

# 4

## Building Automation, Control and Management Systems

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In the context of energy in major Western countries, the civil sector, which has been traditionally overshadowed by industry and transport, has become more and more important.

In Europe, for example, approximately 40% of energy consumption is related to the civil sector, with 70% and 30% related to residential and tertiary, respectively. Tertiary and residential buildings, therefore, constitute an important area for the reduction of consumption.

In addition to the most popular tools that are mainly used to address the performance of loads and components, and the thermal insulation of buildings, automation can play a major role in reducing energy consumption without impacting on the development and improvement of the service that is delivered.

The management of both the building and a process should be both efficient and effective:

1. efficient, for example, in creating such an enclosure optimized in terms of thermal insulation;
2. effective, for example, in the management of energy processes, mainly heat and electricity.

The management can be carried out by humans or by automation systems. Automation can help correct those human behaviours that lead to unnecessary consumption, assisting and guiding the user to the optimal management of facilities, saving energy and helping environmental sustainability.

To date, in contrast to what has happened with other technologies, however, building automation systems<sup>1</sup> have not yet seen widespread development for energy saving in buildings.

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<sup>1</sup> Automation, control and management systems of the building are identified by different acronyms depending on the source and on the level: BACS Building Automation and Control System, within CEN; HBES Home and Building Electronic System, within the CENELEC; still TBM Technical Building Management at CEN. Sometimes some uncertainty in the use of such classifications are even found in the original standardization documents. In this text, even to streamline the form in the absence of specification needs and unless otherwise specified, the terms automation or automation system will generally indicate the system and, without distinction, the installation of automation, control and management of the building whether residential or tertiary.

The causes are many. First, despite the obvious benefits, the technology of automation systems is still poorly understood: on the one hand because of the misinformation of the end users, on the other because of the resistance of some professionals to update. Also, in the residential sector, the implementation of an automation system includes a new approach requiring real design and coordination of activities with the end user.

The main reasons, however, are the higher cost of these systems compared with traditional ones, and because this energy efficiency (EE) technology is rarely counted among those that now have government economical support.

The technologies that use renewable sources, as known, are still expensive and their huge success around the world is due mainly to the availability of public incentives.

In addition the estimation of energy and cost savings related to the adoption of an automation system is quite delicate and complex.

In practice, an automated system works better than a human for energy savings, for the following main reasons:

1. Humans don't pay enough attention to energy savings because they are focused on their other main activities.
2. The human senses are usually not sensitive enough to recognize in real time the need or the possibility of switching off a service. For example, lighting is switched on in the morning before sunrise. During the day the contribution of daylight is more than sufficient, but our senses do not immediately perceive that the light level is more than the minimum needed but are only aware of this when the level becomes really excessive.

## 4.1 Automation Functions for Energy Savings

Some automation functions that are often of interest with reference to comfort levels may play an important role in reducing consumption.

The basic idea is very simple: to automate and then optimize the use of existing (electrical and non-electrical) energy uses in a building, switching it off completely or partially when it is not needed.

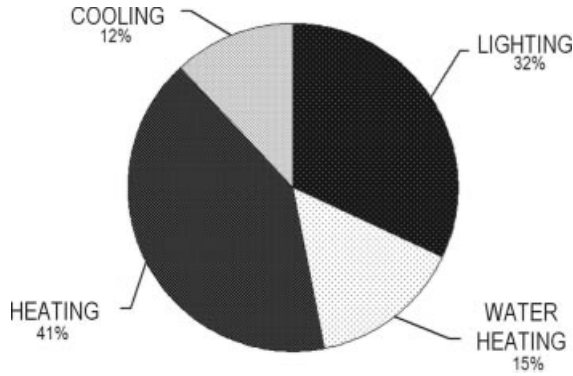
In general, automation tasks related to energy savings are typically quite simple and less expensive than those related to other application classes (Table 4.1).

Figures 4.1 and 4.2 show the percentages of energy consumption in the tertiary and residential sectors. One can easily see that, while the energy consumption for heating is high in both cases, the use of electricity for lighting greatly predominates in the tertiary sector (offices and shopping centres require high energy consumption during working hours).

### 4.1.1 Temperature Control

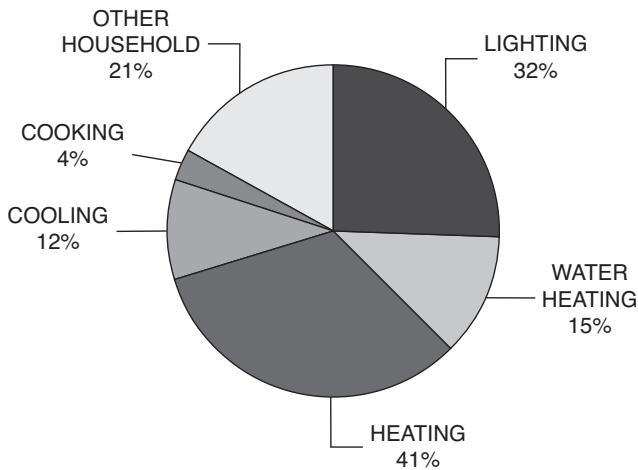
Limiting heating or cooling periods and climatic conditions to real needs allows one to achieve significant reductions in energy requirements in the residential as well as the tertiary sector.

The most important automation functions that are useful in reducing consumption by acting on the temperature controls are:



**Figure 4.1** Energy consumption in the tertiary sector (ref. Italy)

1. Micro-zones with independent thermostats and valves to optimize, at the same time, comfort and consumption, instead of central or no control.
2. Indoor Air Quality (IAQ) control: a sensor analyses the air quality, activating the air exchange system only once the air becomes stale and not just periodically.
3. Air exchange scheduled at times when it is not too cold in winter and not too hot in summer, to avoid excessive temperature gradients and, therefore, losses.
4. Integration of a weather station (rain, wind, brightness) with the temperature control to avoid losses and to implement awnings, blinds, outdoor lighting and irrigation.
5. Adjusting the indoor climate conditions according to occupancy or time, switching off or controlling the opening of doors or windows.



**Figure 4.2** Energy consumption in the residential sector (ref. Italy)

6. Introducing the possibility of local or centralized manual switching between different modes (Comfort, Precomfort, Economy, Off).
7. Introducing a frost protection function to protect furniture and equipment in environments with occasional occupancy.
8. With reference to maintenance and the most efficient operating conditions for the mechanical installation in case of heating only, the sticking of valves during the long period of standstill in the summer can be avoided by setting a function that periodically opens and closes electromechanical devices (antisticking).

#### 4.1.2 Lighting

Limiting the intensity of artificial lighting to when it is really needed during different periods may have an important impact on electricity consumption, especially in the service sector where the corresponding consumption is more important.

The main possibilities offered by an automation system that allows a reduction in energy consumption by acting on the lighting are as follows:

1. Automatically switching lighting on and off with all kinds of lamps (by means of timers or occupancy sensors or the level of light or twilight) instead of manually (with traditional commands or remote control).
2. Command of the power of the marker lamps or LEDs or lighting appliances in general through light sensors.
3. Automatically switching lighting on and off according to motion (high-traffic areas) or with occupancy.
4. Automatic control of external equipment and lighting showcases using a twilight criterion.
5. A temporary switch off of groups of non-critical equipment.
6. Adjustment of the light intensity by means of electronic devices to increase or decrease the light level using sensors instead of traditional manual commands of various kinds.
7. Brightness automated control for the maximum use of natural lighting with artificial lighting integrated only when needed.
8. Switching between different groups of devices that are programmed to optimize the useful life of sources.
9. The ability to count the hours of operation of an apparatus by optimizing preventive and routine maintenance.
10. The replication of the command points (individual and group) anywhere the bus cable is, will increase the probability of an effective human intervention.

#### 4.1.3 Drives and Motors

The automation of a function for reducing a consumption as well as the introduction of a drive involves an additional consumption. But for various reasons, including laziness and lack

of sensitivity of human senses, the balance can become easily positive, since, practically and statistically, human actions are not so effective.

The main functions of automation, based on drives that can lead to a reduction in consumption, are as follows:

1. Shutters for windows and door locks can be automated. To reduce energy losses the opening and closing doors can be controlled by micro switches, scenarios, timers or can be operated by remote control, or controlled by light sensors or weather stations that measure wind speed and the presence of rain. Similarly, awnings can be automated.
2. Venetian blinds: move up/down and angle adjustment of blades.
3. Integration with electric door locks.
4. Irrigation systems: scheduling start and end times to open and close water valves or depending on sunlight, avoiding unnecessary wastage of water if it rains, and preventing damage to plants.
5. Integration with systems management pools.
6. Control of shading devices (blinds, shutters, etc.) manually or automatically. Operations such as up, down, opening, closing or tilting of the slats can be made automatically depending on the position of the sun to avoid direct sunlight with less need for air conditioning in the summer (energy saving) and glare protection (greater visual comfort for workstation screens).
7. Integration of the command and control scenarios for meeting rooms, multipurpose rooms, showrooms, etc.
8. Weather alarms (rain, wind, frost) can maximize the use of control shading devices, putting them to a secure position or blocking them just when necessary.

#### *4.1.4 Technical Alarms and Management*

Technical alarms can also play an active role in limiting the consumption of a building: the detection of an abnormal condition at the outset avoids the system operating in abnormal conditions where it could be less efficient with higher losses, etc.

The main functions of automation that can lead to a reduction in consumption in a building are as follows:

1. The detection of hazardous gases such as methane, LPG, carbon monoxide (in the kitchen, garage, near fireplaces and stoves), smoke, fire, flood water.
2. The closing of solenoid valves for gas and water in a given scenario.
3. Combining an actuator, plug sockets can be switched off for selected users, eliminating the consumption of appliances in standby mode without switching off the users who require uninterrupted power.
4. Protective automatic reset in case of nuisance tripping.
5. Installation management.
6. Scheduling events, bidirectional control via phone or internet.
7. Environmental and/or electrical parameter monitoring and logging for trend analysis.

### 4.1.5 Remote Control

Remote control of the system can help in reducing the consumption of a building, allowing direct human intervention in the unexpected situations that require it. The ability to intervene directly when there is an unexpected situation avoids, at the outset, the operation of the system in conditions that are potentially characterized by a lower efficiency, higher losses, etc.

The main automation functions leading to a reduction in consumption based on remote control are:

1. Control of bus devices.
2. Enquiry of the status of bus devices.
3. Delivery of alarms or events.
4. Command and/or control of multiple coordinated functions.

## 4.2 Automation Systems

The line between traditional electrical systems and automation systems can be found in the native ability to communicate, of each device developed for the automation system:

1. Low voltage electrical systems in the traditional control device act directly on the power circuit of the controlled user.
2. In the automation systems, the control circuit is separated from the power circuit. The former consists of a network through which signal control devices and actuators, with their own electronic processing and communication, are able to exchange information in the form of messages encoded in digital form. The loads and the devices that need the power supply to operate are connected to the power network (power bus) and, for control, in addition to a signal bus. The devices that do not need a power supply to operate, like the command button, for example, are connected just to the signal bus.

The applications that are achievable with a traditional system differ, in practice, from those achievable with an automated system. This is because as soon as a bit more articulated logic is needed, the wiring complexity of the traditional system increases exponentially to the point of making the implementation impractical.

Applications built with an automation system can be classified as shown in Table 4.1.

Those of interest for energy saving are virtually all in Class 1. There is sometimes confusion over the differences between SCADA (Supervisory Control and Data Acquisition) systems and Distributed Control Systems (DCS). Generally speaking, a SCADA system always refers to a system that coordinates, but does not control processes in real time. The discussion on real-time control is muddled somewhat by newer telecommunications technology, enabling reliable, low latency, high speed communications over wide areas. Most differences between SCADA and DCS are culturally determined and can usually be ignored. As communication infrastructures with higher capacity become available, the difference between SCADA and DCS will fade. SCADA and DCS are compared below.

1. DCS is process oriented, while SCADA is data acquisition oriented.
2. DCS is process driven, while SCADA is event driven.

**Table 4.1** Application classes of an automation system

Class 1	
Command	Lighting, heating, ventilation, air conditioning, actuation in general
Alarms	Rescue, intrusion, gas leak, fire, flood, technical alarms
Sound diffusion	Control
Class 2	
Sound diffusion	Speakers
Communication	Phone, etc.
Class 3	
Communication	Broadband video

3. DCS is commonly used to handle operations on a single zone while SCADA is preferred for applications that are spread over a wide geographic location.
4. DCS operator stations are always connected to its I/O, while SCADA is expected to operate despite failure of field communications.

Elements of a distributed control system may directly connect to physical equipment such as switches, pumps and valves or may work through an intermediate system such as a SCADA system.

### 4.2.1 KNX Systems

KNX<sup>2</sup> is a specific DCS system that consists of a series of input/output connected to a shared transmission medium, a bus, plus some system devices necessary for operation. Each device on the network exchanges information containing a set of datapoints, i.e. control and process variables that each device interprets. The data points can be inputs, outputs, parameters and diagnostic data.

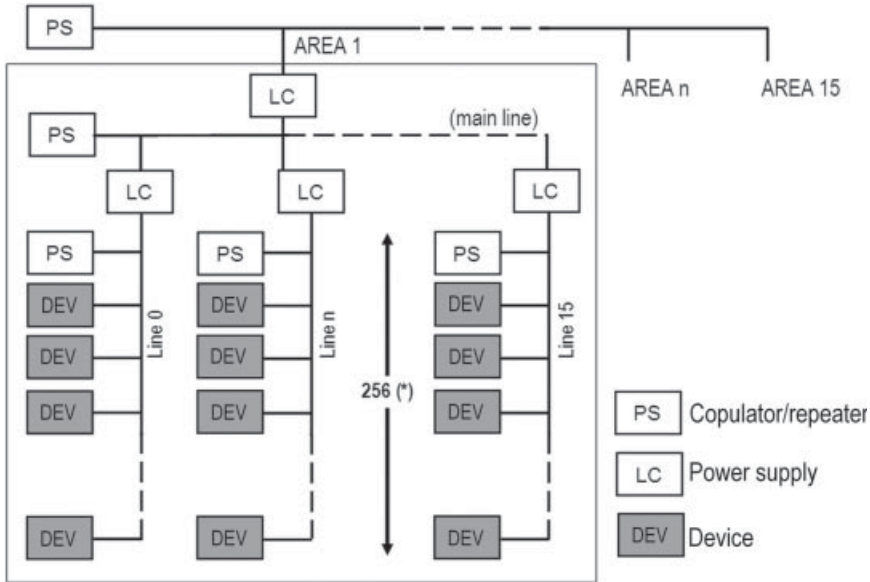
These simple rules of communication together with the characteristics of the transmission medium constitute the architecture of the KNX system.

A KNX system is a distributed computing network (i.e. there is no device that centralizes the logic of the system) whose nodes have an individual address of 16 bits. In total therefore, in theory, up to 65 536 devices can be addressed.

#### 4.2.1.1 Architecture

By analysing the routing rules and some electrical rules, for a KNX network you obtain the overall architecture shown in Figure 4.3.

<sup>2</sup>Of the DCS systems available on the market, KNX systems are the only ones that are standardized by an International IEC standard. In the author's opinion, standardization is a crucial issue for the possibility of the future development of automation in buildings.



**Figure 4.3** General architecture of a KNX network (\*). Each line, separated by an LC, is made by a maximum of four segments each one made by a maximum of 64 devices

### *Area, Line Device*

The KNX technology, line level, allows any topology: star, tree and bus, but not ring. A series of up to 256 devices is a line. A maximum of 15 lines can be connected by a main line, constituting an area. A KNX installation can contain up to 15 areas, connected by a backbone line.

### *Physical Address*

Each part of the KNX network, with the exception of power, is uniquely identified by a physical address. The address consists of three numerical fields separated by a dot:

1. The 1<sup>st</sup> field defines the area of belonging (range from 0 to 15).
2. The 2<sup>nd</sup> field indicates the line (range from 0 to 15).
3. The 3<sup>rd</sup> field identifies the device (range from 0 to 255).

### *Group Address*

The equipment in a system communicate with each other via KNX group addresses. Normally, the group addresses are structured in a hierarchy with three levels:

1. The main group, normally it is the system level (e.g. lighting, temperature control, etc.).
2. The group, a unique feature of the system considered (e.g. switches, dimmers, etc.).
3. The subgroup, devices belonging to the same function (e.g. light kitchen, bedroom window, etc.).



Group addresses are represented by separating the numeric fields that define the main group, the group and the subgroup using the forward slash (/). There is also a version of routing groups at two levels, but it is less used.

**Power Supply**

The power supply is the device that supplies power to devices connected to the bus line. The power supply is normally fed directly to the mains voltage and provides a DC voltage of 29 V directly to the bus terminals.

**Coupler (Line, Field, Repeater)**

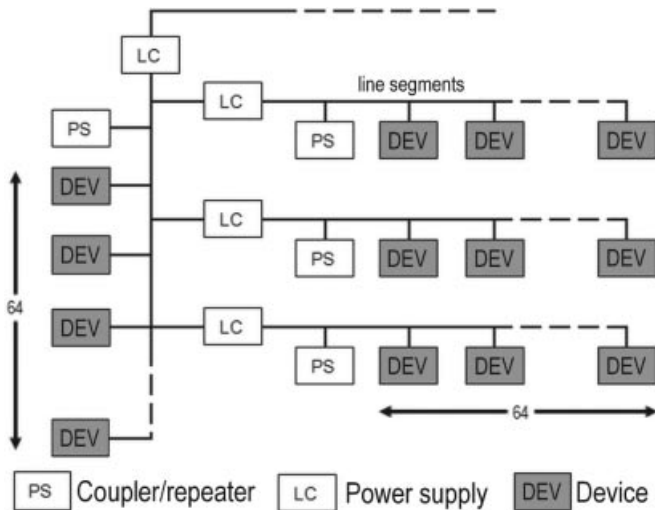
A bus line with a power supply is generally determined by a maximum of 64 connected devices, taking into account the power consumption of the devices and the total maximum current.

KNX on each line, however, can be theoretically up to 256 devices connected to the bus if the line is structured into four segments (Figure 4.4), each with its own power supply; they are connected together by repeaters.

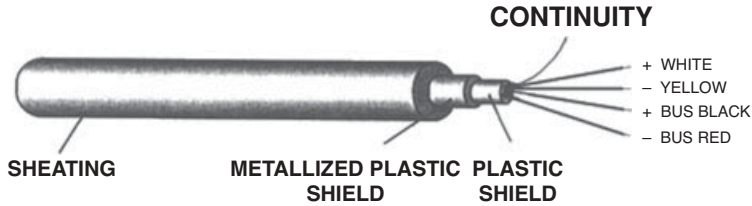
A repeater is just a special way of employing a coupler that galvanically separates bus lines and regenerates the signal, which prevents an electrical fault propagating to other lines and also allows one to expand the ‘overall architecture’ of a KNX system up to a maximum of 65 536 devices.

The device coupler can be used in different ways:

1. coupler area/region: linking the areas along the main backbone (backbone line)
2. line coupler/area: linking the lines in an area along the main line (main line)
3. repeater (booster) links two line segments, regenerating the degraded signal.



**Figure 4.4** Maximum size of a KNX line



**Figure 4.5** Twisted pair

- filter frames: you can set the device coupler to block the transmission of some telegrams, thereby avoiding when unnecessary to send them across the network. The scope is to increase the ability of communication and decrease the likelihood of errors and collisions between packages.

The couplers are addressed as any other KNX device, and can only be configured with the ETS software.

#### 4.2.1.2 Transmission Media

##### *Twisted Pair – TP*

This is a communication cable through a bipolar twisted (helical winding), shielded and double insulated cable.

In a KNX system the bus TP-1 derived from EIB, speed 9600 bits/s is to be used. Through this transmission medium KNX and EIB can communicate with each other and are fully interoperable.

The cable to be used (Figure 4.5) shall be certified KNX as YCYM type 1 or  $2 \times 2 \times 0.8 \times 2 \times 0.8$  mm. In the case of 4-wire the red–black wire pair is for signal transmission and power and the yellow–white pair for additional SELV applications. Where it is necessary to use halogen-free cables, the cable type is KNX certificate JH (St) H  $2 \times 2 \times 0.8$ .

#### 4.2.1.3 Power Line

For PL (Power Line), communication uses existing power lines (230 Vac, 50 Hz) superimposing on the power voltage high frequency waves encoding control information. The two modes of transmission are:

- PL-110: EIB derived, 1200 bits/s. With this means of transmission KNX and EIB communicate and are fully interoperable with each other.
- PL-132: derived from EHS, 2400 bits/s. EHS and KNX devices can be connected but do not communicate with each other without an appropriate converter.

#### 4.2.1.4 Radio Waves

With RF (Radio Frequency) transmission, communication is operated via radio waves to 868.30 MHz carrier frequency transmission inside the ISM band (Industrial Scientific

Medical), with a speed of 16.38 kbit/s. The logic states 0 and 1, needed for the digital encoding of the message are generated by a deviation from the carrier frequency.

The RF devices, which can be divided into two groups depending on the communication, may be unidirectional or bidirectional.

#### 4.2.1.5 Ethernet

Independently of the particular transmission medium, in this case the communication is done by transferring KNX telegrams over an Ethernet network encapsulated in packages in standard protocol IP (Internet Protocol).

According to a procedure known as 'KNX/IP routing', in the largest installations, the IP network can be used as a high speed backbone (Fast-Backbone) to send KNX telegrams.

#### 4.2.1.6 Configuration

Once the devices have been installed and the bus has been connected, two more steps are needed to put the installation into service:

1. The level of network topology, when the physical addresses are defined: in practice in this step the global architecture of the system is created.
2. The level of node, when the configuration of the application of each node are defined and the group addresses are defined (binding). The group addresses are the logical links between two or more devices connected to the KNX network. Without this link, all the devices on the network receive all the messages, but are unable to understand if the message was addressed to themselves or to another device.

Guaranteeing the consistency of the protocol and the interoperability between the devices, the KNX standard allows one to adopt devices with different configuration methods.

A KNX device can be configured in three different ways:

1. System (S-mode): it is necessary to use a PC with the ETS software.
2. Easy (E-mode): no need for a PC but other techniques for programming functions.
3. Automatic (A-mode) will not be further investigated as it is specified for the consumer market.

Table 4.2 compares the characteristics of the E-mode and S-mode configuration methods.

#### *S-mode*

The S-mode configuration is ideal when functions are required for automation and control and the various and complex system requirements are high with reference to the number of devices, the personalization features and the spatial distribution (building automation systems in the strict sense): it is based on the ETS software and requires the use of a PC.

The main advantage of this method lies in the flexibility of the design and the configuration.

**Table 4.2** Comparison between E-mode and S-mode

Characteristics	E-mode	S-mode
Max. number of devices	64	>64.000
Network architecture	One line	Maximum 15 lines per area and maximum 15 areas
Configuration	Configurator or ETS software	ETS software only
Protocol	KNX	KNX
Functions settable on the devices	The main one only	all

***E-mode***

The E-mode configuration installation is possible in two ways:

1. using a simplified method of steps leading to the reduction and simplification of all the steps necessary to put into service;
2. using the ETS software.

The E-mode devices, unlike the S-mode, already contain within them the possible configurations that, although they limit the number of functions available, on the other hand they greatly simplify the process of commissioning the system.

The available functions are usually sufficient to meet all the domestic application needs.

**4.2.2 Scada Systems**

SCADA generally refers to computer systems that monitor and control industrial, infrastructure, or facility-based processes. The term SCADA usually refers to centralized systems that monitor and control entire complex sites or buildings.

It was initially developed for:

- Infrastructure processes including electrical power transmission and distribution, wind farms, civil defence siren systems, water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, and large communication systems.
- Industrial processes including those of manufacturing, production, power generation, fabrication and refining, and it may run in continuous, batch, repetitive, or discrete modes.

They have also been quickly adopted in facility processes, including buildings, airports, ships, and space stations. They monitor and control HVAC, access, and energy consumption.

A SCADA System typically consists of the following subsystems:

- A Human–Machine Interface (HMI) is the apparatus that presents process data to a human operator and, through this, the human operator monitors and controls the building or the process.
- A supervisory system, acquiring data on the building and sending commands to it.

- Remote Terminal Units (RTUs) connecting to sensors in the building, converting sensor signals to digital data and sending digital data to the supervisory system.
- Programmable Logic Controller (PLCs) used as field devices because they can be more economical, versatile, flexible, and configurable than special-purpose RTUs.
- Communication infrastructure connecting the supervisory system to the Remote Terminal Units.

Most control actions are performed automatically by Remote Terminal Units (RTUs) or by Programmable Logic Controllers (PLCs). Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an HVAC large unit, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop.

Data acquisition begins at the RTU or DSC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (DSC) controls. Data may also be fed to a Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing.

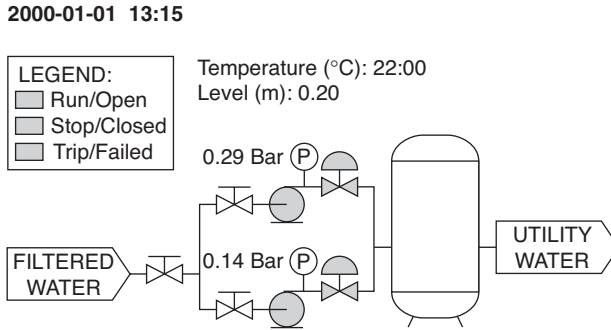
SCADA systems typically implement a distributed database, commonly referred to as a tag database, which contains data elements called tags or points. A point represents a single input or output value monitored or controlled by the system. Points can be either hard or soft. A hard point represents an actual input or output within the system, while a soft point results from logic and math operations applied to other points. Most implementations conceptually remove the distinction by making every property a 'soft' point expression, which may, in the simplest case, equal a single hard point. Points are normally stored as value-timestamp pairs: a value, and the timestamp when it was recorded or calculated. A series of value-timestamp pairs gives the history of that point. It is also common to store additional metadata with tags, such as the path to a field device or PLC register, design time comments, and alarm information.

#### **4.2.2.1 Human-Machine Interface**

A Human-Machine Interface is the apparatus that presents process data to a human operator, and through which the human operator controls the process.

An HMI is usually linked to the SCADA system's databases and software programs, to provide trending, diagnostic data, and management information, such as scheduled maintenance procedures, logistic information, detailed schematics for a particular sensor or machine, and expert-system troubleshooting guides.

The HMI system usually presents the information to the operating personnel graphically, in the form of a mimic diagram (Figure 4.6). This means that the operator can see a schematic representation of the plant being controlled. For example, a picture of a pump connected to a pipe can show the operator that the pump is running and how much fluid it is currently pumping through the pipe. The operator can then switch the pump off. The HMI software will show the flow rate of the fluid in the pipe decrease in real time. Mimic diagrams may consist of



**Figure 4.6** Typical Basic SCADA Animations

line graphics and schematic symbols to represent process elements, or may consist of digital photographs of the process equipment overlain with animated symbols.

The HMI package for the SCADA system typically includes a drawing program that the operators or system maintenance personnel use to change the way these points are represented in the interface. These representations can be as simple as an on-screen corridor light, which represents the state of an actual corridor light, or as complex as a multi-projector display representing the position and parameters of all the water pumps in a big building.

An important part of most SCADA implementations is alarm handling. The system monitors whether certain alarm conditions are satisfied, to determine when an alarm event has occurred. Once an alarm event has been detected, one or more actions are taken (such as the activation of one or more alarm indicators, and perhaps the generation of email or text messages so that management or remote SCADA operators are informed). In many cases, a SCADA operator may have to acknowledge the alarm event; this may deactivate some alarm indicators, whereas other indicators remain active until the alarm conditions are cleared. Alarm conditions can be explicit – for example, an alarm point is a digital status point that has either the value NORMAL or ALARM, which is calculated by a formula based on the values in other analogue and digital points – or implicit: the SCADA system might automatically monitor whether the value in an analogue point lies outside high and low limit values associated with that point. Examples of alarm indicators include a siren, a pop-up box on a screen, or a coloured or flashing area on a screen (which might act in a similar way to the ‘fuel tank empty’ light in a car); in each case, the role of the alarm indicator is to draw the operator’s attention to the part of the system ‘in alarm’ so that appropriate action can be taken. In designing SCADA systems, care is needed in coping with a cascade of alarm events occurring in a short time, otherwise the underlying cause (which might not be the earliest event detected) may get lost in the noise. Unfortunately, when used as a noun, the word ‘alarm’ is used rather loosely in the industry; thus, depending on context, it might mean an alarm point, an alarm indicator, or an alarm event.

#### 4.2.2.2 Remote Terminal Unit (RTU)

The RTU connects to physical equipment. Typically, an RTU converts the electrical signals from the equipment to digital values such as the open/closed status from a switch or a valve, or measurements such as pressure, flow, voltage or current. By converting and sending these

electrical signals out to equipment the RTU can control the equipment, such as opening or closing a switch or a valve, or setting the speed of a pump. It can also control the flow of a liquid.

SCADA solutions often have Distributed Control System (DCS) components. Use of 'smart' RTUs or PLCs, which are capable of autonomously executing simple logic processes without involving the master computer, is increasing. A standardized control programming language, IEC 61131-3 (a suite of five programming languages including Function Block, Ladder, Structured Text, Sequence Function Charts and Instruction List) is frequently used to create programs that run on these RTUs and PLCs. Unlike a procedural language such as the C programming language or Visual Basic, IEC 61131-3 has minimal training requirements by virtue of resembling historic physical control arrays. This allows SCADA system engineers to perform both the design and implementation of a program to be executed on an RTU or PLC. A Programmable automation controller (PAC) is a compact controller that combines the features and capabilities of a PC-based control system with that of a typical PLC. PACs are deployed in SCADA systems to provide RTU and PLC functions. In many electrical substation SCADA applications, 'distributed RTUs' use information processors or station computers to communicate with digital protective relays, PACs, and other devices for I/O, and communicate with the SCADA master in lieu of a traditional RTU.

Virtually all major PLC manufacturers offer integrated HMI/SCADA systems, many of them using open and non-proprietary communications protocols. Numerous specialized third-party HMI/SCADA packages, offering built-in compatibility with most major PLCs, have also entered the market, allowing mechanical engineers, electrical engineers and technicians to configure HMIs themselves, without the need for a custom-made program written by a software developer.

#### **4.2.2.3 Supervisory Station**

The term 'Supervisory Station' refers to the servers and software responsible for communicating with the field equipment (RTUs, PLCs, etc.), and then to the HMI software running on workstations in the control room, or elsewhere. In smaller SCADA systems, the master station may be composed of a single PC. In larger SCADA systems, the master station may include multiple servers, distributed software applications, and disaster recovery sites. To increase the integrity of the system the multiple servers will often be configured in a dual-redundant or hot-standby formation providing continuous control and monitoring in the event of a server failure.

#### **4.2.2.4 Communication Infrastructure and Methods**

SCADA systems have traditionally used combinations of radio and direct serial or modem connections to meet communication requirements, although Ethernet and IP over SONET/SDH is also frequently used at large sites such as railways and power stations. The remote management or monitoring function of a SCADA system is often referred to as telemetry.

This has also come under threat with some customers wanting SCADA data to travel over their pre-established corporate networks or to share the network with other applications. The legacy of the early low-bandwidth protocols remains, though. SCADA protocols are designed to be very compact and many are designed to send information to the master station only when

the master station polls the RTU. Typical legacy SCADA protocols include Modbus RTU, RP-570, Profibus and Conitel. These communication protocols are all SCADA-vendor specific but are widely adopted and used. Standard protocols are IEC 60870-5-101 or 104, IEC 61850 and DNP3. These communication protocols are standardized and recognized by all major SCADA vendors. Many of these protocols now contain extensions to operate over TCP/IP. Although some believe it is good security engineering practice to avoid connecting SCADA systems to the internet so the attack surface is reduced, many industries, such as wastewater collection and water distribution, have used existing cellular networks to monitor their infrastructure along with internet portals for end-user data delivery and modification. This practice has been ongoing for many years with no known data breach incidents to date. Cellular network data is fully encrypted, using sophisticated encryption standards, before transmission and internet data transmission, over an 'https' site, is highly secure.

RTUs and other automatic controller devices were being developed before the advent of industry-wide standards for interoperability. The result is that developers and their management created a multitude of control protocols. Among the larger vendors, there was also the incentive to create their own protocol to 'lock in' their customer base. A list of automation protocols is being compiled here.

Recently, OLE for Process Control (OPC) has become a widely accepted solution for intercommunicating between different hardware and software, even allowing communication between devices originally not intended to be part of an industrial network.

### 4.3 Automation Device Own Consumption

For a correct assessment in principle in an automation system the device's own consumption should be considered to estimate the total consumption (and eventually corresponding cost). However, as is easily understood, the consumption of the devices is very low compared with the energy savings introduced: it is therefore possible to ignore them without introducing a significant error.

Table 4.3 lists the most frequent consumptions by the devices used in the proposed design solutions for automation systems.

The voltage supplied from the KNX system bus is 30 VDC, the power consumption of devices can vary from 30 mW to 540 mW. So usually low power consumption does not significantly affect the total consumption and can be neglected in the calculation.

### 4.4 Basic Schemes

This section describes the automation functions that are useful for a rational use of energy. For easy reference, the functions have been divided on the basis of the system under control.

#### 4.4.1 Heating and Cooling

##### 4.4.1.1 Automatic Control of Every Room by Thermostatically Controlled Valves or Electronic Regulator (Figure 4.7)

In every room there is a controller (R) that is not coordinated with those of other environments. The device is not connected to the bus, but it has a current output to control the discharge valve



**Table 4.3** Typical automation device’s own consumption (ref. KNX)

Device	Own consumption (mA)
Actuator 1 channel	5
Actuator 4 channels	10
Actuator 8 channels	15
Actuator 12 channels	15
Actuator 1 channel for motor	8
Actuator 2 channels for motor	18
Actuator 8 channels for motor	18
Actuator dimmer	7
Contact interface 4 channels	9
Infrared motion sensor	5
Thermostat	5
Chronothermostat	5
Control panel*	2
Touch screen panel*	1
USB interface	5

*Note:* Own consumption for the control panel and touch screen panel indicate the power drawn by the only bus system, as these devices are powered directly from the mains.

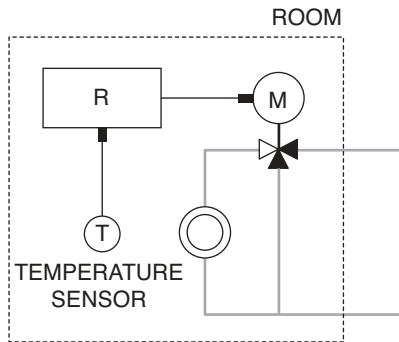
of the heat transfer fluid. Alternatively, a thermostat could be used or a thermostatic valve for the environment.

**Category**

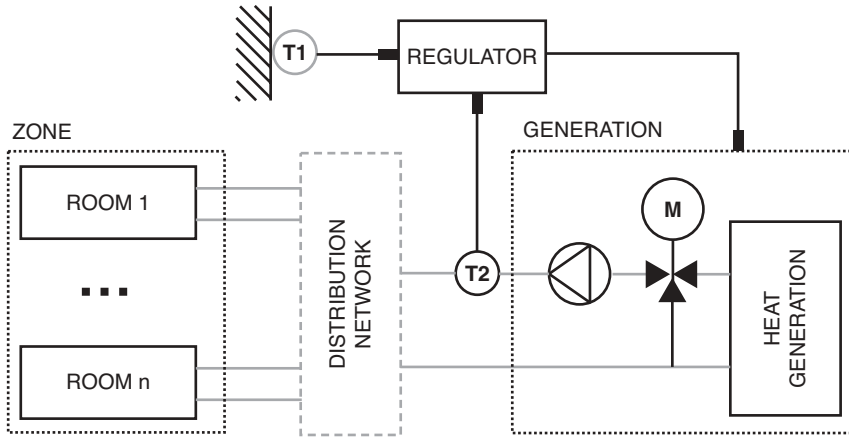
Emission control

**Logic**

Temperature can be adjusted in each individual zone, but there is no communication between the controllers.



**Figure 4.7** Automatic control of every room by thermostatically controlled valves or electronic regulator scheme



**Figure 4.8** Control of water temperature with compensated supply temperature depending on the outside temperature

### *Main Components*

Stand alone thermostats or electronic controllers

Thermostatic valves

#### **4.4.1.2 Control of Water Temperature with Compensated Supply Temperature Depending on the Outside Temperature (Figure 4.8)**

The regulator (R) sends a signal to the heat generator on the basis of which the temperature of the fluid is varied depending on the outside temperature. Temperature sensors detect the temperature of the fluid flow (T2) and the external flow temperature (T1). There are no room temperature sensor nor communication with the bus outside the thermal sub-system.

### *Category*

Water temperature control in the distribution system (supply and return)

### *Logic*

The temperature of the heat transfer network is adjusted with outside temperature compensation. For thermal calculations, it needs the flow temperature to obtain an average temperature inside the zone to the set point value.

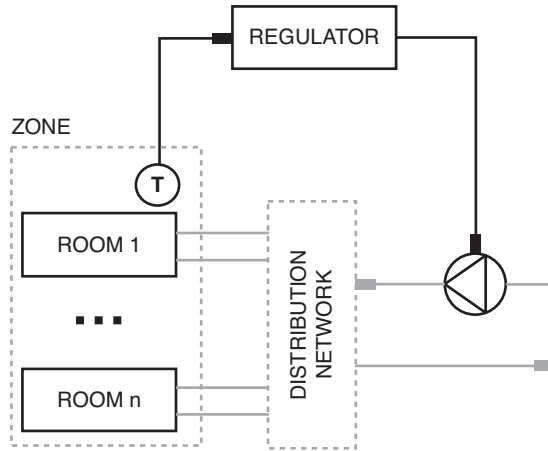
### *Main Components*

Electronic controller with:

- External temperature sensor
- Supply temperature sensor

#### **4.4.1.3 On/Off Control of Distribution Pump (Figure 4.9)**

The On/Off control on the distribution pump is based on the temperature set on the thermostat of the area, which activates or stops the flow of heat transfer fluid. In the compact boiler, pump



**Figure 4.9** On/Off control of distribution pump

distribution is usually built inside the compact boiler. There is no communication with the bus outside the thermal sub-system.

**Category**

Distribution pump control

**Logic**

Controller (R) stops the function of the distribution pump when the temperature exceeds the set point. Operation starts again when the temperature drops below the set point.

**Main Components**

Regulator or thermostat

**4.4.1.4 Automatic Control Function with a Fixed Time Program (Figure 4.10)**

The thermostat, which is the same for all environments, measures the temperature of the area using a sensor (T) and handles the generation operation based on time and on the temperature set point. The circulation of the heat transfer fluid is started by commanding, for example, the pump (PG) and the distribution valve (VG), when the zone temperature falls below the prescribed value during the time set on the thermostat. There is no expected communication with the bus outside the thermal sub system.

**Category**

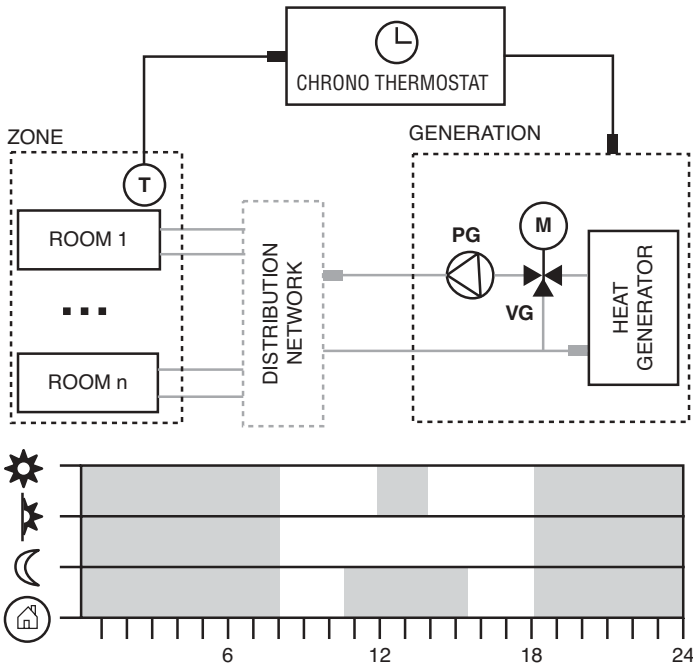
Generation and/or distribution and intermittent clock

**Logic**

The control works according to the time and the temperature profile set on an environment thermostat in anticipation of the presence of people but without considering the variations in thermal load and the actual occupancy.

**Main Components**

Thermostat or electronic controller



**Figure 4.10** Automatic Control Function with a fixed time program

**4.4.1.5 Partial Interlock (Depending on the HVAC System)**

The interlock between heating and cooling systems consists of a controller (RC) that activates the heating when the outside temperature is below the heating set point (e.g. 20°C), and a controller (RF) that activates the cooling when the outside temperature is above the cooling set point (e.g. 24°C). The sensor signal TE can vary the width of the neutral zone depending on the outside temperature.

The scheme depends on the type of system used.

**Category**

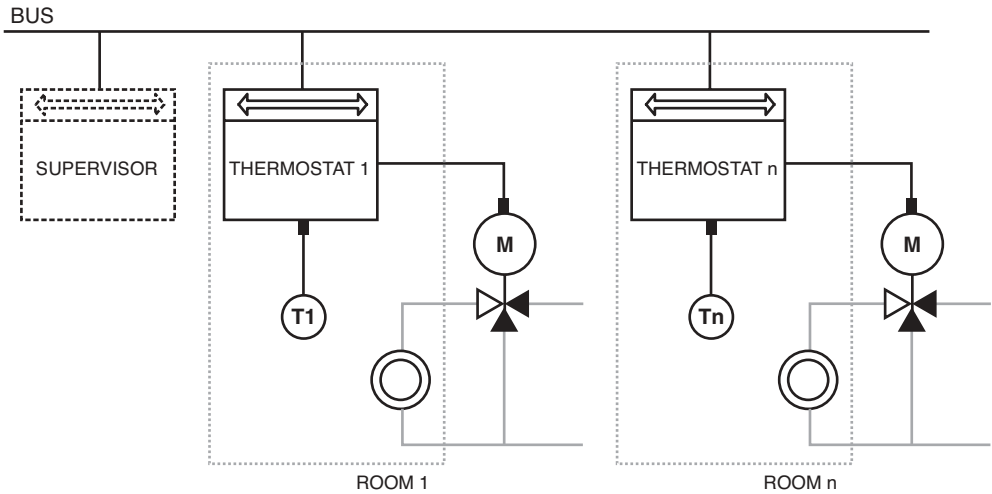
Interlock between heating and cooling at an output and/or distribution level

**Logic**

The flow temperature of the two heat transfer fluids can be influenced by the outside temperature to decrease the possibility of heating in summer and cooling in winter. To minimize the possibility of simultaneous heating and cooling, the control function is achieved by providing a suitably large interval between the flow temperature of the heat transfer medium and that of the cold heat transfer (neutral zone).

**Main Components**

- Heating flow regulator
- Cooling flow regulator
- Outside temperature sensor



**Figure 4.11** Function of automatic control of any room with communication between the regulators and toward the system BUS

#### 4.4.1.6 Function of Automatic Control of Any Room with Communication Between the Regulators and Toward the System BUS (Figure 4.11)

The temperature of each room can be adjusted by a thermostat coordinated with regulators in other rooms.

##### *Category*

Emission control

##### *Logic*

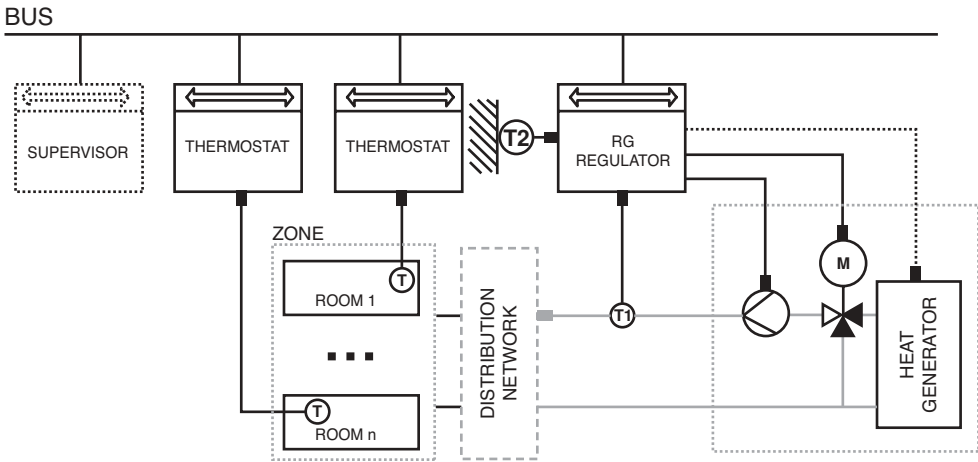
A thermostat with a temperature sensor integrated or remote via a mixing valve regulates the flow of heat transfer fluid. The function allows the coordination of temperature adjustment between different environments and their management from any central location.

##### *Main Components*

- Thermostats
- Mixing solenoid (or intercept)
- Possible central supervisor

#### 4.4.1.7 Control of Internal Temperature (Figure 4.12)

In any environment, the temperature is regulated by an electronic regulator that acts on the respective valve and pump. The temperature of the heat transfer fluid in any environment is continuously modified and optimized, depending on the outside temperature and the set-point. The temperature adjustment of the heat transfer in the network can be made with a mix of supply with the return, or by acting directly on the burner performance.



**Figure 4.12** Control of internal temperature

**Category**

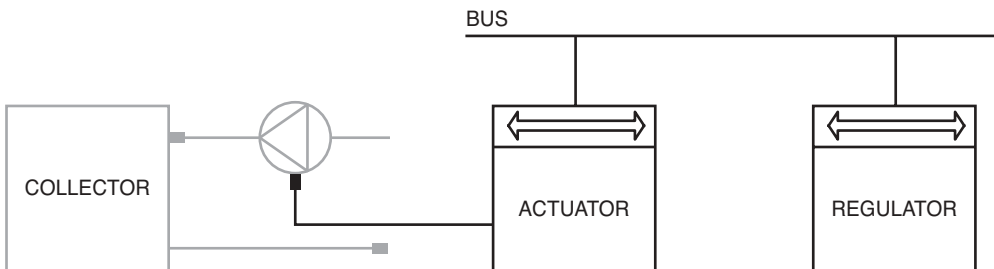
Water temperature control in the distribution system (supply and return)

**Logic**

The generation regulator (RG) regulates the flow water temperature by adjusting the mixing valve, or directly on the burner. The adjustment is due to the thermostat, which senses the temperature in every room, the T2 sensor that detects the external temperature and the sensor T1, which detects the flow temperature of the fluid. For each outdoor temperature, including a preset number, you get the minimum radiator hot water temperature needed to reach the set point.

**Main Components**

- Generation regulator
- Flow temperature sensor in the network (remote)
- Outside temperature sensor
- Room thermostats



**Figure 4.13** Control of the distribution pumps at a variable speed with  $\Delta P$  constant

**4.4.1.8 Control of the Distribution Pump at a Variable Speed with  $\Delta P$  Constant (Figure 4.13)**

A variable speed drive in the pump can be controlled in an On/Off way or can regulate the heat flow to load. In case of partial load, this reduces electricity consumption.

*Category*

Control of distribution pump

*Logic*

The pump head is kept constant and its scope (speed) is adjusted in proportion to the load (opening or closing of one or more hydraulic circuits).

*Main Components*

- Circulation pump with variable and self-regulated in  $\Delta P$  constant speed
- Regulator
- Actuator (variable frequency inverter that could be incorporated in the pump or in the regulator)

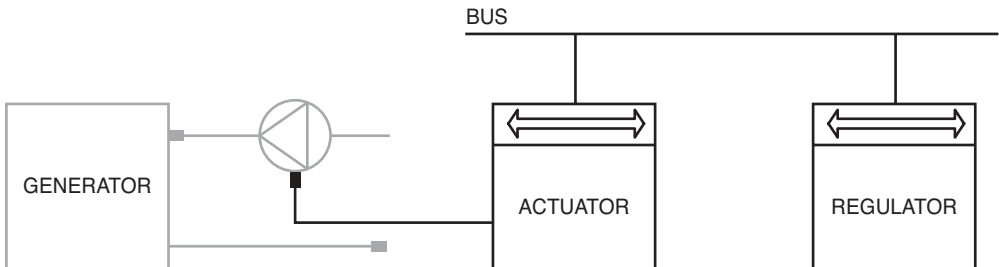
**4.4.1.9 Automatic Control with Optimized Start/Stop (Figure 4.14)**

The activation is with reference to the start time of the period of comfort, so that the required temperature is reached by the set start time. The setting depends on the type of system controlled, i.e. the type of terminals (fan coils, radiators, floor panels, radiant ceiling, etc.), on the type of control (boiler, flow temperature) and on the type of building (ground, isolation, etc.).

The optimized stop time anticipates the off time of the plant so that the specified temperature for the end time period of comfort is not below a certain value.

*Category*

Intermittent control of generation and/or distribution



**Figure 4.14** Automatic control with optimized start/stop

**Logic**

Starting and stopping are achieved without the use of external devices. The controller software uses the data entered in the starting phase (e.g. thermal inertia and orientation of the building, constant of time of terminals) to optimize production and distribution of energy without compromising comfort.

**Main components**

- System controller
- Possible central supervisor for monitoring and/or management of the system

**4.4.1.10 Function of Integrated Control of All Rooms with Management of Requests (e.g. for Occupancy, Air Quality, etc.) (Figure 4.15)**

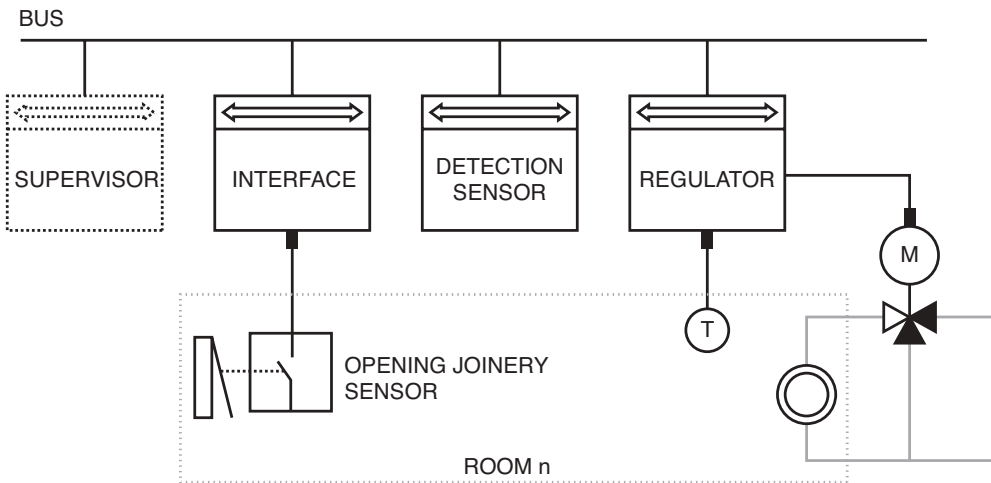
The function provides for monitoring the temperature of each room with the possibility of turning off the heating or to put it on low power when there is nobody in the room or the exterior doors are open. The controller must be able to communicate with other controllers and towards the bus system.

**Category**

Emission control

**Logic**

The regulator controls the flow of hot water commanding an On/Off mode or modulating the mixing solenoid valve. The heater can be discontinued or placed in a state of Precomfort when the occupancy sensor reveals a lack of people in the room or when the sensor reveals



**Figure 4.15** Function of integrated control of all rooms with management of requests (e.g. for occupancy, air quality, etc.)



a door opening to the outside. The controller and devices such as the occupancy sensor and the binary interface send, on the bus line, information related to the local control (e.g. thermal load, occupation, windows/doors status, etc.).

#### ***Main Components***

- Thermostat
- Motion sensor
- Environmental temperature sensor
- Doors-open sensor
- Contact interface
- On-Off solenoid/regulation

#### **4.4.1.11 Function of Total Interlock**

The central system prevents, by electrical interlock, the simultaneous starting of both hot and cold generators: it is possible to condition the system with the outside temperature to improve comfort and to properly implement the heat/cool change.

The scheme depends on the type of system used.

#### ***Category***

Intermittent control of generation and/or distribution

#### ***Logic***

The overall interlock between the cooling and heating ensures that, in the environment, the hot and cold generators never operate simultaneously in the same area. This depends on the type of generator used, on the distribution of heat transfer fluid and its control (central or in individual zones).

#### ***Main Components***

- Flow regulator for heating
- Flow regulator for cooling
- External temperature sensor

### ***4.4.2 Ventilation and Air Conditioning***

#### **4.4.2.1 Time Control (Figure 4.16)**

A program controls the switching on and off at set times of the injection and extraction fans (V1 and V2). The room air flow is controlled by V1 and/or V2 fans and is set for the maximum load. For energy saving, when fans are on, thermal generators for room air conditioning of the AHU (air handling unit) should be turned off.

#### ***Category***

Air flow control in environment

#### ***Logic***

The system operates under centralized planning, controlling air flow, according to a predetermined time program.

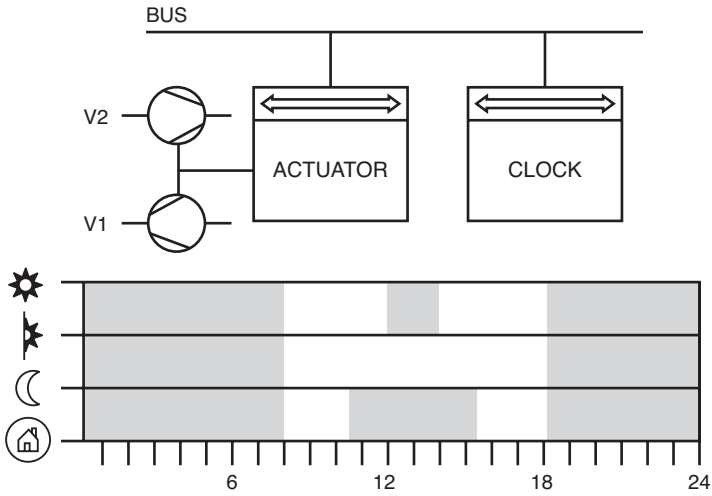


Figure 4.16 Time control

**Main Components**

- System clock
- Actuator

**4.4.2.2 Time On/Off Control (Figure 4.17)**

A program controls the switching on and off of the entry and extraction fans (V1 and V2) at regular times by an actuator. The room air flow is controlled by fans V1 and/or V2 and is set for the maximum load. For energy saving generators should be turned off for AHU

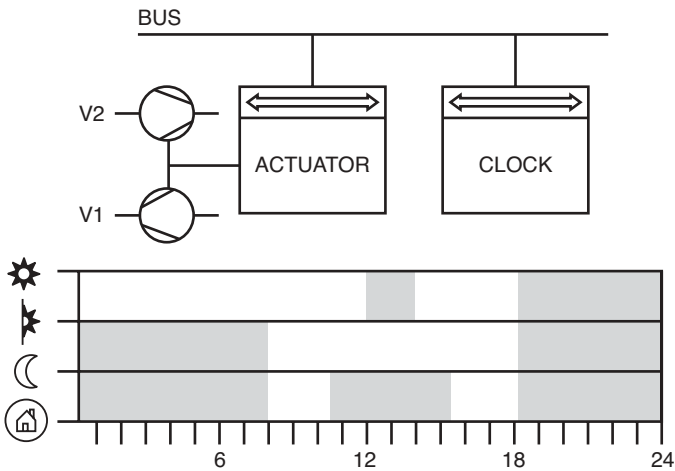
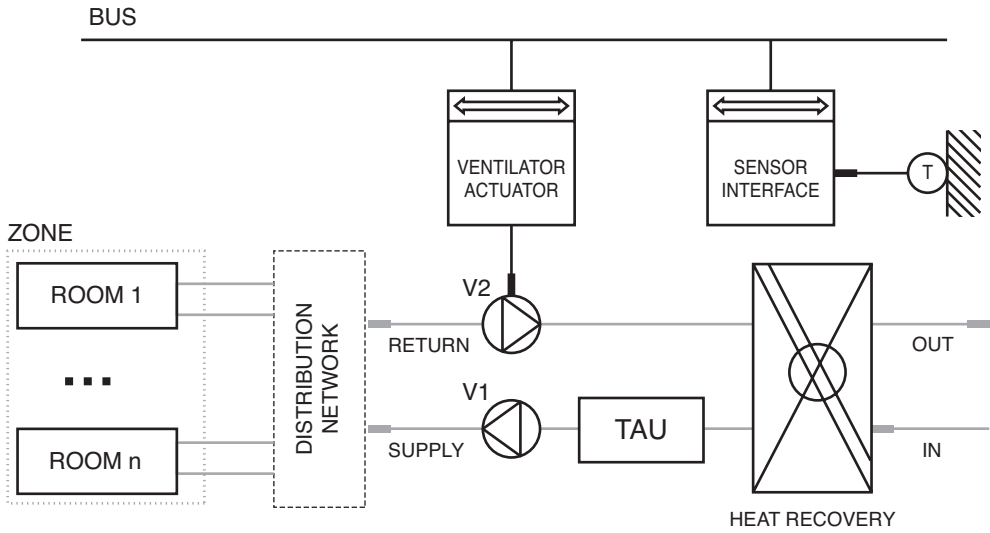


Figure 4.17 Time On/Off control



**Figure 4.18** Defrost control with heat recovery

room-air conditioning when the fans are off, sending a special message to the actuator of AHU controllers.

**Category**

Air flow control into the air handling unit

**Logic**

This function affects the flow of air conditioning in every room of the local area taking as a reference only one room. The air handling system provides the flow for the maximum load to all areas during periods of occupation, prepared by a time schedule.

**Main Components**

- System clock
- Actuator

**4.4.2.3 Defrost Control with Heat Recovery (Figure 4.18)**

During the winter, ice forms in the heat recovery due to humidity and the outside air temperature. It is therefore necessary to increase the power of the exhaust fan to ensure the proper flow of fresh air in spaces, resulting in a greater consumption of electricity. By taking control of cycle defrost an increased consumption of energy is avoided.

**Category**

Defrost control with heat recovery

**Logic**

The formation of ice on the external coil determines the automatic activation of the defrost cycle, which usually lasts about 3–5 minutes. The AHU continues to provide heat to the

interior space for about 50% of the requirements, without increasing energy consumption. The outside temperature sensor and its interface activates the defrost cycle, controlling the exhaust fan (V2).

#### ***Main Components***

- Actuator of the return fan
- The outside temperature sensor (the sensor can be incorporated)

#### **4.4.2.4 Control Function of the Recovery Operation**

The recovery operation can be counterproductive, so it should be stopped or excluded from the flow duct.

The scheme depends on the type of system used.

#### ***Category***

Control function of the recovery operation.

#### ***Logic***

The heat recovery will start automatically when the machine and temperature conditions permit it.

#### ***Main Components***

The heat recovery manufacturer usually provides the temperature sensors (appropriately placed) and the related actuators to stop the machine in case of overheating. This condition may degrade or prevent the operation of the recovery in hot weather. The control components are highly dependent on their type (eg. cross-flow heat recovery, heat exchangers, spinning mass, etc.) and on the construction used, so a temperature control should be requested from the supplier of the machine.

#### **4.4.2.5 Night Cooling (Figure 4.19)**

Through the system clock, the time is established at which night cooling is started; the interface sensor detects the T1 room temperature and the T2 outside temperature.

The controller performs the following comparisons:

1. The T1 room temperature is higher than a fixed value SP1:  $T1 > SP1$ .
2. The T2 outside temperature is lower than a fixed value SP2:  $T2 < SP2$ .
3. The difference in temperature between the room and outside exceeds a fixed value SP3:  $(T1 - T2) > SP3$ .

And, in sequence:

4. It deactivates the air handling unit (AHU).
5. It opens the entry/release shutters and outdoor air and it closes the recirculation damper.
6. It activates the forced ventilation (V1 and V2).

#### ***Category***

Natural cooling

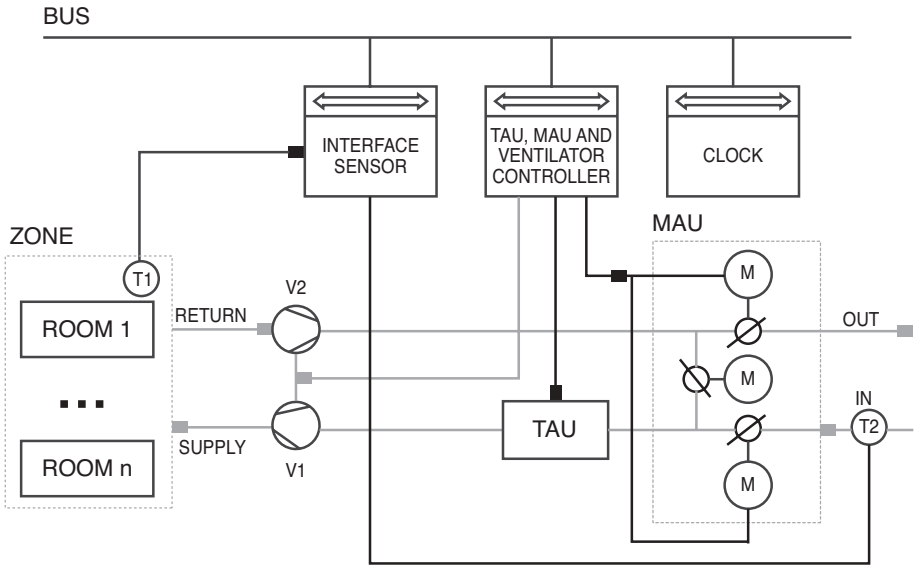


Figure 4.19 Night cooling

**Logic**

Hot and cold coils are disabled; the single night ventilation is active, which allows you to use, especially in spring and autumn, outside air to pre-cool the premises at night. In this way, the cooling, which would slow down due to the thermal inertia of the building, becomes faster and cheaper and air conditioning energy can be saved the following day.

**Main Components**

- Damper controller (UMA)
- Fan controller
- AHU controller
- System clock by programming time (day–night)
- Interface temperature sensors

**4.4.2.6 Constant Set Point Control (Figure 4.20)**

The flow temperature is set manually on the AHU controller while the interface temperature sensor sends the value of the measured temperature to the AHU. The deviation from the set value is cleared by the AHU, regulating hot or cold coils gradually.

**Category**

Flow temperature control

**Logic**

The flow temperature is set up manually at AHU level (set point temperature) for the maximum load provided for all controlled premises. The set point is constant but, if necessary, it can be adjusted manually. This is true for both heating and cooling.

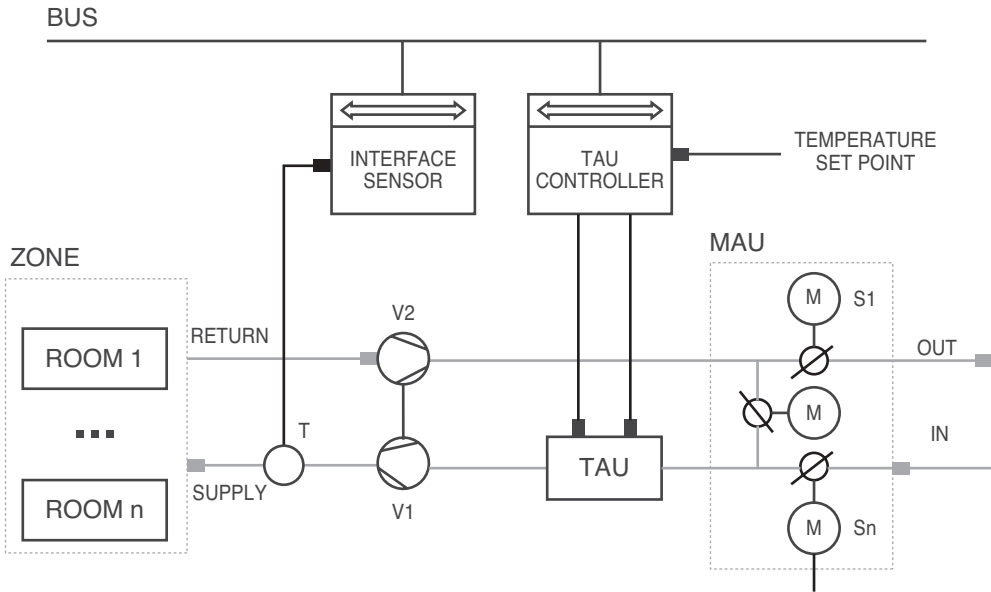


Figure 4.20 Constant set point control

**Main Components**

- Interface temperature sensors
- AHU controller

**4.4.2.7 Humidity Limitation on the Flow of Air (Figure 4.21)**

The humidistat controls the maximum relative humidity limit set for the flow by air entering, either continuously or intermittently, the AHU humidifier, so that the relative flow humidity is maintained below the set threshold. As the air humidification causes air cooling, when TAU is on, it is necessary to heat the air, controlling the temperature with the T sensor.

**Logic**

In small systems, humidity control is achieved with a humidistat that controls the humidifier every time the humidity drops below the set value, switching it off.

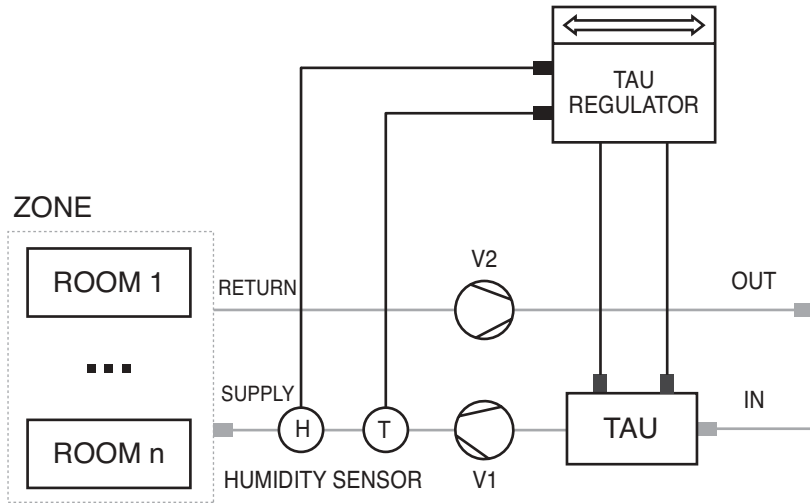
This humidification system is a typical On/Off control.

**Main Components**

- Humidistat
- Temperature sensor
- Regulator for AHU

**4.4.2.8 Automatic Control of Pressure or Flow (Figure 4.22)**

The shutters of the duct S1, Sn, open or closed, carry the load variable for air flow in the general flow duct. The pressure sensor P detects the differential pressure variable value (e.g. pressure difference between the duct and surrounding space). The fan actuator adjusts the



**Figure 4.21** Humidity limitation on the flow of air

air pressure in the channel to a set value to compensate for the variation of pressure every time a damper changes state. The differential prescribed pressure value can be referred to the number of dampers installed: a proper compensation is achieved by varying the value prescribed according to the number of open shutters over the total number.

**Logic**

The flow of treated air in every room matches the demand of the load (total or partial users/connected spaces). In this way, at a partial load, consumption is reduced to that of the unit treatment air fan.

**Category**

AHU flow control

**Main Components**

- Fan actuator
- Pressure sensor interface

**4.4.2.9 Free Cooling (Figure 4.23)**

When the outside weather conditions allow it, the gradual adjustment of the outdoor air dampers (S1), expulsion (S2) and recirculation (S3) enables the mixing of indoor air (circulation) with the outside air to cool the environment. The TAU controller controls the heating and cooling coils to maintain the required temperature in the room. Note that, without the intervention of the AHU, the space-air follows the conditions of the outside air temperature by adding the heat produced by electrical appliances, solar radiation, the presence of people and so on, then it always remains a bit hotter.

When the room temperature detected by the CT sensor increases, the UMA works on the dampers to mix outdoor air (cooler than the interior) with recirculating air, without reaching

BUS

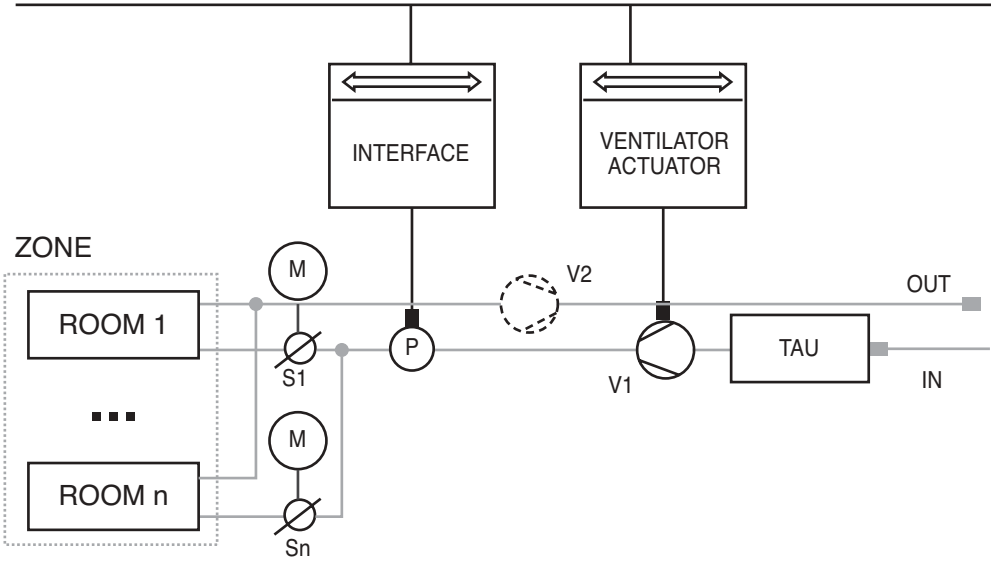


Figure 4.22 Automatic control of pressure or flow

BUS

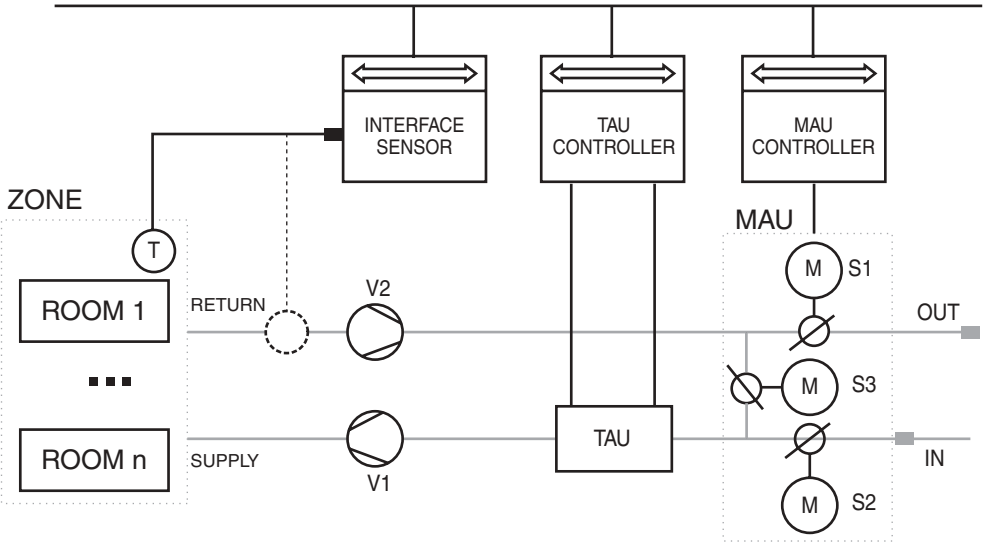


Figure 4.23 Free cooling



the activation temperature of the cooling coil. In this way free cooling is obtained by measuring only the room temperature. Instead of T sensor, a temperature sensor measuring the return air can be used (dashed in the diagram).

**Category**

Free mechanical cooling

**Logic**

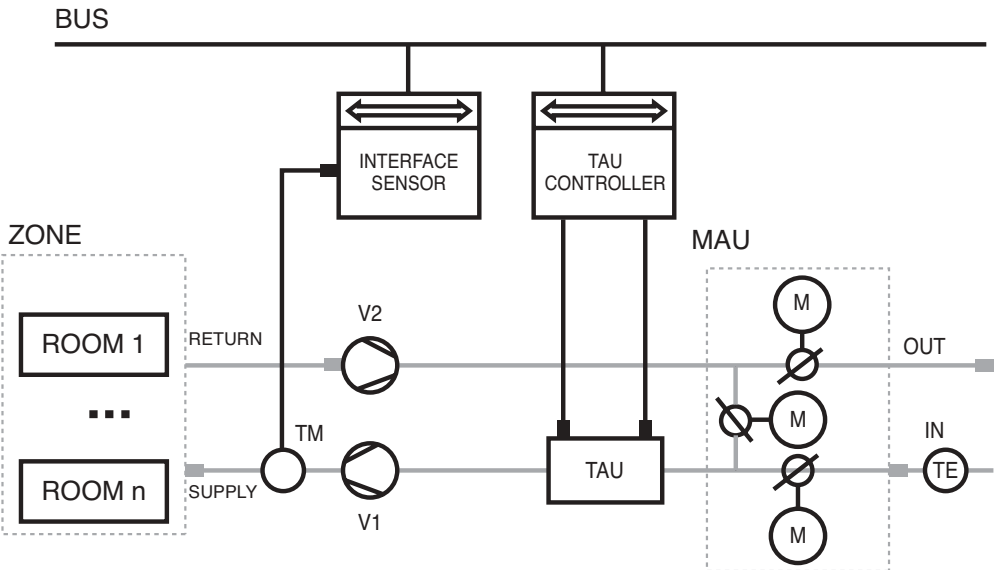
In spring and autumn, the room temperature controller can be calibrated to compensate for the excess heat with a larger amount of outside air, giving free cooling. When the outdoor temperature is in the range 10–20°C for several months a year, this measure can guarantee important savings. You can refresh the space without using the AHU and heat recovery, but using the outside air when it has a temperature below that of the indoor air.

**Main Components**

- UMA actuator
- AHU/UMA controller
- Interface temperature sensor

**4.4.2.10 Set-Point External Temperature-Dependent (Figure 4.24)**

The control of the flow temperature is influenced by the outside temperature (climatic compensation). The compensation function is stored in the TAU controller that regulates the activation of hot and cold coils. This function allows the modification of winter and summer supply temperature within the predetermined ranges of outdoor temperature.



**Figure 4.24** Set-point external temperature-dependent

**Category**

Flow temperature control

**Logic**

The set-point of the supply temperature is set for the total continuous load in the different zones. The flow temperature is adjusted on the basis of a simple function (e.g. linear) of the outside temperature, corresponding to the likely demand for individual rooms served. The system does not allow one to take into account requests for changes in individual rooms.

**Main Components**

- Interface temperature sensors
- AHU controller

**4.4.2.11 Control Function of Flow Air Humidity (Figure 4.25)**

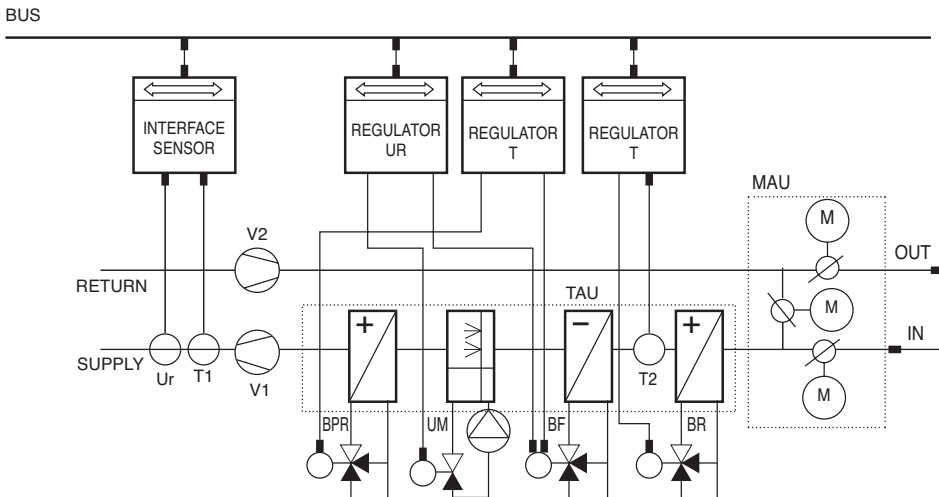
A control adjusts the relative humidity of the flow air to a specified value that is constant in all rooms. The control is carried out by the use of regulators that act in sequence on all parts of the AHU in order to bring the humidity up to the specified value: the sequences of cooling, condensation, humidification and hotting causes changes in the air humidity content in absolute and/or relative terms. In order to obtain efficient adjustments (e.g. simultaneous heating and cooling) it is important to set the set-point controllers with the largest possible dead zones.

**Category**

Humidity control

**Logic**

Under the conditions of temperature  $T1$  and humidity  $Ur$ , the set points set up in the temperature and humidity regulators and in the interface sensors, the system controls the devices



**Figure 4.25** Control function of flow air humidity

BF, UM and BPR to cool or heat, humidify or dehumidify in order to maintain the relative humidity and flow air temperature to the values set. The relative humidity is detected by the sensor Ur in the flow duct. Along with humidity detection, it is still necessary to also measure the flow temperature through the T1 sensor. Dehumidification is achieved with the cold coil (Bf) that receives commands both from the temperature humidity controller and the controller (a software switch of priorities, present in the regulators, it gives precedence to the command that requires the greatest cooling capacity). The temperature controller controls the cold (BF) and heat (BPR) coils based on the signal received from the temperature sensor T1. The preheating coil BC is not involved directly in the control of the humidity but it allows to protect the coil against freezing in cold weather and to ensure a minimum temperature (12–16°C), detected by the sensor T2 and the controller connected to it, for optimal functioning of the system.

**Main Components**

- Air-relative humidity regulator
- Temperature regulator (T1 and T2)
- Interface sensors T/Ur
- Flow air humidity control (humidity control).

**4.4.2.12 Occupancy Control Function (Figure 4.26)**

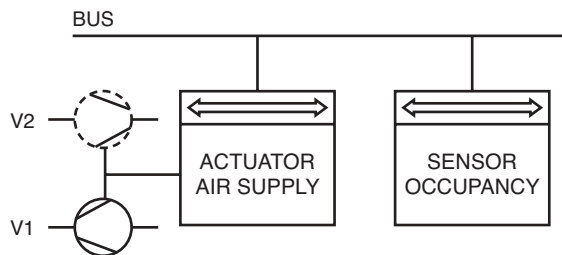
Where people are present, the occupancy sensor enables the flow and activates through the flow air actuator, the circulation fans V1 and/or V2 in the spaces. For energy saving the AHU generators should be turned off when the fans are inactive.

**Category**

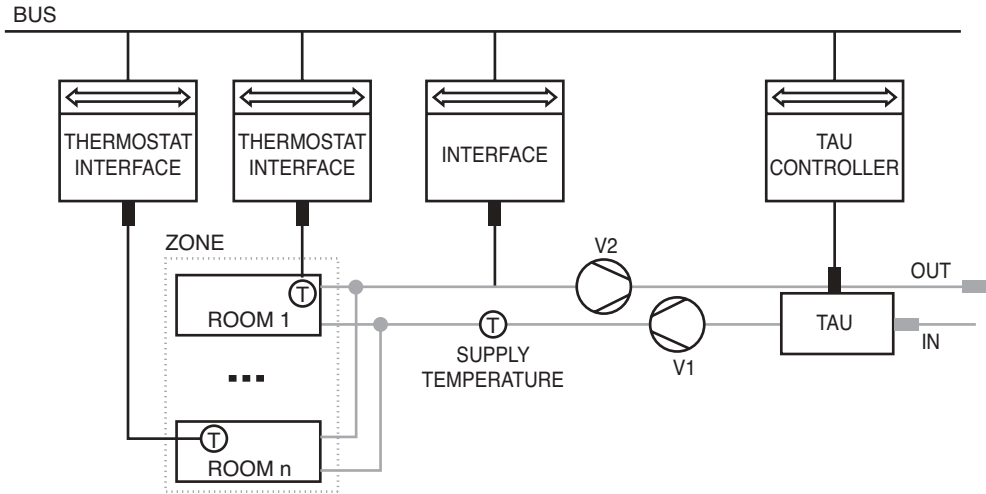
Space flow air control

**Logic**

The system controls the flow of supply air, set to the maximum load, according to the presence of people in the environment/area. In this way the energy loss is minimal, only occurring during periods of actual employment and at a partial load.



**Figure 4.26** Occupancy control function



**Figure 4.27** Function to set point, load-dependent

#### *Main Components*

- Supply air actuator
- Occupancy sensor
- AHU controller

#### **4.4.2.13 Function to Set Point, Load-Dependent (Figure 4.27)**

The system is able to reduce the production of heat and cold to that which is strictly necessary in order to avoid loss in production and distribution. The AHU controller collects the load data (exemplified by the value of the space temperature) that is coming from all areas/zones and optimizes the value of the flow temperature  $T_m$  with sequences of hot or cold.

#### *Logic*

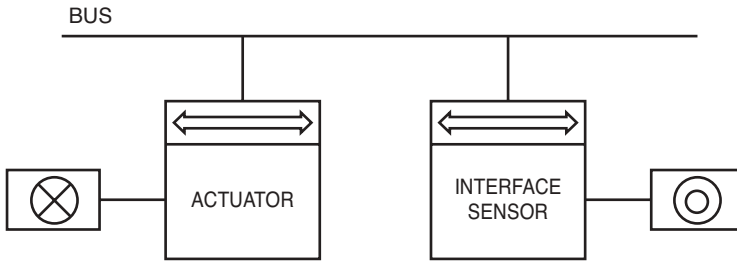
The flow temperature set point is a function of the active loads in different rooms: the adjustment can be achieved with a system that centralizes the collection of data based on temperatures and/or the state of air conditioners in the rooms and sets the flow temperature accordingly.

#### *Category*

Flow temperature control

#### *Main Components*

- Interface temperature sensors
- AHU controller



**Figure 4.28** Function of switch on manual and automatic shut-off

### 4.4.3 Lighting

#### 4.4.3.1 Function of Switch on Manual and Automatic Shut-Off (Figure 4.28)

A generated signal causes automatic shutdown at least once a day, typically during the evening, to inhibit unnecessary operations at night and avoid unnecessary energy consumption. The light may be turned off gradually as the switch-off warning to any user.

#### *Category*

Occupancy control

#### *Logic*

Switching on the lighting occurs by acting on the power command connected to the input device. Shutdown can be manual, but can also take place automatically after a preset time. The lighting is switched on and off manually by one or more control points with instant-closing and delayed opening.

#### *Main Components*

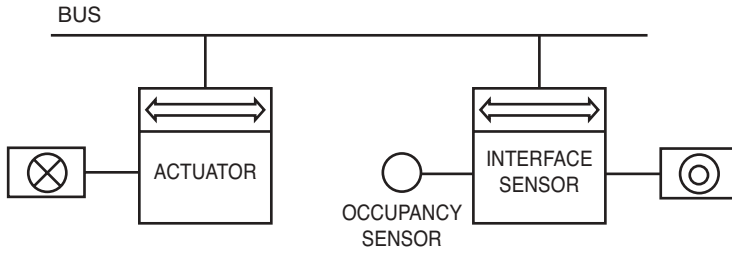
- Bus interface for input of manual control of lighting
- Lighting control actuator

#### 4.4.3.2 Manual Power Control Function and Occupancy Detection Auto-On/Reduction/Off (Figure 4.29)

The occupancy sensor or the manual control command on the light through the actuator. Then, when the sensor no longer detects a presence, the lighting is automatically reduced to a certain percentage and/or switched off.

#### *Category Occupancy Control Logic*

Lighting can be turned on manually by commands installed in the illuminated area. If the users do not switch the light off manually, the light is kept on by the system automatically in a reduced state (not more than 20%) for a certain time interval following the last detection of a presence in the controlled environment (e.g. 3 minutes). If for another given period of time no presence is detected in the environment, the light is switched off completely.



**Figure 4.29** Manual power control function and occupancy detection auto-on/reduction/off

**Main Components**

- Occupancy sensor
- Actuator

**4.4.3.3 Motorized Control with Automatic Drive Control of Sunscreens (Figure 4.30)**

The blinds controller adjusts the position through the actuator, depending on the ambient light detected by the light sensor.

**Category Occupancy Control Logic**

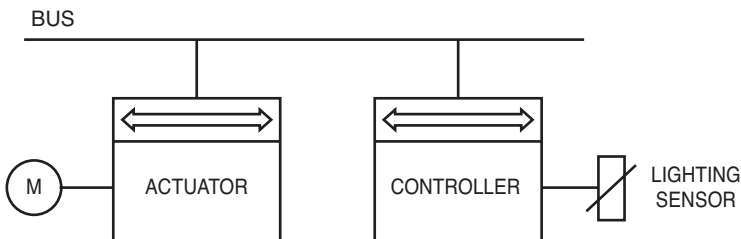
A daylight control allows energy saving in winter, and protects against glare and against overheating in summer. The flow of heat lost at night can be reduced by controlling the blinds.

**Main Components**

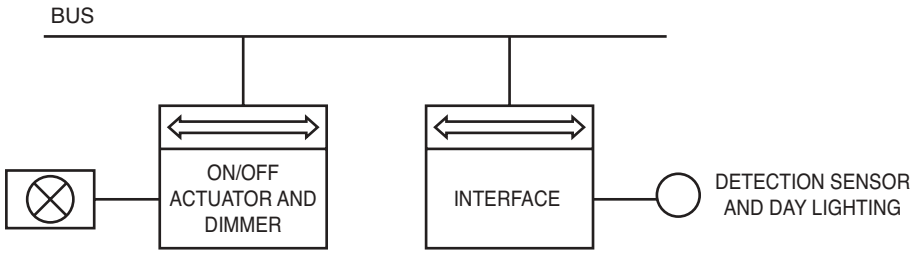
- Ambient light sensor
- Curtains/Blinds controller (summer/winter)
- Actuator

**4.4.3.4 Automatic Daylight Control Function (Figure 4.31)**

The occupancy sensor controls the power of the lighting system through the actuator, depending on the presence of people and the ambient light.



**Figure 4.30** Motorized control with automatic drive control of sunscreens



**Figure 4.31** Automatic daylight control function

**Category**

Daylight control

**Logic**

The system adjusts the brightness of the lamps in the given area according to the light coming from the outside. The light shuts down after a delay after the last detection of the presence of people.

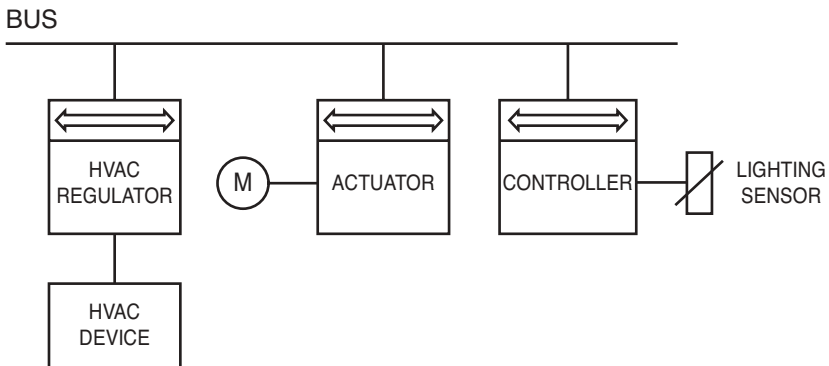
**Main Components**

- Occupancy and daylight sensor
- On/Off actuator and dimmer

**4.4.4 Sunscreens**

**4.4.4.1 Control Combined Light/Blinds/HVAC Function (Figure 4.32)**

The free solar energy control saves energy in winter, and provides protection against glare and overheating in summer. The flow of heat lost at night can be reduced by controlling shutters.



**Figure 4.32** Control combined light/blinds/HVAC function

**Logic**

The controller adjusts the position of the blinds through the actuator, depending on the ambient light measured by the sensor (ambient light sensor). A controller regulates the operation of the HVAC according to the data coming from the sensor.

**Category**

Sunscreens control

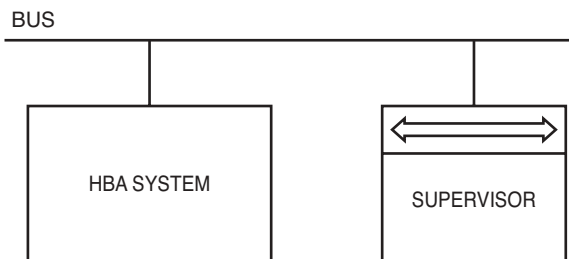
**Main Components**

- Ambient light sensor
- Shutter actuator
- Curtain/blinds controller (summer/winter)
- HVAC controller

**4.4.5 Technical Building Management****4.4.5.1 Function Centralized Control (Figure 4.33)**

The system allows easy adaptation to users' needs and provides the following functions:

- centralized setting time programs and set point;
- centralized optimization of the system;
- control at regular intervals of the operation settings of the heating, cooling, ventilation and lighting and their set point in such a way that they are well prepared for the current use and meet the real needs;
- setting the operating parameters of the auditors;
- assessment, at regular intervals, of controllers of premise/area. Their set points are often modified by the user. The centralized system can detect and correct scroll settings due to user error or misunderstanding;
- interlock control (emission and distribution) between heating and cooling: it is only partial since its set point must to be regularly changed in order to minimize the simultaneous use of heating and cooling;
- the functions of alarms/faults detection and supervision are appropriate to the needs of the user and allow the settings optimization of the different controllers. This must be done with



**Figure 4.33** Function centralized control



easy instructions to detect abnormal operation (alarm) and simple means of recording and displaying results;

- implementation of energy management programs based on the presence or absence of personnel in the rooms;
- automatic start of automation scenarios and control based on the evolution of the occupancy parameters and of factors that affect energy consumption.

### **Category**

Home system or building automation control scheme

### **Logic**

It allows the system control and management to be centralized.

### **Main Components**

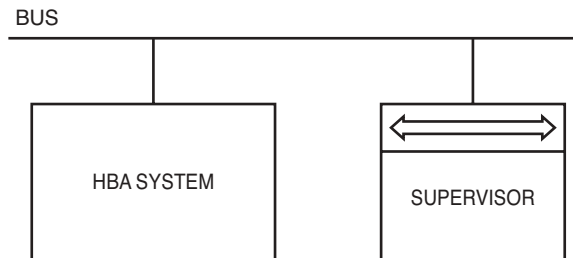
- Touch screen
- PC
- Smart phone, etc.

## **4.4.6 Technical Installations in the Building**

### **4.4.6.1 Function of Fault Detection, Diagnosis and Provision of Technical Support (Figure 4.34)**

The TBM (Technical Building Management) system adds to the functions of the centralized automatic control:

- device diagnostics,
- device status,
- operation time,
- type of fault,
- fault detection in devices/actuators/sensors/control elements,
- capacity of the system to activate the request for technical support both for periodic maintenance and system malfunctions.



**Figure 4.34** Function of fault detection, diagnosis and provision of technical support

**Category**

Technical building systems management (TBM) scheme

**Logic**

To improve the efficiency of a plant, it is particularly important that the system is able to provide a regularly diagnostic on the efficiency of the plant, its operating parameters and to identify failures. It is important to be able to link these management parameters with a technical support, whose frequency will depend on the complexity of the plant.

**Main Components**

- Touch-screen panel
- PC
- Smart phone, etc.

#### 4.4.6.2 Function of the Report on Energy Use, Internal Conditions and Possibilities for Improvement (Figure 4.35)

For real optical management of a system and to monitor its effectiveness it is essential that a system includes a display of the energy consumption parameters and of the various operating conditions. This ensures continuous energy efficiency and the ability to intervene at a later time, adapting the system to changes in housing needs and alterations in the environment.

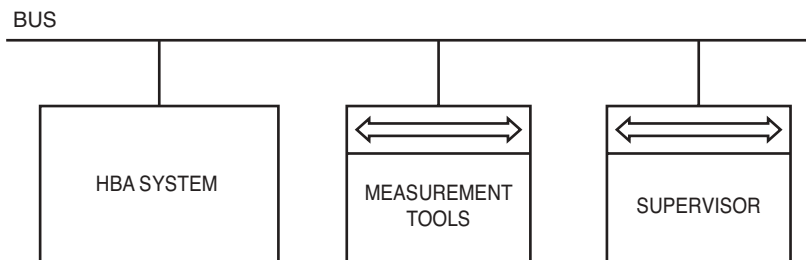
**Category**

Technical systems Building Management (TBM) scheme

**Logic**

A report on the status of the energy consumption and indoor conditions (heating, cooling, lighting, etc.) must be prepared. This informative report can cover for example:

- a building energy certificate,
- evaluating the improvement of energy and building system,
- a detection function,
- energy detection,
- monitoring the temperature of the room and internal air quality,
- monitoring the power consumption of the system.



**Figure 4.35** Function of the report on energy use, internal conditions and possibilities for improvement

### *Main Components*

- Measurement of energy consumption (software and hardware)
- Software on personal computers

## **4.5 The Estimate of Building Energy Performance**

Understandable difficulties in dealing with the impact of the integrated management, in terms of energy saving, of various functions of the building has meant that until now the automation has not been considered as well as the efficient components to achieve the goals set by official authority in saving energy consumption. Even if not yet fully mature, in the opinion of the authors, the European standard EN 15232 'Energy performance of buildings. Automation Effect, control and technical management of buildings' might make a crucial contribution in facing this situation by allowing the exploitation of the potential of the automation applications for the rational use of energy resources.

The tools and statistical data made available by the standard document should allow the designer, the public administrator and also the end user, to introduce quickly enough the basic strategic choices for achieving a good technical and economic compromise, as well as an environmental balance between reduced consumption during the life of the building and building's first cost. Available data show that the automatic adjustment of different levels of lighting or heating and cooling, depending on the absence or presence of people in a living or working context has the following advantages:

- it always brings, whatever the level of automation, real reductions compared with traditional systems in energy consumption without affecting comfort and security;
- by delegating even simple tasks to automation, such as turning off unnecessary lighting, which could potentially be done by a human user, in fact could lead to tangible and measurable results in the direction of limiting consumption. The availability of conventional and officially recognized instruments, like the standard EN 15232, could help in the process of including building automation in the legislative instruments addressed to energy saving.

### *4.5.1 European Standard EN 15232*

In a building, good energy management is a basic and fundamental factor in reducing energy consumption and raise the quality of life (comfort) while working in an indoor environments. A practical limit in diffusion of automation, among other common tools for reducing consumption, is linked to the difficulties in evaluating *ex ante* the benefits in terms of energy savings. To allow a formal evaluation of the effectiveness of the investment or in comparing investments, the uncertainty of the results is crucial.

While the *ex-ante* quantification of benefits related to the adoption of a more efficient apparatus, such as water heaters, are easily estimated, the impact of a system, like the building automation one, involves a set of horizontal skills and modelling problems.

In this direction, in the opinion of the authors, a focal point is given by the publication of the European Standard EN 15232 ‘Energy performance of buildings. Automation Effect, control and technical building management’. Mostly *ex ante*, the standard sets just the problem of estimating the impact on energy consumption of building automation, control and management systems. It allows to concretely add to the classical approach based on the adoption of a more energy performing component (thermal insulation, heat generator, low energy light bulbs, etc.), the one of improving and optimizing the usage of a standard component. This last approach also allows the adoption on existing components and, of course, the combination with the adoption of a more performing component.

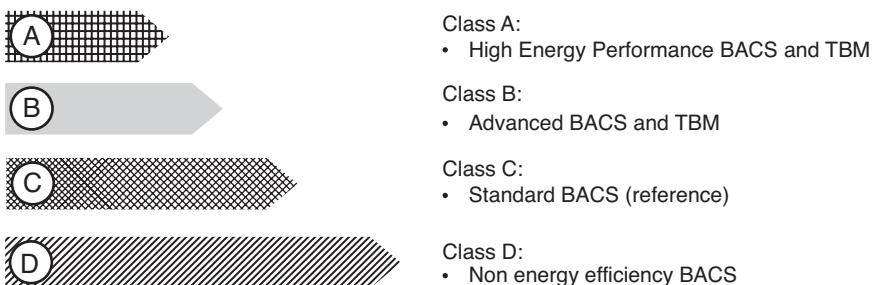
The main innovative features of the Standard EN 15232 can be summarized as follows:

- a conventional definition of four classes for classification of the technology contents of automation in terms of building energy performance;
- a list of all the automation, control and management functions related to building energy performance and a correlation of these with the performance ratings above;
- the definition of conventional methods for estimating building energy performance.

#### 4.5.1.1 Automation Classes for Energy Efficiency

From an energy efficiency perspective, the standard EN 15232 defines four conventional classes, corresponding to the installed level of automation, control and management system (Figure 4.36):

- Class D ‘NON ENERGY EFFICIENT BACS’: this includes the traditional and technical systems with no automation for energy efficiency.
- Class C ‘STANDARD’: this corresponds to buildings with automation systems and normal controls and is considered the reference class.
- Class B ‘ADVANCED’: this includes buildings with automation and control systems as well as TBM (Technical Building Management: technical installations management in the building) for centralized control.



**Figure 4.36** Graphical representation (not in the standard) of the classes of installed automation, control and management system

- Class A ‘HIGH ENERGY PERFORMANCE’: as Class B but with more performing automatic control, such as to ensure high performance energy system. Such an approach gives a series of communication advantages:
    - It is already qualitatively known by the user.
    - It summarizes in a single significant and simple parameter (the class) the performance result of a complex system hardly understandable by the general public.
- The definition of each class is based on the existence or not of a set of automation control and management functions without details of their implementation.

#### 4.5.1.2 Definition of Automation Classes

A tool provided by the Standard EN 15232 is the list of all the automation, control and management functions relating to the building energy performance and from the correlation of these with the automation classes for energy efficiency in the previous section.

The functions required for the definition of belonging to a given class differ for residential buildings and tertiary sectors. Class C requires the construction of minimum functions for automation and control. Class B requires the characteristic functions of the previous class plus some additional specific features such as room controllers to communicate with the building central control. Class A requires some specific features of TBM as additional features to Class B. It may be noted that although even if tied to the rigidity introduced by the adopted approach<sup>3</sup>, the tables can be a useful operational tool for all figures involved in the building sector, in particular:

- Owners, architects and building designers/installers for the definition of automation functions
- Public authorities for a definition of the minimum requirements relating to the efficiency of automation
- Public authorities and inspectors for the definition of assessment and verification procedures
- Public authorities for the definition and verification of procedures for calculating energy efficiency
- Electrical designers and automation programmers for the definition of the hardware components, the software and procedures for verifying the energy performance of the system.

Tables 4.4–4.6 give examples of tables for heating control, a HVAC system and lighting control.

#### 4.5.2 Comparison of Methods: Detailed Calculations and BAC Factors

The main contents of the EN15232 standard for the quantitative estimation of efficiency and energy savings introduced by the application of automation control and management systems

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<sup>3</sup> With reference to Table 4.6, we consider, for example, the case of an underground building aiming at class A, but in which obviously the adoption of an automatic control for daylight makes no sense.

**Table 4.4** Examples of tables defining the functions of automation, control and management with an impact on building energy performance. Heating control

AUTOMATIC CONTROL		DEFINITION OF CLASSES							
HEATING CONTROL		Residential				Non residential			
Emission control		D	C	B	A	D	C	B	A
	The control system is installed at the emitter or room level, for case 1 one system can control several rooms								
0	No automatic control	Diagonal				Diagonal			
1	Central automatic control	Diagonal				Diagonal			
2	Individual room automatic control by thermostatic valves or electronic controller	Diagonal	Grid			Diagonal	Grid		
3	Individual room control with communication between controllers and to BACS	Diagonal	Grid	Grey		Diagonal	Grid	Grey	
4	Integrated individual room control including demand control (by occupancy, air quality, etc.)	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Control of distribution network hot water temperature (supply or return)</b>									
	Similar function can be applied to the control of direct electric heating networks								
0	No automatic control	Diagonal	Grid			Diagonal	Grid		
1	Outside temperature compensated control	Diagonal	Grid			Diagonal	Grid		
2	Indoor temperature control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Control of distribution pumps</b>									
	The controlled pumps can be installed at different levels in the network								
0	No control	Diagonal				Diagonal			
1	On/off control	Diagonal	Grid			Diagonal	Grid		
2	Variable speed pump control with constant $D_p$	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
3	Variable speed pump control with proportional $D_p$	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid

to the various types of new or existing buildings consist of an impressive statistical work and simulations carried out by experts in the field of European legislation in the CEN/CENELEC<sup>4</sup>.

In particular, the EN 15232 standard offers two different procedures for calculating the efficiency of automation, control and management systems (Figure 4.37):

- Detailed calculation
- Calculation based on efficiency factors (BAC factors in the English text of the standard).

The detailed calculation is best used only when the system is completely known, that is, when all functions have already been established. The method of efficiency factors, certainly characterized by a higher level of formality and accuracy, while being based on measurements and calculations performed on a large number of different types of buildings, in rooms with

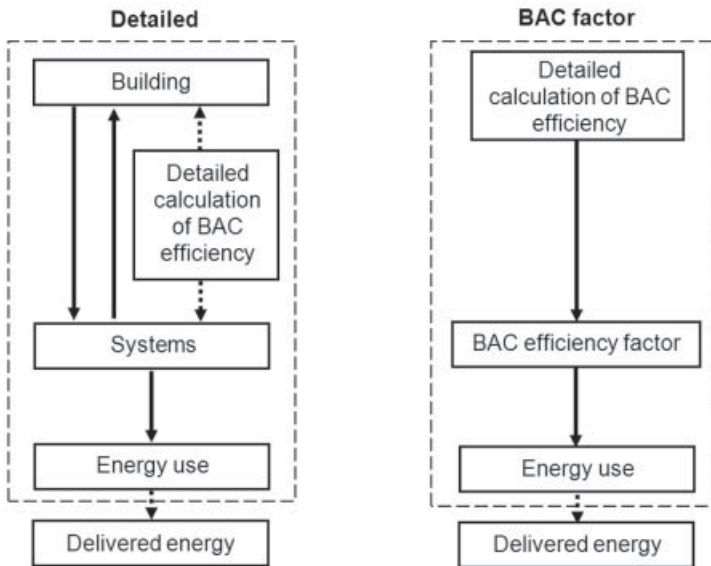
<sup>4</sup> The work has also given rise to other standards of EN15000, EN12000 and EN13000, dedicated to the automation of heating, cooling, ventilation, hot water, lighting, shutter control/spaces brightness, the centralization and integrated control of different applications, diagnostics and consumption/improving detection of automation parameters.

**Table 4.5** Examples of tables defining the functions of automation, control and management with an impact on energy performance. Control of the HVAC system

AUTOMATIC CONTROL		DEFINITION OF CLASSES							
		Residential				Non residential			
VENTILATION AIR CONDITIONING CONTROL		D	C	B	A	D	C	B	A
<b>Air flow control at the room level</b>									
0	No automatic control	Diagonal				Diagonal			
1	Manual control								
2	Time control	Diagonal	Grid	Grey		Diagonal	Grid	Grey	
3	Occupancy control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
4	Demand control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Air flow control at the air humidifier level</b>									
0	No automatic control	Diagonal				Diagonal			
1	On/off time control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
2	Automatic flow or pressure control with or without pressure control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Heat exchange ... control</b>									
0	Without ... control	Diagonal				Diagonal			
1	With ... control	Diagonal	Grid		Grid	Diagonal	Grid		Grid
<b>Heat exchange overheating control</b>									
0	Without distributing control	Diagonal				Diagonal			
1	Without overheating control	Diagonal	Grid		Grid	Diagonal	Grid		Grid
<b>Free mechanical cooling</b>									
0	No control	Diagonal				Diagonal			
1	Night control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
2	Free cooling	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
3	... directed control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Supply temperature control</b>									
0	No control	Diagonal				Diagonal			
1	Content set point	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
2	Visible set point with outdoor temperature compensation	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
3	Visible set point with load ... compensation	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>Humidity control</b>									
0	No control	Diagonal				Diagonal			
1	Supply air humidity ...	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
2	Supply air humidity control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
3	Room or ... air humidity control	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid

**Table 4.6** Examples of tables defining the functions of automation, control and management with an impact on energy performance. Lighting control

AUTOMATIC CONTROL		DEFINITION OF CLASSES							
		Residential				Non residential			
LIGHTING CONTROL		D	C	B	A	D	C	B	A
<b>Occupancy control</b>		D	C	B	A	D	C	B	A
0	Manual on/off switch	Diagonal	Grid			Diagonal			
1	Manual on/off switch + additional sweeping extinction signal	Diagonal	Grid			Diagonal	Grid		
2	Automatic detection Auto-On/Dimmed			Grey	Grid			Grey	Grid
3	Automatic detection Auto-On/Auto-Off			Grey	Grid			Grey	Grid
4	Automatic detection Manual on/Dimmed	Diagonal		Grey	Grid	Diagonal		Grey	Grid
5	Automatic detection Manual on/Auto off	Diagonal		Grey	Grid	Diagonal		Grey	Grid
<b>Daylight control</b>		D	C	B	A	D	C	B	A
0	Manual	Diagonal	Grid	Grey		Diagonal	Grid	Grey	
1	Automatic	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid
<b>BLIND CONTROL</b>		D	C	B	A	D	C	B	A
0	Manual operation	Diagonal	Grid			Diagonal			
1	Motorized operation with manual control	Diagonal	Grid			Diagonal			
2	Motorized operation with automatic control	Diagonal	Grid	Grey		Diagonal	Grid	Grey	
3	Combined light/blind/HVAC control (also mentioned above)	Diagonal	Grid	Grey	Grid	Diagonal	Grid	Grey	Grid



**Figure 4.37** Flow charts of the detailed method and the method of the efficiency factors (EN 15232 Standard)



different boundary conditions, is suggested for making a rough estimate in the initial phase of the building project/provision and of the control system and energy management. However, in the opinion of the authors, it is the most important tool introduced by the standard. With reference to the most energy-intensive applications, the method based on efficiency factors makes it possible to assess, quickly and on a tabular basis, the impact of the automation control or management system chosen as a relative value based on the examined building energy needs. It also provides direct evidence of the economic value of the saving on operating costs that is achieved by adopting a given level of automation, control or management.

#### 4.5.2.1 Detailed Calculation

The detailed calculation includes five different basic types:

1. Direct method, based on a simulation of the system in accordance with EN 13790 'Thermal performance of buildings – Calculation of energy use for space heating and cooling'.
2. Method based on mode of operation, considering sequentially the different states of each application (heating, lighting, etc.) and for each state determines the energy consumption, obtained by the sum of the total consumption of each application.
3. Method based on the time operation, which considers the duration of operation Total/ Excluding/Partial of the devices, resulting in a savings ratio that characterizes the given function.
4. Method based on room temperature, which considers the influence of temperature control accuracy (low hysteresis) in energy savings' calculations.
5. A method of correction factors, used when the automatic control works in a combination of several factors, such as the effects of the presence of people, the temperature value and the time of operation.

##### ***Direct Method***

The direct method is used to calculate the energy performance of a building based on an analytical simulation or a simulation on an hourly basis (EN ISO 13790). With the direct method it is possible to calculate the impact of a number of automation features, such as intermittent heating, varying the set-point temperature, heating or cooling, by pulling down the sun blinds and so on. Obviously, the method loses its effectiveness if the control would lead to corresponding changes in the time intervals of less than the simulation step.

##### ***Method Based on Mode of Operation***

The method based on the operating mode is particularly useful in cases where the automatic control system allows it to act on the energy-intensive system in different modes. An example is an air conditioning system that allows two modes of ventilation (presence and absence of people), the heating may be normal or intermittent or otherwise. The approach to calculating the impact on consumption is to calculate the energy consumption in each mode and the total sum of the values thus obtained. The calculations are performed for each mode of operation, considering the state of the relative control system: for example, on/off fan. Of course, each mode corresponds to a given state of the control system.

### ***Method Based on the Operation Time***

The method based on the operation time can be used in cases where the control system has a direct impact on the period of operation (on/off) of a device (such as for the control of a fan or luminaire).

Consumption ( $E$ ) over a given time interval ( $t$ ) can be estimated using the following equation:

$$E = P \cdot t \cdot F_C$$

where  $P$  is the power of the controlled system and  $F_C$  is the coefficient representing the impact of the control system and is the ratio between the time when the controlled system is automatically switched off because not needed and the total period of time.

By extension, the method based on operation time can be used if the control system modulates the system rather than switches it on or off; in this case, it represents the equivalent operating time.

### ***Method Based on Room Temperature***

The method in question is devoted to cases where the control system has a direct impact on the room temperature. The principle is to consider the calculation of energy requirements according to EN ISO 13790 that will consider the impact of a temperature control system.

In general you should at least take account of the following:

- emission control (heating and cooling);
- intermittent emission and/or distribution control;
- optimization related to the coordination of various control devices;
- detection of errors in operating systems and techniques to provide support for the diagnosis;
- room control;
- intermittent heating control.

Consumption ( $E$ ) over a given time interval ( $t$ ) can be determined as:

$$E = L \cdot ((\theta_{SP} - \Delta\theta_C) - \theta_R) \cdot t$$

where:

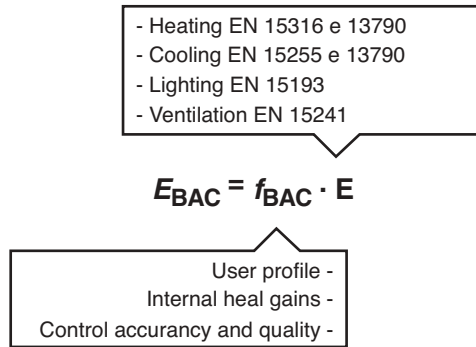
- $L$  is a transfer coefficient
- $\theta_{SP}$  is the set point
- $\Delta\theta_C$  is the impact of the actual control system (equal to 0 if the system is perfect, positive in case of heating and negative in case of cooling)
- $\theta_R$  is the reference temperature, for example the outdoor temperature

### ***Method of Correction Coefficients***

The method of correction coefficients can be useful when the control system acts on multiple factors such as time, temperature, etc.

Consumption ( $E$ ) can be estimated as:

$$E = EPC \times C$$



**Figure 4.38** Conceptual framework of the application of factors in the BAC method (EN 15232)

where:

- EPC is the consumption in the reference case, for example, if the system is controlled ideally or if there is not a function of automation or management
- XC is the factor that represents the increase or decrease of energy consumption compared with consumption in the reference case. The values depend on the type of control but also depend greatly by the climate and the type of construction, etc.

#### ***Method of Factors: Boards and Formulae for Calculating***

The determination of efficiency factors contained in the standard and therefore the effect of the adoption of automation, control and management functions for different types of buildings are the result of the comparison of annual consumption in a room of reference with that introduced in the same room under the same conditions (time of occupation, user profile, weather conditions, sun exposure) with the use of different levels of automation, control and management (A, B, C, D).

The method of efficiency factors is applicable to residential buildings as well as offices, reading rooms, schools and similar, hospitals, hotels, restaurants, malls and shops. The efficiency factors provided are different for different applications: electrical and thermal (heating, cooling). Please note that the energy required for artificial lighting was not taken into account in the calculation of BAC efficiency factors (Figure 4.38), therefore the impact of automation and control on the lighting system must be assessed separately using the EN 15193 standard.

The following tables (from the EN 15232) show directly the relationship between the consumption of room/building with Class A, B or D and the class C, (i.e. the reference class). Table 4.7 shows efficiency factors.

As a summary of what is reported in the tables, it is worth noting that compared with an environment with minimum C requirements, for example automation of cooling in an office, there are energy savings and therefore economic savings on quantifiable consumptions as reported in Tables 4.8 and 4.9. Even if the standard takes the class C as reference, practically there are many cases where the situation (existing or alternative basis) for comparison is the one corresponding to class D, without any automation, control or management. In this

**Table 4.7** Efficiency factors (from EN 15232)

Building	Building type	$f_{BAC,EL}$				$f_{BAC,HC}$			
		D	C	B	A	D	C	B	A
Non residential	Offices	1.10	1	0.93	0.87	1.51	1	0.80	0.70
	Lecture hall	1.06		0.94	0.89	1.24		0.75	0.5 <sup>a</sup>
	School	1.07		0.93	0.86	1.20		0.88	0.80
	Hospital	1.05		0.98	0.96	1.31		0.91	0.86
	Hotel	1.07		0.95	0.90	1.31		0.85	0.68
	Restaurant	1.04		0.96	0.92	1.23		0.77	0.68
	Wholesale and retail trade service buildings	1.08		0.95	0.91	1.56		0.73	0.6 <sup>*</sup>
Residential	Single family houses Apartment block Other res. Building or similar	1.08		0.93	0.92	1.10		0.88	0.81

case the gap increases considerably. In the case of an office, actually, the gap in consumption between a building in Class A and one without automation, that is class D, results in almost 54%.

For ease of calculation, from the definition tables of the efficiency factors BAC contained in EN 15232, the coefficients reported in Table 4.10 were obtained, in order to derive the consumption corresponding to different solutions, directly from the consumption corresponding to the starting Class D.

With  $f_{BACi}$  represented by the coefficients shown in the standard EN 15232 and with  $k_n$  being the multiplying coefficients with respect to Class D.

**Table 4.8** Estimated percentage of the savings achievable by adopting different automation systems with respect to Class C. Example of an office

Class	Saving
B	$(1 - 0.8/1) 100 = 20\%$
A	$(1 - 0.7/1) 100 = 30\%$

**Table 4.9** Estimated percentage of the savings achievable by adopting different automation systems with respect to Class C. Example of a dwelling

Class	Saving
B	$(1 - 0.88/1) 100 = 12\%$
A	$(1 - 0.81/1) 100 = 19\%$

**Table 4.10** BAC coefficients reworked by type of energy consumption

Thermal energy		
$k_c$	$f_{BACc}/f_{BACd}$	0.909
$k_b$	$f_{BACb}/f_{BACd}$	0.800
$K_a$	$f_{BACa}/f_{BACd}$	0.736
Electrical energy		
$k_c$	$f_{BACc}/f_{BACd}$	0.926
$k_b$	$f_{BACb}/f_{BACd}$	0.861
$k_a$	$f_{BACa}/f_{BACd}$	0.852

Please note that using the method of the factors of efficiency, at an early stage, does not exclude the possibility of subsequent detailed calculation for a more accurate estimate or adjustment of system functions to make them, with successive approximations, as effective as possible. A complete example of applying the method of the efficiency factors is shown in Table 4.11 and refers to a complex of offices with known electrical and thermal consumption (respectively row 6a-6b and row 1). The heating requirements of the office complex is 100 MWh/y, both for heating and for cooling. Adding to the heating requirements (line 1), losses of related systems (line 2), we obtain the total thermal energy used in the offices during the reference period. To determine the consumption that can be obtained in passing from a Class C system to a Class B, using the method of factors it is sufficient to multiply the total consumption of thermal energy (line 3) for the relative factor BAC (line 4), obtaining the total thermal consumption (row 5) with the advanced automation system at advanced efficiency (Class B) and, with this, the energy savings obtained equals 20%. The power consumption of the aux services required to operate the heating and cooling (line 6a) represent, together with illumination (line 6b), the total electricity consumption of the offices. Using the same

**Table 4.11** Example: offices changing from Class C to Class B

No.	Description	Calculations	Unit	Heating	Cooling	Fan	Lighting
1	Thermal energy need (Class C)		MWh/y	100	100		
2	System losses (Class C)		MWh/y	33	28		
3	Total (Class C)	$\Sigma 1 \div 2$	MWh/y	133	128		
4	BAC $f_{BAC,HC}$ (Class B)			0.80	0.80		
5	Thermal energy consumption (Class B)	$3 \times 4$	MWh/y	106	102		
6a	Auxiliary services		MWh/y	14	12	21	
6b	Lighting						34
7	BAC factor $f_{BAC,e}$ (Class B)			0.93	0.93	0.93	0.90*
9	Electrical energy consumption (Class B)		MWh/y	13	11	20	31

\*Calculated according to the Standard EN 15193

calculation procedure, this time by referring to the factor  $f_{BAC,e}$  (line 7), the savings amount to 7.4%, compared with the system in Class C.

The same table can be obtained with any spreadsheet.

## Further Readings

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