch sensor and a room temperature controller (Busch-triton®). This device contains an in-built sensor and processor. The sensor sends its temperature reading to the processor, which then processes the information. It also allows you to set and control the (programmable) setpoint for the room temperature.

The five-gang switch sensor can send, for example, switching, dimming, blind, measurement, or ventilation messages. The top three rocker switches are assigned to the room temperature controller. The bottom two rocker switches can be used to control the lighting scenes. The integrated LCD displays the actual room temperature, the setpoint temperature and the operating mode.

The operational system interface, shown in Fig. 1.7, is not visible from the outside. Furthermore, the in-built microcontroller controls the system directly. This device regulates the room temperature by comparing the setpoint temperature with the room temperature reading, and then sends the controller's output signal via a bus to the heater's in-built electrical actuator.

## 1.4 Usage of DDC Automation Devices

This subchapter explains the input and output functions of DDC automation devices as part of building automation. Based on a ventilation system the assignment of the device to an operational system is shown in an exemplary way. The chapter is concluded with an overview of the usual scope of services and supplies for a turnkey system.

### *1.4.1 Basic Functions of Building Automation*

The purpose of the DDC automation devices is to monitor, control and regulate the previously named systems (see 1.2.1) independently. To do so, the information from the systems is connected to the DDC by using sensors and actuators. This connection can be either a physical connection using a wire or a communicative connection using a bus. The amount of necessary input and output functions of the DDC highly depends on the size of the system that is to be connected. However, since the different sensors and actuators are very diverse, an adjustment of the automation device to different forms of signals should be considered as well.

The assignment of these functions and their quantity to operational systems is accomplished by using an information list as seen in Fig. 1.13 in accordance with VDI 3814 Part 1 and EN ISO 16484 [12]. The colloquial name of an information list of this kind is data point list. Columns 1–5 of section 1 contain information on which physical input and output functions the required DDCs need to have. The functions mentioned here are called basic functions. The functions mentioned in section 2 refer to a connection of sensors and actuators by bus instead of an

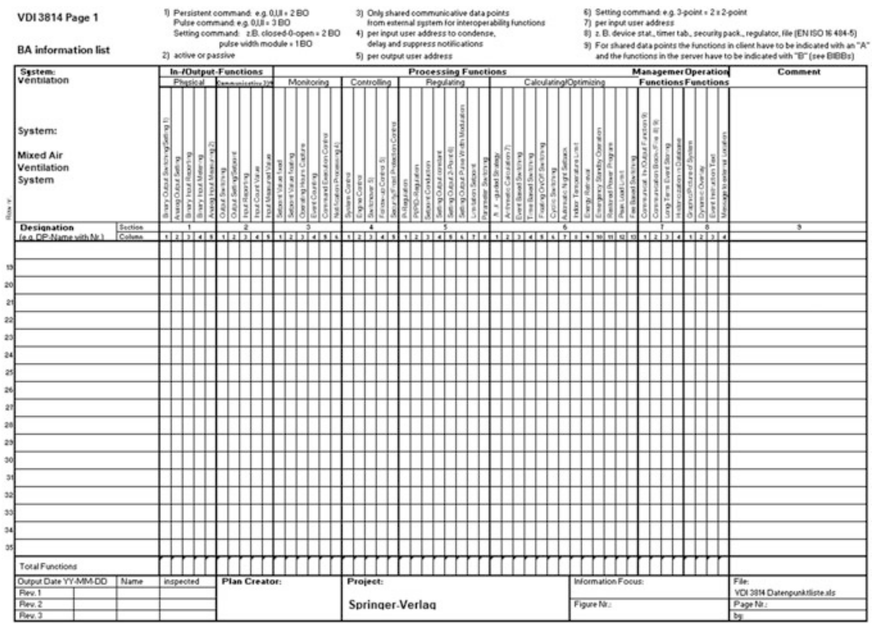


**Fig. 1.13** Information list in accordance with VDI 3814 part 1 and EN ISO 16484

individual connection of every aggregate by wire. For cost efficiency reasons, the individual signals are usually connected by wire.

The additional columns in the information list contain information on the planned processing functions of the DDC for monitoring, controlling, regulating and optimizing (sections 3–6). Many of the energy management functions described in section 5 can be found in section 6. Finally, the last columns are for management and operation functions of the control computer (sections 7–8) [2].

### 1.4.1.1 Basic Function Reporting

The purpose of the basic function reporting is the status detection of information from the operational system. The respective inputs of the DDC automation device are called binary input (BI) or digital input (DI).

Essentially, two kinds of reports can be distinguished for the function reporting. Status and maintenance notifications are gathered with a normally open contact as seen in Fig. 1.14. Since this contact is open by default, the circuit is called normally open (n. o.).

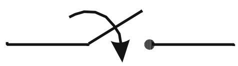

**Fig. 1.14** Basic function reporting by use of normally open contact

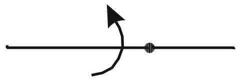

**Fig. 1.15** Basic function reporting by use of normally closed contact for wire break control

Particularly vital information like malfunctioning or alarm notifications are gathered using a normally closed contact as seen in Fig. 1.15. Since this contact is closed by default, the circuit is called normally closed (n. c.). The benefit of this layout is an additional wire break control that can lead to an alarm as well.

#### 1.4.1.2 Basic Function Metering

The purpose of the basic function metering is to gather count values such as values of electricity meters, water meters or heat meters. The respective inputs of the DDC automation device are special binary inputs that are equipped with a conversion function within the device. Impulses provided by meters over potential-free contacts are captured here and converted into energy values. Generic electrical meters provide e.g. 9 impulses per kWh that can be processed for energy data acquisition or for accounting purposes.

The disadvantage of gathering count values by means of a physical wire connection is that a disruption through wire break leads to a difference in the values displayed by the meter and the ones captured by the DDC. In this case, an equalization within the DDC program is necessary. Therefore, the basic function metering is usually realized with a communicative connection of an electrical meter with bus connection (cf. Fig. 1.4 bottom right). Should a disruption of signal occur now, the system can automatically update itself afterwards.

#### 1.4.1.3 Basic Function Measuring

The purpose of the basic function measuring is the capture of steady analog measurement signals from the operational system. The respective input of the DDC automation device is called analog input (AI).

Essentially, two kinds of measurement can be distinguished for the function measuring. There are sensors equipped with electronic components which can convert the captured physical values. For example, sensors that capture the relative humidity in a room belong in this category. The relative humidity can't be measured directly so the sensors are equipped with oscillating circuits with capacitors that are sensitive to moisture. This signal is then converted into an electrical value that is equivalent to relative humidity. The DDC automation device processes output signals from such sensors as active signals. The device can process two active signals:

- 0/4–20 mA and
- 0/2 – 10 V

The purpose of the selectable value range restriction is wire break control. The specified measuring range 0/2 –10 V is a lot more common in building automation. Signals with a specified measuring range of 0/4–20 mA are more common in industry automation.

However, the most common measuring values in building automation are temperature values. Due to the vast number of necessary sensors and the resulting costs, this measurement value is gathered with two-wire technique as a passive signal at the DDC inputs. To do so, the automation device measures the resistance in the range of 0–2000 Ω and converts the result into the respective temperature value. The most commonly used temperature sensor in building automation is the Pt-1000-sensor. At 0 °C, the resistance value of this platinum sensor is exactly 1000 Ω. For temperatures above the freezing point, the resistance value increases by 3.85 Ω/K. For temperatures below the freezing point it decreases respectively.

For the basic function measuring the DDC automatically monitors breaches of set limit values with 2 adjustable top and 2 adjustable bottom values.

#### 1.4.1.4 Basic Function Switching

The purpose of the basic function switching is the control of e.g. motors, fans or pumps in operational systems. The respective outputs of the DDC automation device are called binary output (BO) or digital output (DO). Essentially, two kinds of signal outputs can be distinguished for the function switching.

One way to control aggregates is by pulse command. In this case, an output signal is used for start-up and another output signal is used for shut-off. Additionally, a self-holding circuit must be included in the control cabinet.

The other way to control aggregates is by persistent command. As long as the output contact within the DDC automation device is closed, the aggregate that is to be controlled remains switched on and if the output signal de-energizes, the aggregate is switched off. Since this method saves one output contact, it is usually preferred.

For the basic function switching it is important to notice, that apart from very small aggregates, every switching command includes feedback for execution control as well as malfunctioning notifications from e.g. a motor protection device.

#### 1.4.1.5 Basic Function Setting

The purpose of the basic function setting is the output of continuous and non-continuous signals.

The output of continuous signals is used in operational systems to control heating and cooling valves or continuously variable engines with frequency inverters. The respective outputs of the DDC automation device are called analog outputs (AO). The DDC can output the signals:

- 0/4–20 mA and
- 0/2–10 V

Actuators used in building automation primarily process the voltage signal.

A distinctive function is the output of non-continuous signals. This function is used to control e.g. multistate fans. The basic function setting uses the same kind of binary outputs (BO) as the basic function switching. To control a 2-stage fan with the stages 0–I–II by pulse command, three binary outputs are required.

## 1.4.2 System Information Schema

The basic functions can be assigned to the different systems by combining information from the information list described above and the system information schema (see Fig. 1.16). This schema is colloquially called control diagram. In this case, the picture shows the system information schema of a mixed air ventilation system. The information below the double line include a schematic depiction of necessary control tasks for the DDC automation device. The bottom right corner contains a depiction of the control sequence for the temperature control component CO1 that controls the room temperature. The depicted tasks will be elaborated in Sect. 1.4.3.

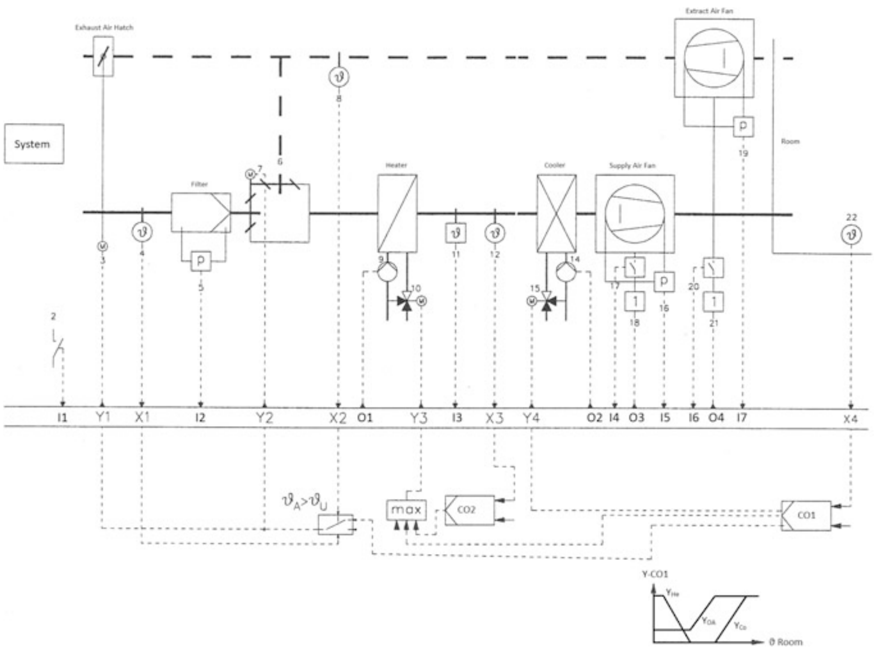


**Fig. 1.16** System information schema of a mixed air ventilation system

The double line also represents the system interface or terminal block. This is where all the aggregates are connected to the DDC automation device using the basic functions explained above. The small arrows point in the direction of primary information traffic. Arrows pointing up towards the system represent output signals. Arrows pointing downwards represent input signals for the DDC automation device. The letters on the double line are abbreviations for input and output functions commonly used in control systems engineering:

- Reports are abbreviated with the letter I,
- Measurement values are abbreviated with the letter X,
- Setting signals are abbreviated with the letter Y and
- Switching commands are abbreviated with the letter O.

The setting signal for the heating valve is called $Y_{He}$ as seen in the control sequence at the bottom right of the schema.

To be able to assign every input and output function to the respective aggregate, all the sensors and actuators depicted in the system information schema are consecutively numbered. This corresponds to the consecutive rows in the information list. For example, number 2 identifies a reporting contact. Regarding the notation, this contact can be identified as a normally open contact. The primary direction of information traffic is from the system towards the DDC automation device. In this case it is a local or remote switch installed in the system. The purpose of this switch is to enable manual operation with simultaneous shutdown of the automatic control (e.g. for test runs).

The complete assignment of basic functions to the mixed air ventilation system can be found in Figs. 1.17 and 1.18.

The depicted information list is an Excel chart. After the assignment of all basic functions has been completed, the necessary amount of input and output functions for the DDC automation device can simply be read in the total line following row 35. In the case mentioned above, 4 binary outputs, 4 analog outputs, 15 binary inputs and 5 analog inputs are required. Additionally, the switching output by bus must be considered.

## 1.4.3 Functions in a Ventilation System

This section gives an example of the necessary control and regulation functions for a DDC automation device assigned to a ventilation system.

### 1.4.3.1 Frost Protection Monitoring

In the mixed air ventilation system depicted in Fig. 1.16, number 11 identifies a so-called frost protector. A frost detector is a special kind of temperature sensors