# Demand-controlled ventilation

## Control strategy and applications for energy-efficient operation

Answers for infrastructure.

SIEMENS

# Contents

# 1 Introduction

To achieve a high level of overall efficiency in a building, it is not sufficient simply to use the best components available. The components also need to be coordinated – not only in terms of technology but also in the way in which they are operated. However, even with perfectly coordinated subsystems, energy consumption will be too high if the subsystems are not operated on the basis of actual demand (e.g., if the ice or chilled water storage tank is charged unnecessarily, or if the air conditioning plant keeps on running when the building is empty).
Systems have a natural tendency to descend into anarchy. Users become negligent. The original setpoints, characteristic curves, switching times, etc., get modified. But usage also changes continuously. In a demand-controlled ventilation system, the air renewal demand is measured continuously by indoor air quality (IAQ) sensors ($CO_2$ or mixed-gas (VOC) sensors), while a controller continuously adjusts the amount of outside air delivered to the room so that it matches the actual (measured) demand.

The aim of this brochure is to show:
- The customer benefits of demand-controlled ventilation
- What is meant by “demand-controlled ventilation”
- How such systems are implemented in practice, in both new and existing plants
- Points to consider at every stage from planning to commissioning and operation

1. **High-efficiency components**
   Buildings, boilers, DHW production, chillers, ventilation and air conditioning systems, heat recovery, lighting and, for example, office equipment.

2. **Optimum interaction of these components**
   A large and/or complex building cannot operate with total efficiency without a building automation and control system.

3. **Demand-based control**
   Heating, lighting, air conditioning and, for example, office equipment.

4. **Display of key variables** (transparency –» savings)
   Monitoring –» controlling –» optimization

Fig. 1 Criteria for high overall efficiency in buildings

# 2 Principles

Apart from its obvious role of maintaining indoor thermal comfort, the primary function of an air handling system is to ensure good indoor air quality (IAQ) using the minimum of energy. An increasingly common means of achieving this objective in today's market is demand-controlled ventilation. This is a method of operating an air handling system to optimum effect whatever the load, but especially with low loads, using sensors and special control strategies to maintain good IAQ while matching the ventilation rate to the calculated demand for air renewal. It should be said that this approach goes significantly further than operation controlled by a time switch.
The demand for air renewal under low-load conditions can now be reliably acquired with sensors, and the availability of suitable sensors is a prerequisite for demand-controlled ventilation and good IAQ. Two essential features of demand-controlled ventilation are the incorporation of thermal tolerance bands (as specified in DIN EN 13779, for example) and the use of special control strategies to reduce the air flow rate, or even to shut down the plant temporarily. The benefits of demand-controlled ventilation are a reduction in running costs and automatic maintenance of indoor comfort irrespective of operating conditions.
The essential features of demand-controlled ventilation are described in VDMA standard 24 773, “Demand-controlled ventilation – Definitions, requirements and control strategies”, written by specialists from Belimo, Honeywell, Johnson Controls, LTG, Messner Technik, Sauter and Siemens [1, 2].

## 2.1 Purpose

In public areas used by a large but varying number of people (Fig. 2), the potential for savings associated with making rational use of energy (heating, cooling and electrical energy) is only partially exploited by ventilation and air conditioning systems operated manually or with a time switch. This is because the demand for air renewal does not remain constant throughout the day, or from one day to the next. Instead, it depends on the changing number of occupants and their activity (Fig. 4). With demand-controlled ventilation, the amount of air introduced into the room is continuously matched to the actual demand, with the result that cost savings are achieved without impairing IAQ comfort.

| Suitable applications: | Generally, any space with: |
|---|---|
| • Restaurants and canteens<br>• Lecture halls and schools<br>• Shopping malls and department stores<br>• Conference centers and sports halls<br>• Reception halls, booking halls, banking floors, check-in areas in airports<br>• Assembly halls, conference rooms, theaters and cinemas<br>• Hotels and residential buildings | • Varying levels of occupancy<br>• Independent ventilation or air conditioning system |

Fig. 2 Examples of applications for demand-controlled ventilation

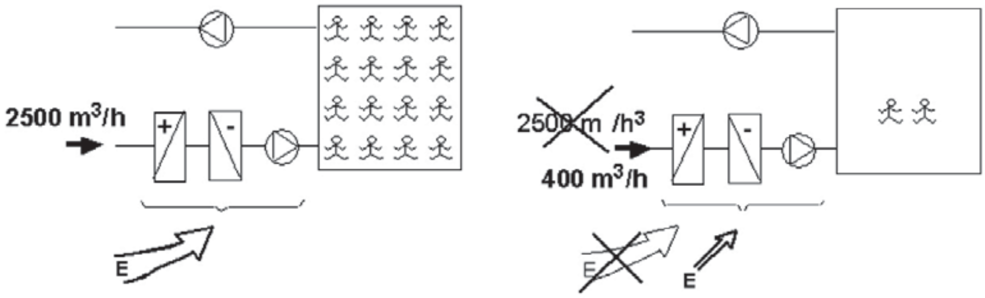
**Which systems are suitable?**
Even existing ventilation systems and full or partial air conditioning systems can be upgraded to provide demand-controlled ventilation. The principal criteria for economic effectiveness are the following:

- Occupancy that varies from day to day
- Systems with air flow rates exceeding 2,000 $m^3$/ hour
- A temperature control system with a zero-energy band or "dead band" (e.g. heating when the room temperature drops below 21 °C, and cooling when it rises above 25 °C)

**2.2 General method**

The minimum volume of outside air for an air handling system is normally designed to provide a specific outside air flow rate per person per hour. This is usually based on a fully occupied space (nominal load conditions, Fig. 3).

**DIN and other standards require an outside air flow rate designed for maximum occupancy**




**To make rational use of energy, the outside air flow rate must be reduced when the space is only partially occupied.**
**→ Demand-controlled ventilation with $CO_2$ or VOC sensors**

Fig. 3 Reducing the outside air flow rate in a partially occupied space

- The outside air flow rate for an air handling system is normally designed for maximum occupancy
- In rooms which are not fully occupied, the outside air flow rate needs to be reduced to make more rational use of energy
- The most energy-efficient solution is demand-controlled ventilation with $CO_2$ or VOC sensors for the reference variable

However, experience shows that it is the exception rather than the rule for a space to be occupied by the number of occupants assumed at the design stage. In many spaces, the level of occupancy varies substantially both over the course of the day and from day to day. During periods of reduced occupancy, the mechanical ventilation system could temporarily be operated at a lower fan stage or reduced fan speed (or even switched off) without any perceptible reduction in IAQ (Fig. 4). Operating the system in this way – on the basis of demand – can save a significant amount of energy normally used for the distribution and conditioning of the indoor air. It should be noted at this point, however, that making rational use of energy does not mean saving energy at all costs! There is a direct relationship between IAQ and the general comfort of the occupants of a space. And energy costs are generally low in comparison with wages or the cost of unfinished work. The aim of demand-controlled ventilation is to maintain good IAQ during normal occupancy hours (provided the space is occupied). In a partially occupied space, however, the ventilation can be reduced as far as possible (Fig. 4).

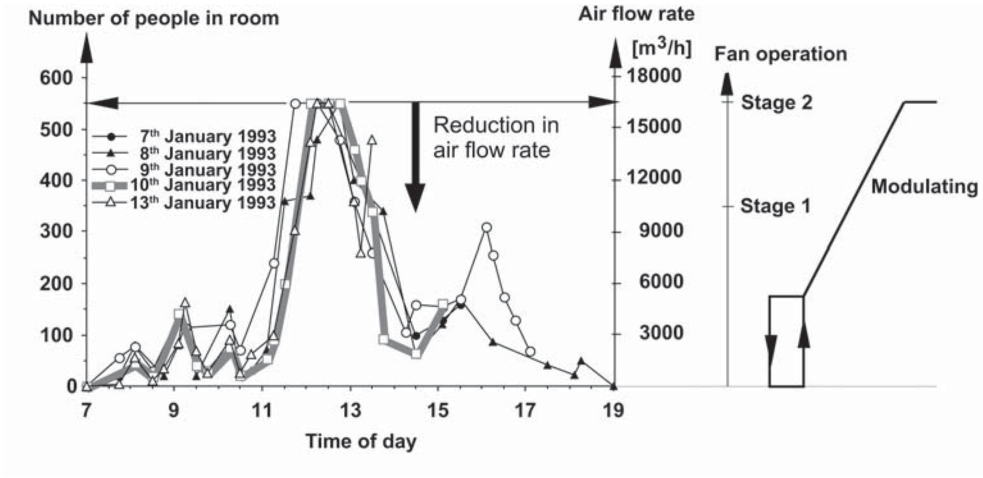



Fig. 4 Results of measurements in the canteen at the University of Zurich

- The number of people using the restaurant varies widely over the day
- At certain times, mechanical ventilation can be significantly reduced, without a noticeable sacrifice in IAQ, by ensuring that the system is operated at fan stage 2 only during peak periods of occupancy. The flow rate delivered by fan stage 1 during the remaining periods is far too high. The solution is demand-controlled ventilation

*Principles of demand-controlled ventilation*

Demand-controlled ventilation is created by adding an IAQ control loop to an existing thermal comfort control system (Fig. 5). An IAQ sensor continuously assesses the air renewal requirement and converts this into an outside air demand signal. The IAQ sensor assesses the quality of the indoor air as it would be perceived by a person on first entering the space. Today's sensors are $CO_2$ sensors and/or VOC sensors (VOC: Volatile Organic Compounds). For definitions, specifications and test data, refer to VDMA Standard 24 772: “Sensors for the measurement of indoor air quality”.
However, simply adding an IAQ control loop does not make demand-controlled ventilation. Another highly significant feature is that control via a time schedule is replaced by a number of demand switches (Fig. 6) responsible for enabling the system. During the potential occupancy hours defined by the time schedule, the air handling system switches on only in the event of a measured demand (for heating or cooling, air renewal, humidification or dehumidification, etc., see Fig. 7).

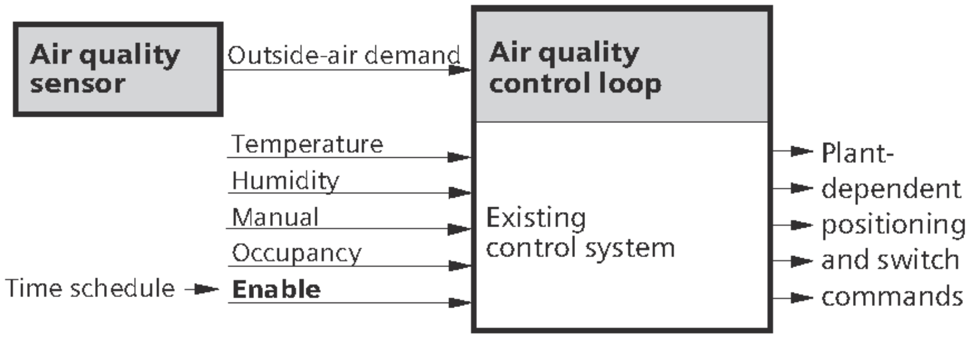



Fig. 5 Principle of demand-controlled ventilation

- **The existing thermal comfort control system** is supplemented with an IAQ control loop (Fig. 5). This has a predefined effect on the outside air flow rate (fan stages or speeds, variable fan speed control, modulating or on/off dampers, adjustable air purification systems, windows, air grilles, etc.)
- An IAQ sensor continuously assesses the air renewal requirement and converts it into an outside air demand signal. The available sensors are $CO_2$ and VOC sensors. Instead of time switch control, the system is enabled by demand switches (Fig. 6)
- Since there is no need to install additional controlled devices for demand-controlled ventilation, existing systems are easy to upgrade

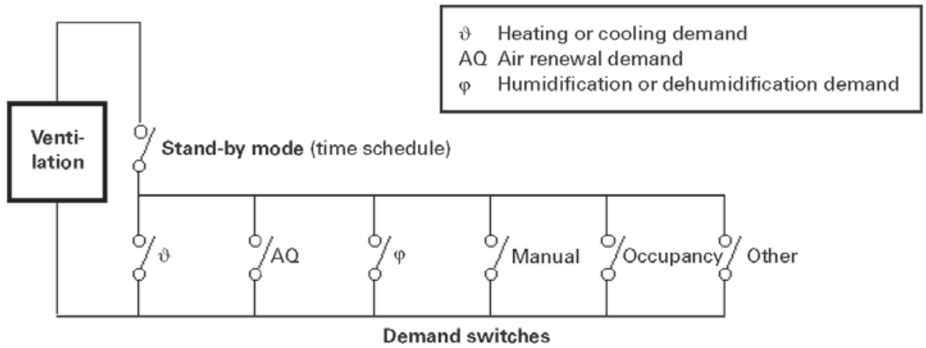



Fig. 6 Enabling the system on the basis of demand signals during standby periods

- When the air handling system is enabled by a time switch, this does not cause the plant to start running immediately. Instead, it switches to standby mode and will not actually start operation until a demand is registered (Fig. 7)
- Frost protection features and the monitoring of minimum and/or maximum room temperature or humidity limits remain in constant operation

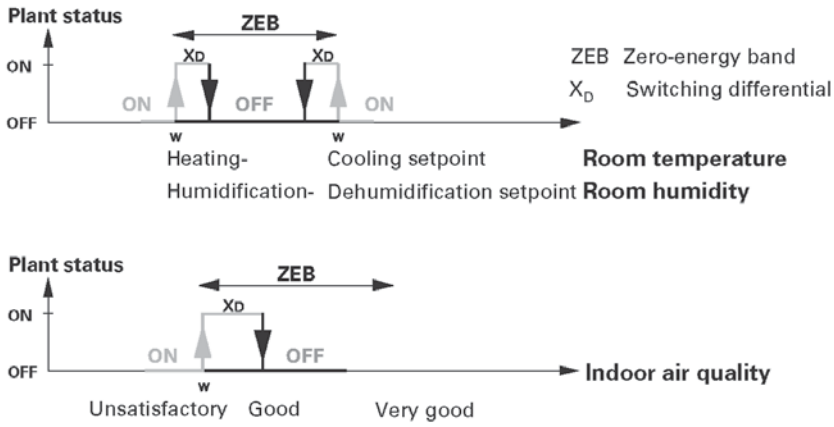



Fig. 7 Demand switches for thermal comfort and IAQ

- If the room temperature is below the heating setpoint, or above the cooling setpoint, the air handling system will operate irrespective of IAQ
- However, if the room temperature is within the zero-energy band for thermal comfort, the system will operate only if IAQ is unsatisfactory
- Base load ventilation may be necessary to extract intrinsic pollutants or to maintain static pressure conditions
- To remove emissions from fabrics and furnishings which accumulate in the indoor air overnight, a boost ventilation period (or “purge”) is advisable at the start of occupancy each day. In spaces left unused for several hours, boost ventilation at the start of each period of occupancy improves IAQ
- The width of the zero-energy band and the switching differential have a significant influence on the number of system starts and the amount of energy saved. Over-frequent plant switching can be prevented by incorporating switch-on delays and a minimum running time

For reasons of air hygiene and health, it may also be advisable in new or refurbished buildings to operate the system outside normal occupancy times for an initial period, to accelerate the removal of undesirable emissions from new fabrics and furnishings.

## 2.3 Control strategy

When implementing demand-controlled ventilation, there are three different categories to consider, based on:

Type of fan control
- On/Off
- Step control (e.g. 0 / 1 / 2)
- Variable speed control

Method of heat recovery
- Plate heat exchanger
- Mixing dampers for recirculated air
- Thermal wheel

The principle for the control of a demand-controlled partial air conditioning system for heating/cooling and heat recovery with a plate heat exchanger is illustrated below (Fig. 8):
IAQ is controlled by adjusting the fan speed (on/off, multistage or variable speed control). Control of IAQ operates in a similar fashion in systems where a thermal wheel is used for heat recovery.

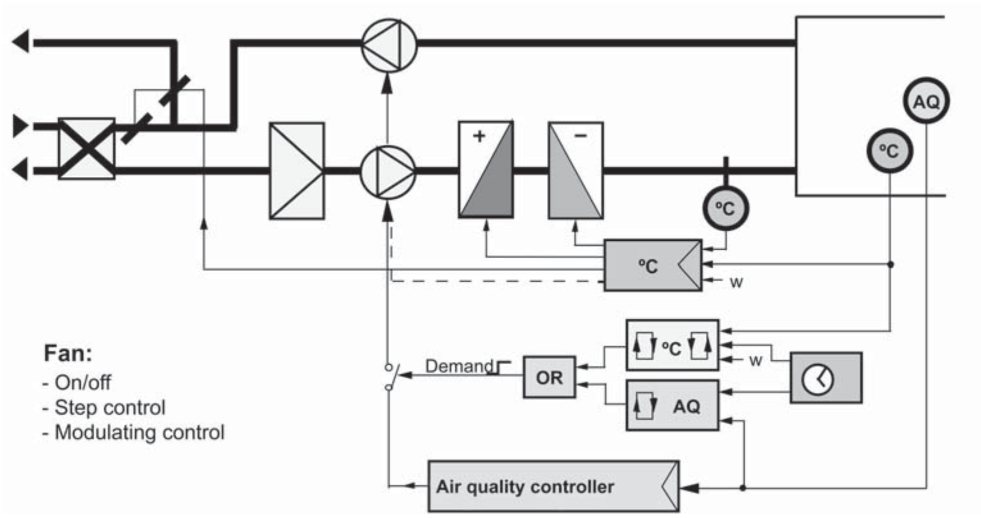



Fig. 8 Implementation of demand-controlled ventilation based on the example of a partial air conditioning system with heating/cooling and heat recovery with a plate heat exchanger

- There are no specific requirements placed on temperature control. As with any normal system, this can be implemented as preferred by the planning engineer and building owner
- Additional requirements: IAQ sensor, demand controller (Fig. 8) and IAQ control loop
- When the system is enabled by the time switch, the plant does not switch on immediately as it would in a conventional system. Instead, it switches to standby mode throughout the normal occupancy period defined in the time schedule
- The system actually switches on when at least one demand controller (Fig. 7) indicates a demand. Heating or cooling demand and air renewal demand are weighted equally (logic OR)
- The IAQ control loop acts on the fan. This will operate in accordance with the air renewal demand (i.e. switching on/off, from one stage to another, or change speed, depending on how the system was designed)
- The control strategies should be so defined that any movement outside the zero-energy band is followed by a return to the band. The aim should be to move back towards the middle of the zero-energy band in switch-controlled systems and towards the zero-energy band limits in variable control systems. Within the zero-energy bands, i.e. in the range in which there is no demand at all, the air handling system should be fully disabled
- Location of sensors: See section 2.7

The principle for a demand-controlled partial air conditioning system for heating/cooling and heat recovery with mixing dampers is illustrated below (Fig. 9): IAQ is controlled initially by reducing the proportion of recirculated air until zero is reached. The fan speed should not be increased to maximum speed until the amount of outside air introduced in response to a continuing air renewal demand reaches 100%.

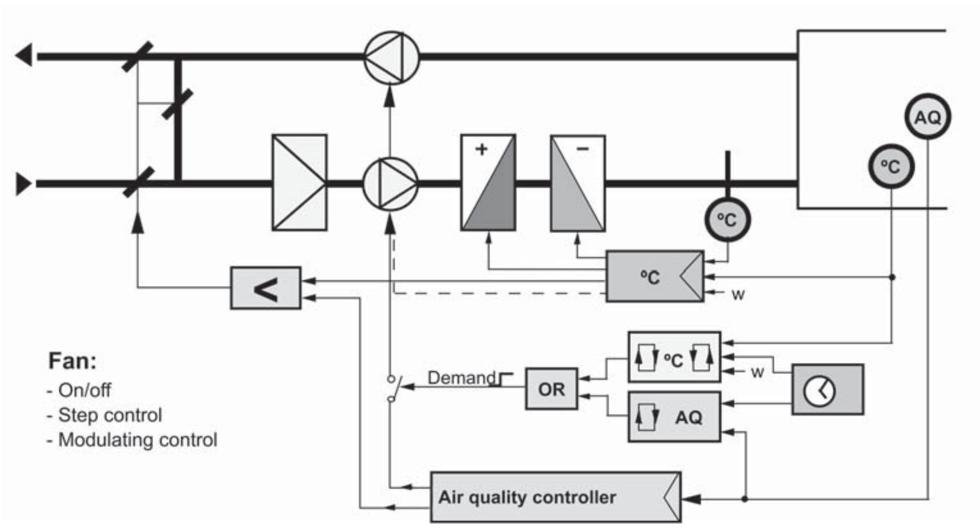



Fig. 9 Implementation of demand-controlled ventilation based on the example of a partial air conditioning system with heating/cooling and heat recovery with mixing dampers

- In contrast to the system with heat recovery via a plate heat exchanger, the IAQ control loop in this case acts not only on the fan, but also on the mixing dampers
- Since distributing the air uses a significant amount of energy, the following control strategy is recommended:
  – Whenever possible, the fan should be operated at the minimum flow rate. The proportion of outside air is determined by both the temperature and the IAQ control system
  – Whenever free heating or cooling is available from the outside air, it makes sense to run the system on 100% outside air
  – If the outside air needs to be heated or cooled, the control strategy must be designed to meet the client's requirements. The recommended approach is one in which the proportion of outside air is determined by either the temperature or the IAQ demand, whichever is the greater
  – With deteriorating IAQ, the first step should be to reduce the proportion of recirculated air down to zero. The speed of the fans should not be increased until the system operates on 100% outside air. If the air renewal demand persists, the fan speed can be increased up to the maximum speed for as long as necessary
- The remaining principles for demand-controlled ventilation (Fig. 8) apply equally to this example
- Sensor location: See section 2.7

## 2.4 Measurement technology

Serious endeavors have been made, especially since the energy crisis in 1973, to decrease the permeability to air of the building envelope, in order to reduce heat losses caused by ventilation. However, the increased impermeability of the building envelope has led to an accumulation of harmful substances in the indoor air. Since most people spend up to 90% of their time indoors, the quality of the indoor air is a question of prime importance.
When discussing IAQ, it is important to differentiate between the following concepts:

- Monitoring of maximum acceptable concentrations (MAC values) and occupational exposure limits (OEL)
- Perceived IAQ
- Avoidance of infection risks
- Explosion protection
- Radon monitoring

We have known for a long time that impurities in the air can be harmful to humans. The primary aim, therefore, must be to prevent the accumulation of recognized harmful contaminants in the indoor air by limiting their emission. But experience shows that traces will always remain, and these have to be removed by ventilation. Pollution caused by harmful substances in the workplace is controlled by legislation (MAC values and OEL in the workplace) and is not considered here. The same applies to infection risks, explosion protection and radon monitoring.

The human perception of ambient indoor conditions is determined largely by the temperature of the room air and of the surrounding surfaces, and by air movement, air humidity and air quality. From the point of view of air hygiene, the ventilation of a space must be such that it fulfils the following requirements: Health must not be endangered by an accumulation of harmful substances, the IAQ must be adequate for comfort, and the humidity level must not be so high that it causes damage to materials. To avoid wasting energy, however, the space should not be over-ventilated.

In residential buildings and many office buildings, rooms are ventilated by opening the windows. But however desirable this method of ventilation may be, it is, for obvious reasons, not always possible. For decades, air handling systems and rooms have been fitted with sensors for the measurement of IAQ, with the aim of improving the quality of the indoor air while making optimum use of energy. The sensors that have penetrated the market are $CO_2$ sensors, and VOC sensors, which measure the presence of organic substances in the indoor air.

*What do we understand by "perceived" IAQ?*

The concept of IAQ cannot be defined precisely and it will always remain a subjective concept because each person has an individual response, and also because the IAQ is influenced by a multitude of gases in the air.
In recent years, however, IAQ has been the subject of wide-ranging research projects and conferences at international level [3]. Of particular interest is the work of professor R. 0. Fanger, who quantified the subjective perception of IAQ using a group of test persons and who, from this study, defined two new units: The "olf" and the "decipol" [4, 5]. Decipol sensors are not currently available. An ideal decipol sensor responds in the same way as the human nose. Since, as already stated, IAQ cannot be measured objectively, the concept of "acceptable IAQ" has been defined. This applies to air which does not contain any known contaminants in harmful concentrations, and which is accepted without complaint by a large majority (80% or more) of the people exposed to it. The types and maximum concentrations of substances considered harmful must be defined by the appropriate authorities. A guide value for acceptable IAQ must be based on an assessment by a newcomer (someone who has just entered an already occupied room) because the human sense of smell quickly becomes accustomed to odors. People who have been in a room for some time are considerably less sensitive to the contamination caused by odors than when they first enter the room.

*Sources of contamination in the indoor air*

Where IAQ is to be influenced by ventilation, consideration also needs to be given to the quality of the outside air introduced into the space. This is particularly relevant in heavily populated areas where air pollutants are emitted locally in large quantities and in circumstances where this could result in an accumulation of these harmful substances. The main sources here are motor traffic, combustion systems and industrial and commercial enterprises. Particularly critical is the pollution caused by nitrogen oxide, ozone (in the summer months) and sulfur dioxide (in the winter months). Airborne dust particles and carbon monoxide can also reach critical levels in urban street canyons. In buildings equipped with mechanical ventilation systems, care should be taken that outside air inlets are not located in the vicinity of sources of pollution.

The sources of indoor air contamination are not limited to those in the outside air (Table 1): Human beings (through carbon dioxide, body odors and tobacco smoke), air handling systems, building materials, furnishings, the combustion of gas for heating and cooking and the use of cleaning agents and household products all contribute to air contamination. The concentration of a substance in the indoor air is essentially based on the balance between its emission rate and the air exchange rate. The World Health Organization (WHO) has produced a list of the 28 most frequent air contaminants, with detailed background information [6].

Wherever possible, the contamination of the indoor air should be avoided by tackling the sources of emission rather than by ventilation measures. The air from rooms used by smokers and from store-rooms or rooms in which photo-chemicals are used should not be mixed with the supply air [7].

*Reference substances causing indoor air pollution in office buildings*

In offices and public buildings, it is generally assumed that humans are the main source of air contamination (through body odors and smoking). However, research by Fanger shows that this assumption is not really generally applicable.
For mechanically ventilated office buildings in which smoking is allowed, the various sources of air contamination were found to be present in the following proportions on average:

13% Humans
25% Smoking
29% Materials in the room
42% Ventilation and air conditioning systems [8]

In relation to the above, however, it is important to note that the emission rate from the most poorly maintained ventilation systems was 30 times higher than that of the best maintained. In the case of materials in the room, individual emission rates were found to vary by a factor of 45. These problems can be overcome by selecting suitable materials and by proper system maintenance.

*Outside air*

| | |
|---|---|
| Biosphere | Pollen |
| Motor vehicles | Nitrogen oxide, carbon monoxide, carbon dioxide, hydrocarbons, airborne particles, oxidants such as ozone |
| Trade and industry | Hydrocarbons, sulfur dioxide, airborne particles, nitrogen oxide |

*Human sources*

| | |
|---|---|
| Metabolism | Carbon dioxide, body odors, water vapor |
| Human activities | Tobacco smoke, airborne particles, cleaning agents, aerosols (solvents and organic compounds) |

*Building materials and furnishings*

| | |
|---|---|
| Chipboard | Aldehydes (e.g. formaldehyde) |
| Insulating materials | Organic compounds, aldehydes |
| Air humidifiers | Microorganisms (fungal spores, bacteria) |
| Paints | Solvents, organic compounds, heavy metals |
| Adhesives | Solvents (carpet adhesive, paints, etc.), aldehydes |
| Building shell | Radon, asbestos, wood preservatives (such as pentachlorophenol) |
| Below ground | Radon |

Table 1 Summary of the principal indoor air pollutants and their sources ([9] page 26)

*Indicator substances for demand-controlled ventilation*
*Carbon dioxide ($CO_2$)*

$CO_2$ is a natural constituent of the air. It occurs as the result of the combustion of compounds containing carbon. Since preindustrial times, the proportion of carbon dioxide in the outside air has risen from approximately 280 ppm (0.028 percent by volume) to approximately 350 ppm.
Human beings continuously exhale $CO_2$ into the environment (at the rate of approximately 20 l/h in the case of sedentary workers). This gives rise in occupied rooms to the average concentrations, shown in Table 2, of $CO_2$ as a function of the outside air supply.

Research has shown that there is a relationship between the carbon dioxide and the body odors simultaneously emitted by the human body [9, 10]. This makes it possible to use the $CO_2$ content of the indoor air as an indicator of the contamination caused by the human body, provided that there are no smokers present, and that there are no other sources of indoor air contamination (see earlier section). It is important to note, here, that in the concentrations normally present in the indoor air (less than 2500 ppm) the presence of carbon dioxide is not significant in health terms. The occupational exposure limit (OEL), or maximum acceptable workplace concentration, is 5,000 ppm. Studies show that a comfortable standard of IAQ can be achieved with an outside air supply of 24 $m^3$ per person per hour (corresponding to a $CO_2$ concentration of 1,000 ppm).

| Outside air supplied per person [$m^3$/h per person] | $CO_2$ concentration [ppm] |
|---:|---:|
| 3.8 | 5,000 |
| 8.5 | 2,500 |
| 14.9 | 1,500 |
| 25.6 | 1,000 |

Table 2 Steady-state values for the concentration of $CO_2$ in a room, as a function of the outside air supply

*Tobacco smoke*

Tobacco smoke is one of the most common indoor air contaminants, both in private homes and in offices. The concentration of tobacco smoke in the indoor air is not easy to define, as tobacco smoke is a complex mixture of several thousand separate components. The most significant pollutants are very fine airborne particles, aldehydes, nitrous amines, nitrogen oxides and carbon monoxide [11]. It should be noted that tobacco smoke is not generally present in the same concentration in all parts of a room. Potential reference substances such as carbon monoxide or the aggregate of airborne particles are technically almost impossible to measure. However, VOC sensors have been shown to be very responsive to tobacco smoke, whereas $CO_2$ sensors are not.

## 2.5 Sensors for demand-controlled ventilation

### 2.5.1 Summary

The sensors used today for automatic measurement of IAQ normally detect the concentration of gases in selected reference substances or mixtures of gases. There are no sensors currently in existence which are capable of detecting all the gases present and assessing their harmfulness or their effect on our well-being. Selective sensors measure the concentration of only one type of gas, such as the $CO_2$ content of the air. VOC sensors, by contrast, measure the weighted influences of various types of gas. Both $CO_2$ and VOC sensors have proven their worth in practice. Siemens also offers combined $CO_2$/VOC sensor (QPA and QPM range). For details, refer to the relevant data sheets.

### 2.5.2 $CO_2$

Infrared gas sensor technology has become the most widespread technology for the measurement of $CO_2$ concentrations in buildings. $CO_2$ is a very powerful absorbent of infrared light with a wavelength of 4.2 µm. This knowledge can be used to determine the concentration of $CO_2$ in the air. Essentially there are two different arrangements, and these are discussed below.

A) Infrared filter photometer with pyroelectric sensor

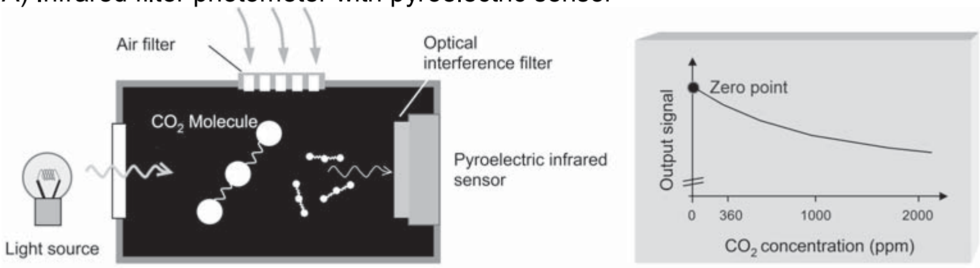



Fig. 10 Principle of measurement with a pyroelectric sensor

- The air probe in the measuring cell is exposed to pulsed infrared light
- The higher the $CO_2$ concentration in the measuring cell, the less light the sensor receives
- The maximum output signal is registered when the $CO_2$ concentration has subsided

The light emitted by the light source passes through a measuring chamber and strikes the sensor via an optical interference filter. The purpose of the interference filter is to ensure that only light with a wavelength of 4.2 µm (the wavelength at which $CO_2$ is absorbing) reaches the sensor. Now, the higher the concentration of $CO_2$ in the measuring cell, the less light is received by the sensor. The air in the measuring cell is exchanged with the air in the environment through small apertures in the cell. To increase sensitivity, the inside of the measuring cell is often reflective, and efforts are made to increase the effective length of the light beam by reflection.

The maximum output signal is measured at zero concentration of $CO_2$. The influence of the drift of the light source and the sensor is solved either by recalibrating the sensor regularly or by linking the sensor to a reference channel. The first method involves relatively high equipment costs and the second leads to high service costs. For this reason, most manufacturers have chosen to fit the sensor with an automatic recalibration mechanism, often referred to as an ABC (automated background calibration) algorithm.
The idea behind this is that all buildings have times when they are not in use. At such times, the measured $CO_2$ concentration in the building drops to a minimum value, which is almost identical to the known concentration in the outside air. This information can be used to recalibrate the sensor automatically and at regular intervals. Unfortunately, this method does not always produce good results in all buildings. For example, the algorithm is not reliable in buildings which are in use for 24 hours per day and seven days a week. Further, the sensor only supplies reliable readings after a long period of adaptation to the building, which can take up to a week. This is a disadvantage in the commissioning phase, because it is impossible to run an immediate check of the correct functioning of the overall building services plant. For this reason, Siemens decided to use the principle of linking the sensor to a reference channel. The ABC algorithm is not used. Siemens $CO_2$ sensors are recalibration-free for at least 8 years and, once installed, are immediately ready for operation.

B) Infrared filter optometer with optoacoustic sensor

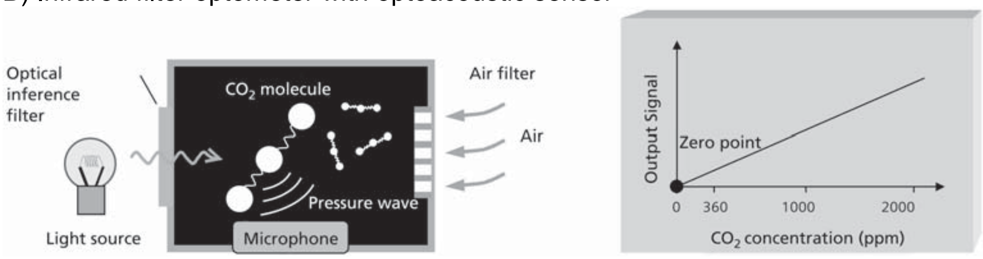



Fig. 11 Principle of measurement with an optoacoustic sensor

- The air probe in the measuring cell is exposed to pulsed infrared light
- This causes the $CO_2$ molecules to oscillate, resulting in a pressure pulse
- A microphone measures the periodical variation in pressure

The light emitted by the light source enters the measuring cell through the optical interference filter. The interference filter only allows light in the 4.2 μm range (the waveband at which $CO_2$ is absorbed) to pass through it. If the pulsed beam of light strikes any $CO_2$ molecules, part of the light is absorbed, and there is a change in the oscillation of these molecules. If a molecule stimulated in this way collides with another molecule of nitrogen or water, for example, the $CO_2$ molecule can transfer its vibration energy to the other molecule, causing the latter to increase its velocity. This increased velocity causes the pressure in the measuring cell to rise, and this can be detected with the microphone.

There will be no wave of pressure if there is no $CO_2$ in the measuring cell. Hence, the zero-point is always clearly defined by the physical principle. The output signal is practically linear. There is no need for the inside of the measuring chamber to be reflective.
Unfortunately, microphones are not very reliable and their output often depends on the surrounding humidity. Furthermore, noise outside of the sensor can cause false measurements.

### 2.5.3 Mixed gases (VOC)

Mixed-gas or VOC sensors detect oxidizable (combustible) gases and vapors, including body odor, tobacco smoke and emissions from materials (furniture, carpets, paints, glues, etc.). Practice shows that these sensors largely measure IAQ as perceived by people, and they have proven their worth in numerous systems [12, 13, 14, 15, 16].

*How do VOC sensors work?*

Essentially, gas sensors based on the principle of the Taguchi cell consist of a sintered semiconductor tube with an internal heater (Fig. 12). The semiconductor tube is highly porous, giving it a very large surface area. The semiconductor is made of doped tin dioxide ($SnO_2$) and acts as a catalytic converter.

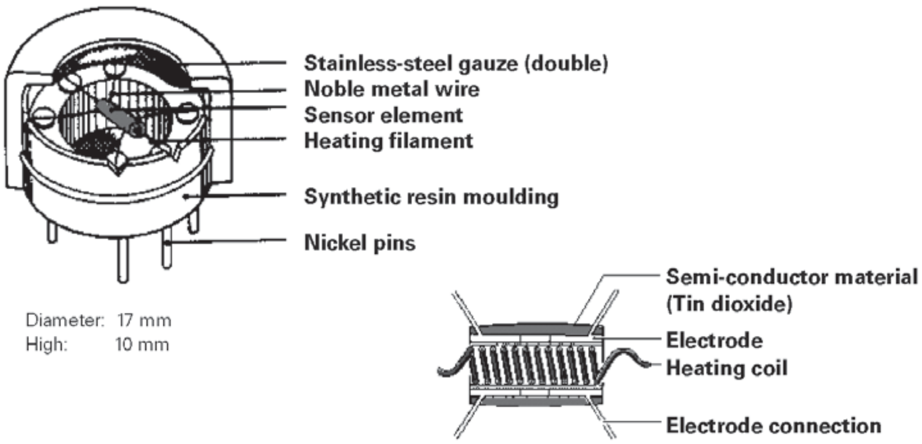



Fig. 12 VOC sensor (Taguchi principle)

These sensors operate with a reversible reaction based on the redox principle (Fig. 13). In the ideal case, gases and vapors which come into contact with the surface of the sensor are oxidized to give $CO_2$ and water vapor. The oxygen required for oxidation is removed from the $SnO_2$. In this process, electrons are released, so altering the resistance of the semiconductor. This change in resistance can be measured as a change in voltage. The partially reduced tin dioxide is reoxidized by the oxygen in the air and reverts to $SnO_2$ again. A dynamic state of equilibrium between oxidation and reduction (redox) prevails, and since this is a catalytic process, there is no degradation of $SnO_2$. The sensitivity of the sensors is determined by the number and extent of the points of contact between the particles of sintered material, the doping, and the temperature of the sensor (determined by the heating filament).

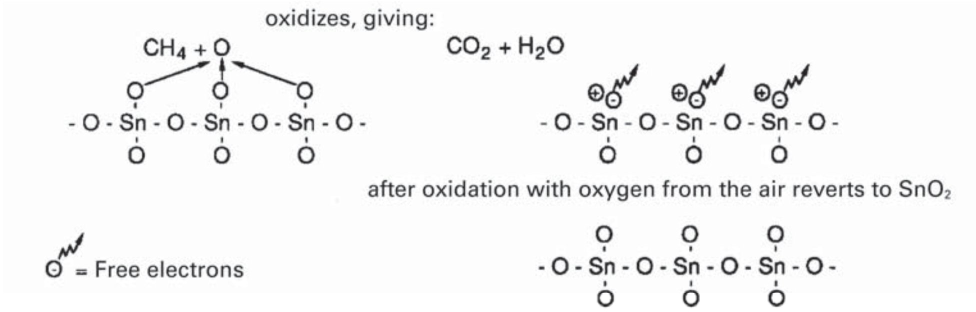



Fig. 13 Principle of operation of VOC sensors

*Wide-band measurement*

VOC sensors measure over a wide band. In other words, the sensor signals give no indication of the type of gases detected, nor in what concentration they are present (Fig. 14). However, owing to the complex and constantly changing composition of the indoor air, it is an advantage if the IAQ sensor is wide-ranging. Sensors used to measure IAQ must be sensitive enough to measure gases and vapors in concentrations of ppm.

Type **TGS 812:** Characteristic curves with various test gases

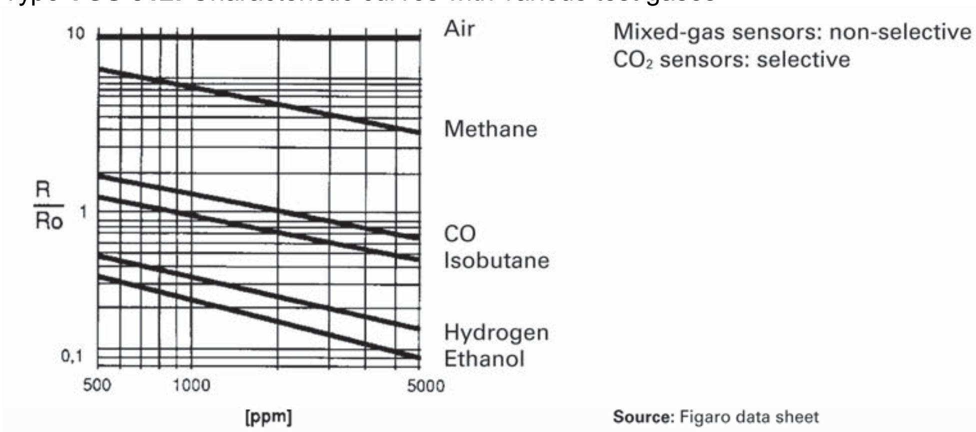



Fig. 14 VOC sensor: Characteristic curves for various test gases

*Automated compensation for the effects of humidity and temperature*

VOC sensors respond not only to combustible gases and vapors, but also to the humidity in the indoor air. Since the sensing element is heated, the room temperature also affects the measured value. Siemens has developed and patented an algorithm which automatically compensates for these two influences. This also means that periodical sensor calibration can be dispensed with.

*Findings with VOC sensors*

VOC sensors are used to very good effect in areas where smoking may be permitted: Restaurants, canteens, conference rooms, function rooms, etc., but also in sports halls, for example.

By way of an example, Fig. 15 shows curves for IAQ and demand-based fan speed control in a restaurant over a period of time. Two VOC sensors of equal weighting are used. The system is a partial air conditioning system with heating and cooling sequences and 2-stage fan control. A plate heat exchanger is used for heat recovery. The control strategy employed is illustrated in Fig. 8. When the restaurant is used by only a very small number of people, the ventilation system operates at stage 1 or is switched off altogether. Over midday, fan stage 2 switches on automatically. Without any impairment of IAQ, this strategy offers significant savings when compared with conventional operation, either manually or based on a time schedule.

**Air quality with mixed-gas sensor**

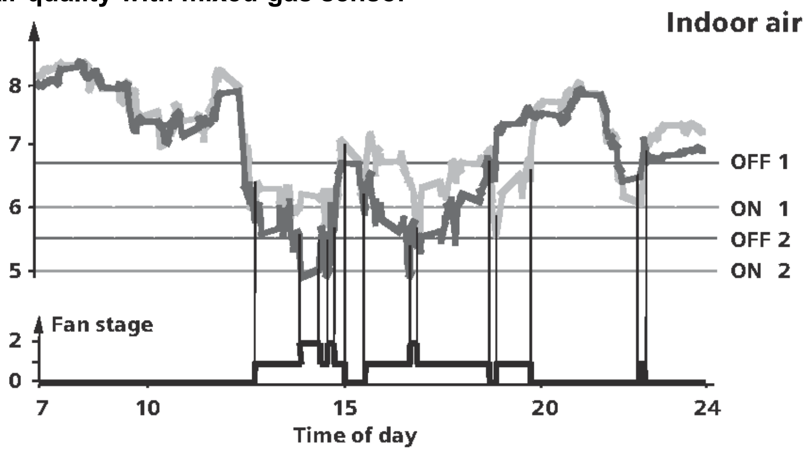



Fig. 15 Demand-controlled ventilation in a restaurant [17]

- Partial air conditioning system with heating/cooling and heat recovery with plate heat exchanger
- Fans with 2-stage control. Reference variable from two equally weighted VOC sensors
- Control strategy as in Fig. 8
- In the period where there is just a small number of guests, the plant runs at fan stage 1 or is switched off altogether. Over the midday period, fan stage 2 is switched on automatically
- Compared with conventional operation, either manually or based on a time schedule, significant savings can be achieved without any impact on IAQ

## 2.6 Simple rules for sensor selection

Some simple rules can be formulated to help decide which of the two available types of sensor to use (see also Fig. 16):

1. If the human beings in a space are the main source of air contamination, the $CO_2$ concentration is the most suitable reference variable for demand-controlled operation of the air handling system. Ideal applications include museums, theaters, lecture halls, cinemas, and open plan offices.
2. Tobacco smoke can be detected only by VOC sensors.
3. If neither of these two sources is dominant, both variables should be measured and evaluated. The sensor measuring the higher demand will determine the intake volume of outside air.
4. If the air is heavily polluted by emissions from materials in the room, then base load ventilation is required, either in the short-term or continuously. This reduces the economy efficiency of the solution. It is therefore important to keep pollution sources of this kind to a minimum.
5. Room or duct sensors? In principle, IAQ can be measured either in the room itself or in the extract air duct.
   – Room sensors enable the plant to be switched off completely, so maximizing energy savings. They can also be positioned to detect the main sources of pollution directly
   – Duct sensors are most often used in VAV systems. They register an average value for IAQ
6. Number of sensors: For spaces of up to 400 m$^2$ with a simple geometry, one sensor is generally sufficient.

| Type of building / space | $CO_2$ | VOC (Mixed gases) |
|---|---|---|
| Museums, theaters, cinemas, lecture halls | X | |
| Restaurants, canteens | (X) | X |
| Shopping malls, department stores | X | (X) |
| Meeting rooms | X | X |
| Conference halls, banqueting halls | X | X |
| Exhibition halls, sport halls, reception areas | X | X |

Fig. 16 Guide to selecting the right type of IAQ sensor for a given application

- $CO_2$ sensors are ideal where the body odor of those present is dominant
- VOC sensors should be used in areas where smoking is permitted

## 2.7 Correct location of sensors

If good IAQ is to be achieved in a room, the sensor must not only be exposed to the main sources of odor, but must also be located in a position where it can acquire the effect of the ventilation system. Note in this connection that odors are spread not only by air currents, but also by diffusion. So, for example, if someone is smoking in a restaurant, the tobacco smoke is soon detectable even in poorly ventilated areas.
This aspect also needs to be taken into account when installing sensors for applications where the first impression is important, e.g. in hotel reception areas, restaurants or shops. In the case of room sensors, a location in the vicinity of the extract air opening generally produces the best results.
If continuous base load ventilation is required throughout the period when the space is in use, then of course, the sensor can be located in the extract air.

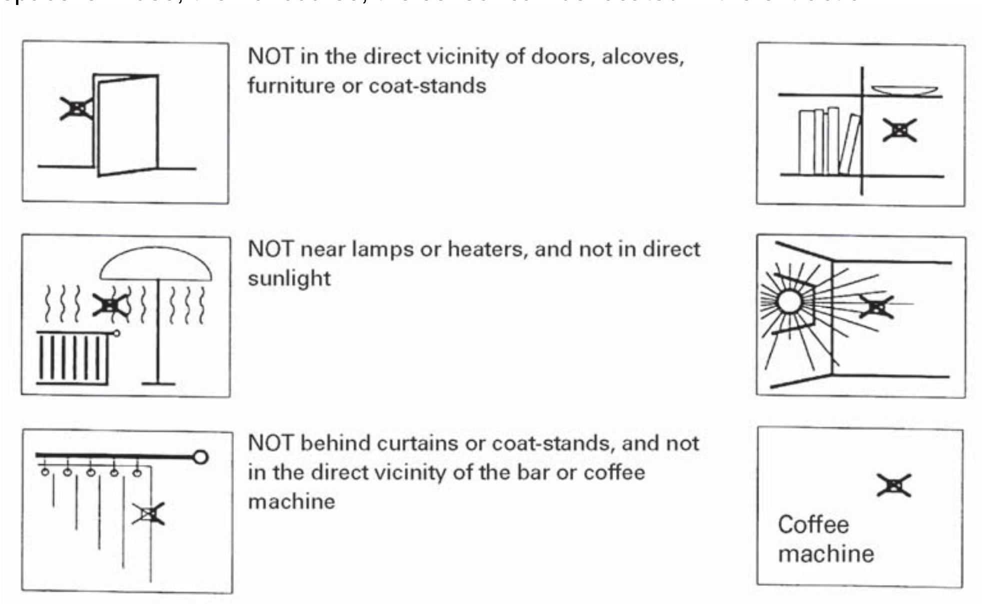



Fig. 17 Where not to install sensors

## 2.8 Controlled devices

The IAQ is influenced by adjusting the outside air in one of the following ways:
- Increasing the air flow rate by use of continuously variable or multispeed fans
- Reducing the proportion of recirculated air in systems with mixing dampers
- Opening the damper in a VAV system

# 3 Economic efficiency and other benefits

Implementation of the technology is one thing, but before a specific approach becomes the norm, evidence must be provided of clearly identifiable customer benefits. The nature of these benefits may be either material or non-material.

**The benefits offered by demand-controlled ventilation are the following:**
- Automatic provision of optimum ventilation
- An increased sense of well-being and higher productivity
- Energy cost savings of 20 to 70% and, hence, less damage to the environment
- Good IAQ, supported by documentary evidence

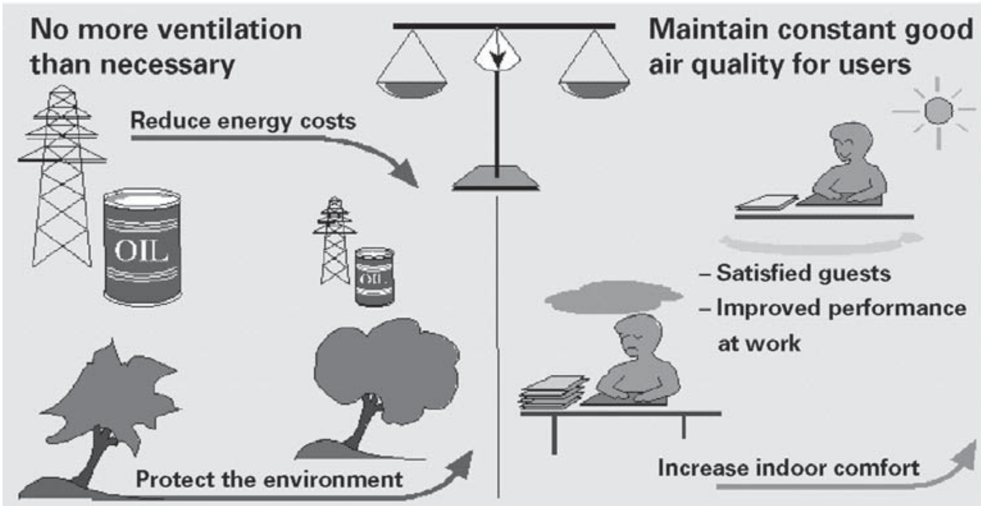



Fig. 18 Benefits of demand-controlled ventilation

## 3.1 Non-material benefits

- Fully automatic operation
  - The operator does not need to attend to the operation of the air handling plant. When the IAQ sensor determines an air renewal demand, the air flow rate is adjusted automatically to actual requirements
  - If doors or windows are opened during the spring and autumn, the ventilation system will switch off automatically. It will automatically switch on again when there is a further demand for mechanical ventilation
  - After a period of use, the space is also ventilated automatically, preventing odors, such as tobacco smoke, from being absorbed unnecessarily by fabrics and furnishings
- Optimum comfort – satisfied and motivated staff
  In the case of oversized ventilation systems or badly located air outlets, demand-controlled ventilation actually increases comfort, because a reduction in operation at the maximum air flow rate is associated with a corresponding reduction in noise and drafts. The way in which people respond to poor IAQ is similar to the way in which they react to unsatisfactory room temperatures. When someone first enters a room full of stale air, their first reaction is to open the window. If this is not possible, first their general sense of well-being and then their productivity is affected by poor IAQ. Saving on IAQ is a false economy: Personnel costs are incomparably higher than energy costs.

**3.2 Material customer benefits**

The material benefits of demand-controlled ventilation depend on the extent to which the volume of air supplied to the room can be reduced without impairing thermal or IAQ comfort (Fig. 19). Empirical values for these savings are shown in Table 4.

**Example:** 2-stage fan control

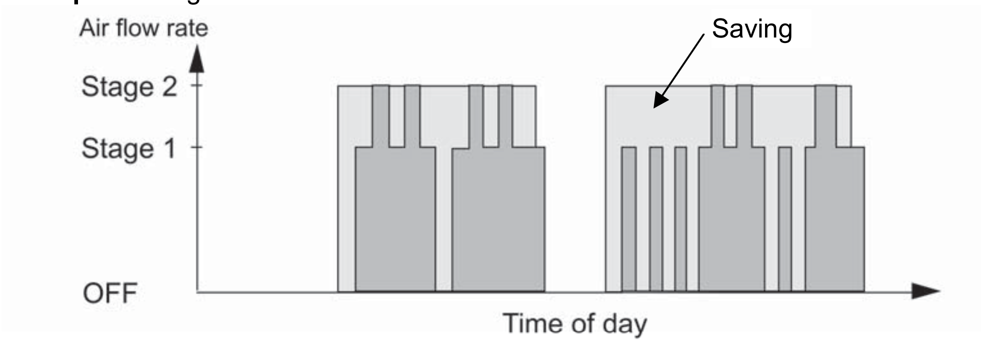



Fig. 19 Compared with a system controlled by a time program (blue area), demand-controlled ventilation shows a significant reduction in hours run (area marked in green)

| | | |
|---|---|---|
| • Lecture halls | | 20 – 50% |
| • Open plan offices | 40% of staff present on average | 20 – 30% |
| | 90% of staff present on average | 3 – 5% |
| • Entrance halls, booking halls, airport check-in areas | | 20 – 60% |
| • Exhibition halls and sports halls | | 40 – 70% |
| • Assembly halls, conference halls, theaters and cinemas | | 20 – 60% |
| • Restaurants and canteens | | 30 – 70% |

The values are based on results from the IEA project, Annex 18 “Demand Controlled Ventilating System” [11, 12, 13] and on the experiences of various controls companies.

Table 4 Empirical values showing the potential energy cost savings in typical demand-controlled ventilation applications

To quantify the material customer benefits of demand-controlled ventilation more precisely, a calculation model was drawn up, based on the constraints and assumptions shown in Table 5. The study is based on a building in the services sector, occupied for 2,750 hours per year.
The influence of internal heat gains was included in simplified form when calculating the heat demand (18 °C supply temperature, 22 °C recirculated air temperature and heat recovery with a plate heat exchanger).

Fig. 20 shows the payback period for the additionally invested capital as a function of system size (air flow rate) and average reduction in the air flow rate achieved.

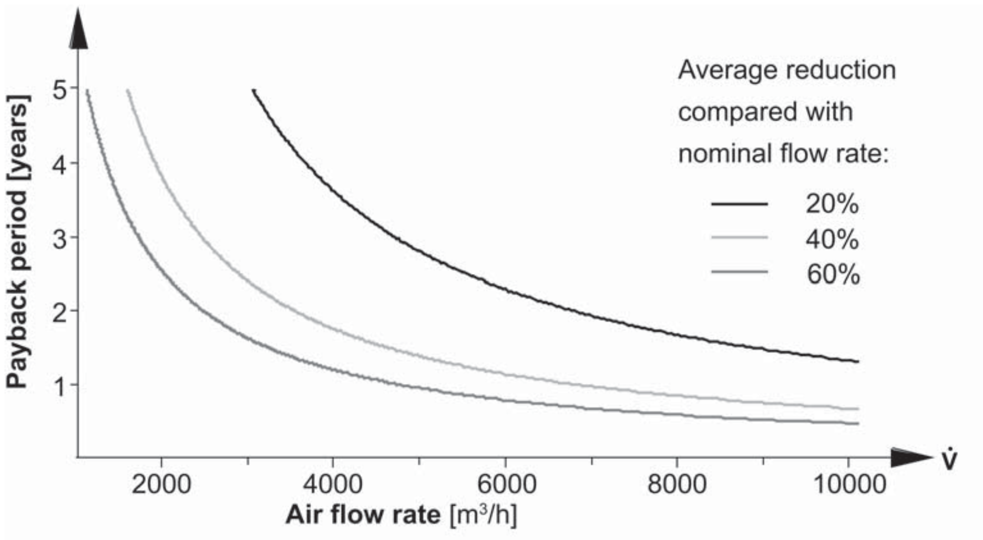



Fig. 20 The payback period for the additional capital invested over and above the cost of a conventional solution is a function of the nominal flow rate and the percentage reduction in flow rate achieved by use of demand-controlled ventilation

- The payback period decreases exponentially as the size of the system increases
- For systems handling 10,000 $m^3/h$, the payback time is typically less than one year (mean air flow rate reduction >40%). The relationship between the payback period and the mean reduction in flow rate achieved is also not linear. For a system handling 3,000 $m^3/h$, the payback period is 5 years for a 20% reduction in air flow rate. If a typical reduction of 40% is achieved, the payback period comes down to 2.2 years. However, improving the reduction in flow rate to 60% only shortens the payback period by approximately 0.7 years
- The calculation model clearly demonstrates that systems with nominal flow rates above 2,000 $m^3/h$ should always incorporate demand-controlled ventilation. When the additional non-material benefits are taken into account, even smaller systems merit this approach
- As discussed earlier, it is quite simple to upgrade existing systems

| | | |
|---|---|---|
| • Nominal air flow rate | 1,000 to 10,000 | $m^3/h$ |
| • Outside air flow rate per person | 40 | $m^3/h$ per person |
| • Mean reduction in air flow rate as a result of demand-controlled ventilation | 20 – 40 – 60 | % |
| • Building occupancy hours | 2,750 | h per year |
| • Supply air/room temperature | 18/22 | °C |
| • Efficiency of heat recovery system | 40 | % |
| • Pressure drop across air handling system at nominal flow rate | 1200 | Pa |
| • Heating degree days/heating days | 3,000/200 | HDD/HD |
| • Capital cost of additional equipment (new system) | 1,000 | € |
| • Electricity costs (kWh rate) | 0.1 | €/kWh |
| • Heat cost | 0.04 | €/kWh |
| • Interest on capital | 0 | % |

Table 5 Constraints and assumptions for the payback periods illustrated in Fig. 20

The main influence on the payback period is the cost saving achieved by reducing the energy used to distribute the air and to heat it to the supply temperature level.

Criteria favoring potential savings:

- High air flow rates
- Plant with long operating hours
- High energy prices (especially electricity)
- Cold climate

Negative factors:

- Small pressure drop across the overall system
- Good heat recovery system
- High efficiency levels
- High interest on capital

# 4 Applications

## 4.1 Main plant configurations

*Type 1 – Ventilation only systems*

- Typical applications: Restaurants, canteens, and cafeterias
- Maximum possible customer benefits, since ventilation system runs only when there is a demand for air renewal
- Possibility of window ventilation
- Room heating with radiators and thermostatic valves or equivalent solution
- Fully automatic operation with scope for manual intervention
- Control strategy:
  - – The ventilation system only runs in response to a demand for air renewal (modulating or with variable speed drives)
  - – Temperature control: Supply air-room air cascade with minimum limitation of the supply air temperature

*Type 2 – Ventilation system with heating in recirculation mode*

- Typical applications: Sports halls, concert halls, theaters, museums, lecture halls, festival halls, and multipurpose halls
- Three operating modes: Mode with people present, heating only, “Building protection” mode
- Control strategy:
  - With people present:
    - – The plant is operated as a function of air renewal or heating demand
    - – If smoking is allowed, $CO_2$ and VOC sensors are used in parallel
  - Heating or “Building protection” mode:
    - – IAQ control not active
    - – 100% recirculated air. Air flow rate and supply air temperature in accordance with ventilation strategy

*Type 3 – Air conditioning system*

- Typical applications: Office buildings, sports halls, concert halls, cinemas and theaters, museums, lecture halls, festival halls, multipurpose halls, shops and shopping centers
- Three operating modes: Mode with people present, heating only, “Building protection” mode
- Control strategy:
  - With people present:
    - – The plant is operated as a function of air renewal or heating and cooling demand
    - – If smoking is allowed, $CO_2$ and VOC sensors are used in parallel
  - Heating or “Building protection” mode:
    - – IAQ control not active
    - – 100% recirculated air. Air flow rate and supply temperature in accordance with ventilation strategy
- Note: In cooling mode, demand-controlled ventilation not only saves on cooling energy, but depending on the humidity conditions, it may also save on the energy used to dehumidify the outside air

**4.2 Enhancements**

The best overall solutions are those in which the air handling system is operated to provide both thermal comfort and IAQ comfort (olfactory comfort) in the most energy-efficient and hence cost-efficient and environmentally friendly way. IAQ comfort may initially involve the reduction or complete elimination by ventilation of unwanted odors. The air vitalizing system takes this further by adding enhancing essential oils to the supply air.

**4.2.1 Economizer tx2**

Conventional air conditioning systems often use the temperature and relative humidity as the controlled variables and control the energy recovery function on the basis of enthalpy. This method does not always produce optimum results and has general shortcomings in terms of response times. Better solutions are achieved if, in place of the temperature-dependent relative humidity, the absolute humidity “x” is used as the controlled variable. The absolute humidity is calculated from the measured temperature “t” and the relative humidity <p.
In partial and full air conditioning systems, demand-controlled ventilation is achieved by controlling the room temperature and humidity not at a constant setpoint, but at the edge of the comfort zone (Fig. 21) and by incorporating the measured IAQ in the control strategy. While the measured room temperature remains within the comfort band of 20 to 24 °C, for example, the partial air conditioning system will not operate unless there is an air renewal demand (via a $CO_2$ and/or VOC sensor). The same principle applies to the room humidity in a full air conditioning system.

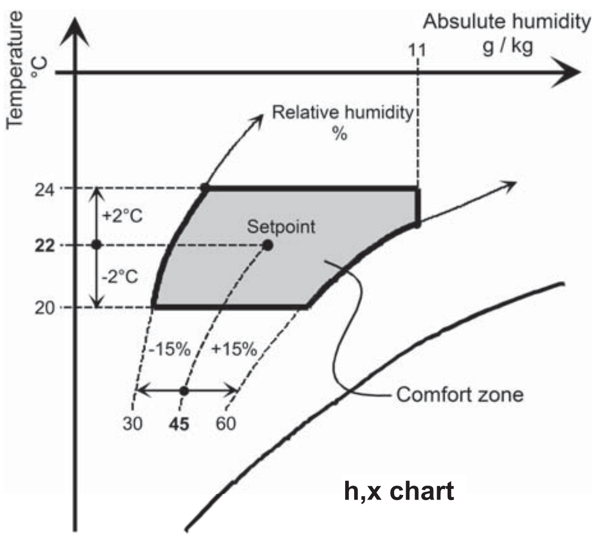



Fig. 21 Comfort zone in the h,x chart

Since heating, cooling, humidification and dehumidification are not equally energy and cost-intensive, it makes sense to optimize these processes too. With the “tx2” energy recovery strategy, the energy recovery system is operated in such a way as to minimize the sum of the weighted demand signals for the heating, cooling, humidification and dehumidification processes. The energy recovery strategy is based on the h,x chart. A vector on the h,x chart and a weighting are assigned to each process. The vectors reflect the theoretical effect of each process. The weighting balances the differing costs of the four processes.
This patented process is described in detail in the brochure “Economizer tx2 – h,x directed control” [18].

### 4.2.2 Air vitalizing system (AVS)

People do not always respond favorably to the air supplied by a ventilation or air conditioning system. Filtering the air removes not only the sources of undesirable odors, but also those with a positive effect. In inner cities, olfactory substances with a positive effect are not normally present in sufficient quantity. The air vitalizing system is a method of introducing natural olfactory substances to the supply air to provide the sensation of natural freshness. It is important to observe both technical and aromachological parameters in this process. The perceived intensity is closely dependent on the dosage and the indoor air temperature and humidity. The level of intensity must be maintained between the detection and recognition thresholds [19, 20, 21, 22].

# 5 Application examples

| Range | Application | Air treatment: Heating | Air treatment: Colding | Air treatment: Humidification | Heat recovery: Recirculated air | Heat recovery: Plate heat exchange | Heat recovery: Thermal wheel | Air volume: On/Off | Air volume: Multispeed | Air volume: Modulating | Air volume: VAV | Product | Application name | Chapter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generic | Partial air conditioning | x | x | | x | | | x | x | x | | | A1958 | 5.1 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| DESIGO RXC | Variable Air Volume | x | x | | | | | | | | AQ | RXC10.1 | VAV01 | 5.2 |
| | Variable Air Volume | x | x | | | | | | | | AQ | RXC32.1 | VAV01 | |
| | Variable Air Volume | x | x | | | | | | | | AQ | RXC32.1 | VAV02 suppl. air only | |
| | Variable Air Volume | x | | | | | | | | | AQ | RXC32.1 | VAV03 suppl. air only | |
| | Variable Air Volume | | | | | | | | | | AQ | RXC31.1 | VAV04 | |
| | Variable Air Volume | x | x | | | | | | | | AQ | RXC31.1 | VAV05 | |
| | Variable Air Volume | x | | | | | | | | | AQ | RXC31.1 | VAV06 | |
| | Variable Air Volume | | | | | | | | | | AQ | RXC10.1 | VAV07 radiator | |
| | Variable Air Volume | | | | | | | | | | AQ | RXC31.1 | VAV08 radiator | |
| | Variable Air Volume | | | | | | | | | | AQ | RXC31.1 | VAV10 electr. radiator | |
| | Variable Air Volume | | | | | | | | | | AQ | RXC31.1 | VAV14, chilled ceiling, radiator | |
| DESIGO PX | Ventilation system | | | | | | | x | | | | | Vnt10 | 5.3.1 |
| | Partial air conditioning | x | x | | AQ | x | x | x | x | | | | Ahu20 | 5.3.2 |
| | Full air conditioning | x | x | x | AQ | x | x | x | x | x | | | Ahu40 | 5.3.3 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| SED 2 | Full air conditioning | x | x | | | | | | | AQ | | SED 2 | Application 10 | 5.4 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Synco 100 | Partial air conditioning | x | x | | | | | | | AQ | | RLM162 | ADCZ01 LM1 HQ | 5.5.1 |
| | Partial air conditioning | x | x | | | | | | | AQ | | RLA162 | ADCZ02 LA1 HQ | 5.5.2 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Synco 200 | Ventilation system | | | | AQ | | | | | | | RLU220 | AAZD01 LU2 HQ | 5.6.1 |
| | Ventilation system | | | | AQ | | | | AQ | | | RLU222 | AAZD02 LU2 HQ | 5.6.2 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Synco 700 | Ventilation system | x | | | AQ | | | | x | | | RMU710B | AEA001 U1B HQ | 5.7.1 |
| | Ventilation system | x | | | | x | | | AQ | * | | RMU710B | ADAE02 U1B HQ | 5.7.2 |
| | Ventilation system | x | | | AQ | | | | AQ | * | | RMU710B | AEA006 U1B DE | 5.7.3 |
| | Partial air conditioning | x | x | | AQ | | | | | x | | RMU720B | AEC001 U2B DE | 5.7.4 |
| | Partial air conditioning | x | x | | | x | | | AQ | * | | RMU720B | ADCE03 U2B HQ | 5.7.5 |
| | Partial air conditioning | x | | x | AQ | | | | x | | | RMU720B | AEDB01 U2B HQ | 5.7.6 |
| | Partial air conditioning | x | | x | AQ | | | | | x | | RMU720B | AEDB03 U2B DE | 5.7.7 |
| | Full air conditioning | x | x | x | AQ | | | | x | | | RMU730B | AEZH02 U3B HQ | 5.7.8 |
| | Full air conditioning | x | x | x | AQ | | | | | x | | RMU730B | AEHB 03 U3B DE | 5.7.9 |
| | Full air conditioning with dehum. | x | x | x | AQ | | | | | x | | RMU730B | AEZH1 U3B DE | 5.7.10 |

AQ: Controlled by air quality
x: Function supported

Table 6 The table provides an overview of the solutions available for demand-controlled ventilation.

(*) Remark relating to Synco™ 700: The dedicated function blocks for supply and extract air fans can be simply adapted for variable speed control based on IAQ or pressure.

**5.1 General example of demand-controlled ventilation**

From the Aerogyr application description A1958:
Measurement of IAQ by use of combined $CO_2$/VOC sensors. Air renewal is controlled as a function of the measured IAQ as follows:

– The fan speed/fan stage is adjusted on the basis of the current air renewal demand
– In systems with direct mixing of the recirculated air, the volume of outside air is adapted to the current air renewal demand

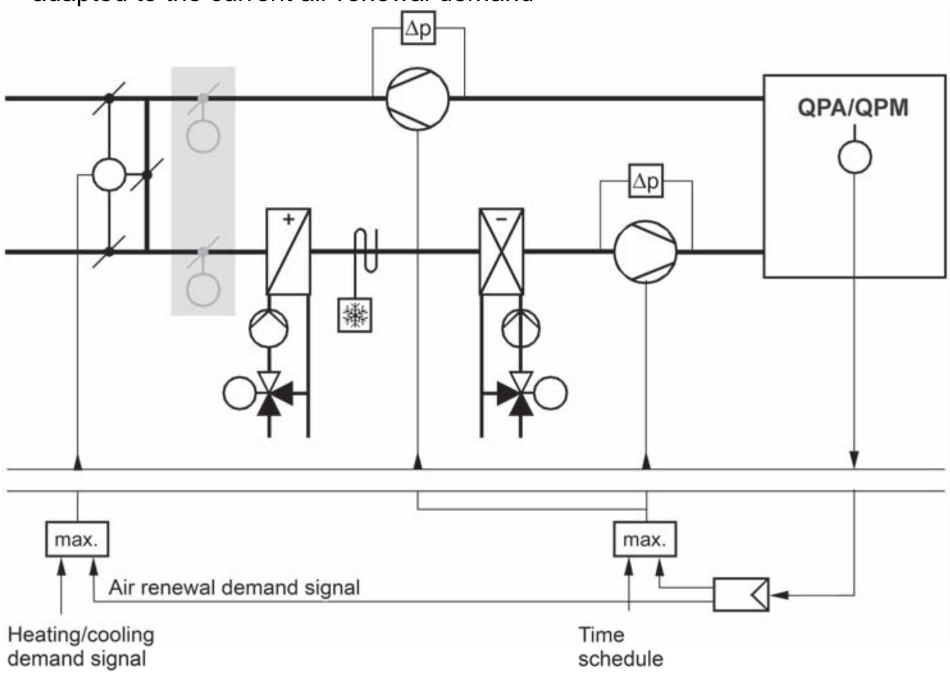



Fig. 22 Example of demand-controlled ventilation

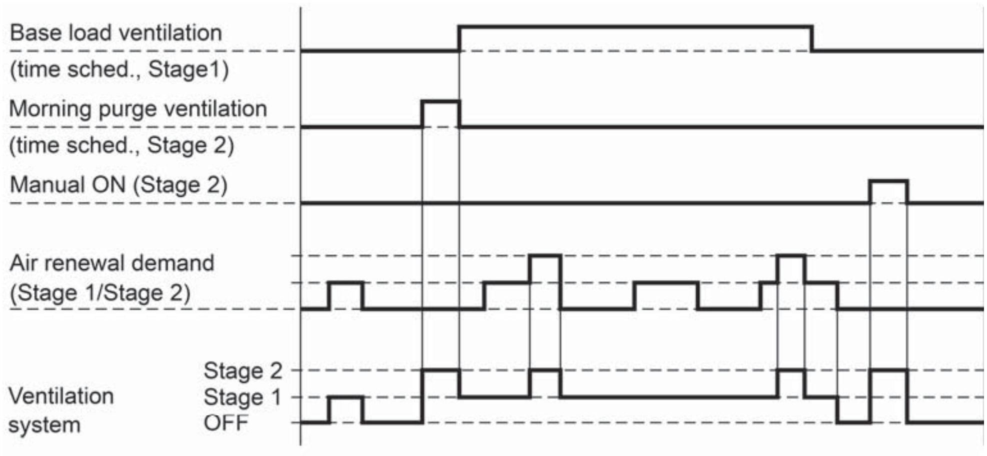
*Description of functions*

The following describes the strategy for demand-based control and the interfaces to the temperature control system. The air renewal demand is measured by combined $CO_2$/VOC sensors. The $CO_2$ signal is an ideal indicator of the number of people in a room, while the VOC signal detects sources of odor such as tobacco smoke, furnishings and fabrics, cleaning agents, etc. A maximum value selector is used, so that the air renewal demand is always determined by the higher of the two signals.
The remaining inputs and outputs depend on the type of plant (fan type, method of heat recovery, etc.) and the required control strategy (time schedule, manual control, occupancy detectors, etc.).


Fig. 23 Control strategies for demand-controlled ventilation

*System release strategies*

A) System with time schedule and manual override




B) System with time schedule and occupancy sensor

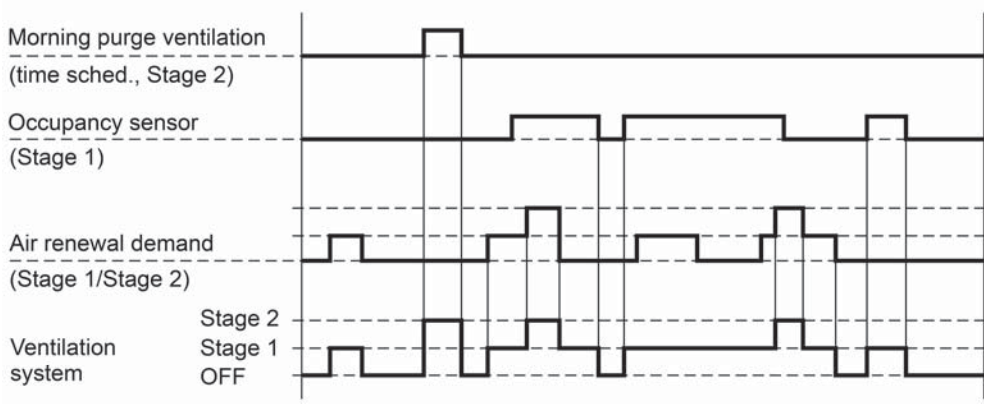



Fig. 24a & 24b Strategies for releasing the system

*Functions*

The functions described below are plant-specific.

- **Basic ventilation:** Can be used as an option. While basic ventilation is active, the comfort temperature is maintained; typically, this is when there are people in the building
- **Preventilation:** IAQ should be good enough before people enter the space. The duration of the preventilation period can be set (two air changes should be sufficient). In the preventilation period, the ventilation system runs at maximum fan speed, with a proportion of outside air determined by the temperature and/or IAQ demand
- **Manually ON:** The fan can be switched on with an override button for a limited period of time. The ventilation system will run at maximum fan speed with a controlled volume of outside air
- **Occupancy detection:** In rooms not used on a regularl basis, occupancy detectors can be installed to detect whether or not the room is occupied. If people are present, the system will run at fan speed 1
- **Coordination with the temperature controller:** Independently of demand-controlled ventilation, the temperature controller must determine whether thermal comfort is achieved while the plant is in operation

*Switching and positioning commands*

The following describes the output sequences of three typical ventilation systems:

A) System with 2-speed fans

- If IAQ deteriorates, the system is switched on at fan speed 1
- Fan speed 2 is switched on if IAQ deteriorates further

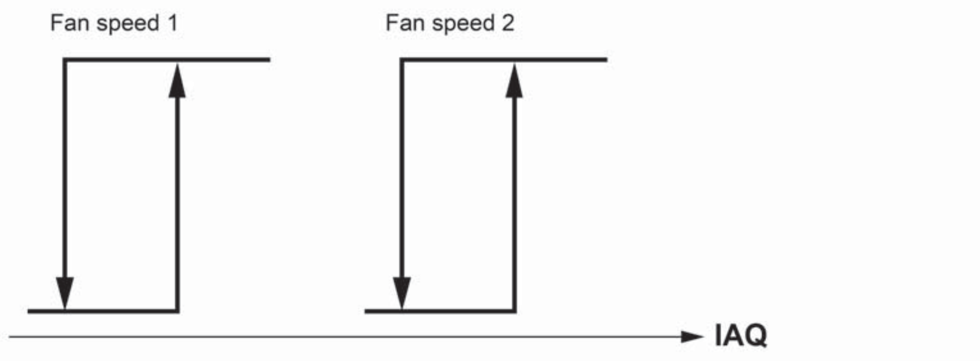



Fig. 25 Fan speed as a function of IAQ

B) System with direct mixing of recirculated air

- After a startup period (if required), the outside air damper travels to the preset minimum position and opens gradually if IAQ continues to deteriorate
- The air heating coil must be sized to operate on 100% outside air, as the outside air damper can be fully opened if $CO_2$/VOC concentration continues to rise
- A maximum value selector determines the higher of the two demand signals (air renewal and temperature)

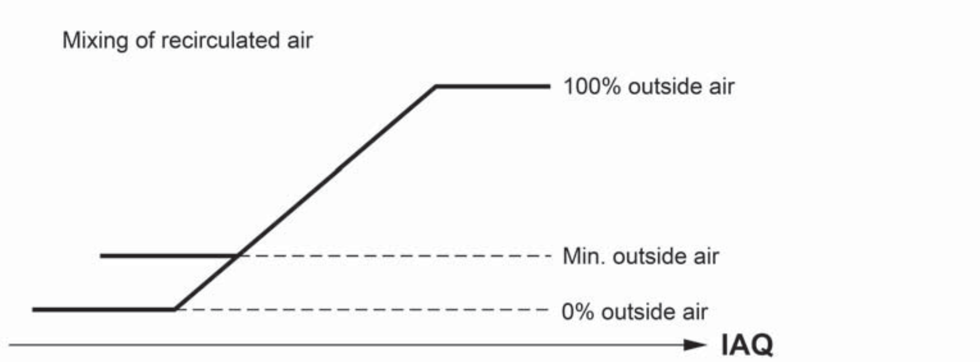



Fig. 26 Mixing ratio of recirculated to outside air as a function of IAQ

C) System with 2-speed fans and direct mixing of recirculated air

- If IAQ deteriorates, the system is initially switched to fan speed 1
- The outside air damper travels to the preset minimum position and opens gradually if IAQ continues to deteriorate
- The system switches to the higher fan speed if $CO_2$/VOC concentration in the room continues to rise

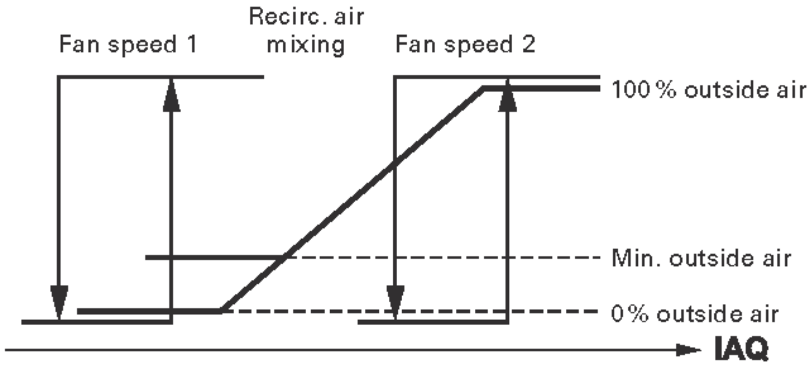



Fig. 27 Combined mixed air and fan speed control

*Commissioning*

- Check to ensure that the sensors are mounted correctly (avoid alcoves and shelves). When mounting a sensor in the extract air duct, choose a location as close as possible to the air outlets
- Check the supply voltage and wiring of the controllers, sensors and other equipment
- Check the control functions of the application and commission the electrical power section and control panel if appropriate
- Once the power section has been connected, the sensor is started without the need for any settings
- After 30 minutes, the functioning of the VOC sensor can be checked with some cotton-wool and alcohol (e.g. with some gas from a cigarette lighter), and the functioning of the $CO_2$ sensor can be checked simply by breathing on it. When the preset switching threshold is reached, the ventilation system should start
- The weighting of the VOC sensor in relation to the $CO_2$ ventilation demand can be adjusted by jumpers in the QPA/QPM sensors for IAQ
- The factory setting should be adequate for normal applications
- Commission the programmed IAQ control loop
- Set the temporary parameters and stabilize them in conjunction with the temperature control loop

*IAQ control with VAV*

All VAV applications support IAQ-dependent control – a function only used in Comfort and Precomfort modes. The IAQ control settings are selected inside the DESIGO RXT 10 tool on the “Device” menu under “Configuration, Settings, Air quality”.

*Measuring IAQ*

IAQ is measured by a sensor installed in the room (e.g. QPA/QPM) or in the extract air duct.

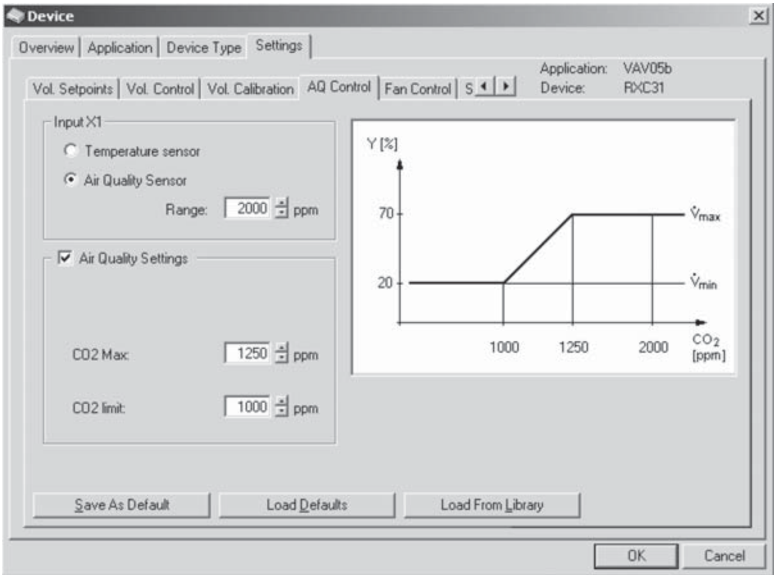



Fig. 28 Setting the IAQ control parameters on the RXT10 commissioning and service tool

IAQ can be measured via the locally connected sensor at input X1 or via LON bus. In such cases, the bus signal takes priority over the local sensor at input X1. Hardware input X1 of the controller can be configured to allow connection of the local IAQ sensor.

| Parameters | Basic setting |
|---|---|
| Input X1 | Temperature sensor |

The following network variable is used for the connection via LON bus:

**nviSpace$CO_2$**

| Input X1 | Description | Value range |
|---|---|---|
| | $CO_2$ pollution of the indoor air | 0...5,000 ppm |

If the sensor does not deliver a valid measured value (0 ppm) or if the value of the network variable is “invalid”, the function is disabled and the IAQ demand signal is set to a volumetric flow of 0%.
If only the measured local sensor value is required, but not the IAQ control function, the latter can be disabled. The measured value will, however, still be mapped to the network variable **nvoSpace** $CO_2$.

| Parameters | Basic setting | Range | Resolution |
|---|---|---|---|
| Range (ppm) | 2,000 | 0...5,000 | 1 |
| $CO_2$ max. | 1,250 | 0...5,000 | 1 |
| $CO_2$ limit | 1,000 | 0...5,000 | 1 |

The “Range” parameter specifies the maximum value of the sensor, which corresponds to the DC 0…10 V signal at input X1. The measured value of the locally connected IAQ sensor at input X1 can be read via the building automation and control system. The following network variable is used for this purpose:

**nvoSpace$CO_2$**

| Input X1 | Description | Value range |
|---|---|---|
| | $CO_2$ pollution of the indoor air | 0...5,000 ppm |

Note: The output value 0xFFFF (65535) indicates an error (defective sensor, etc.).

*Determining the IAQ setpoint*

If the IAQ value of the room is below the programmed $CO_2$ limit, it is controlled in accordance with $V_{min}$. If this value is exceeded, the volumetric flow is increased slowly until finally, at the programmed $CO_2$ max value, the controller is operating at $V_{max}$ (see Fig. 29). $V_{min}$ is determined by the lower of the two setpoints for heating and cooling and $V_{max}$ by the higher of the two.
The difference between $CO_{2\ max}$ and the $CO_2$ limit must be greater than or equal to 100 ppm. The $CO_2$ limit setpoint for IAQ control must be greater than 250 ppm. If a setpoint of 0 ppm is defined, the IAQ control process is disabled and the air flow rate demand signal from the IAQ control system will be set to 0%.

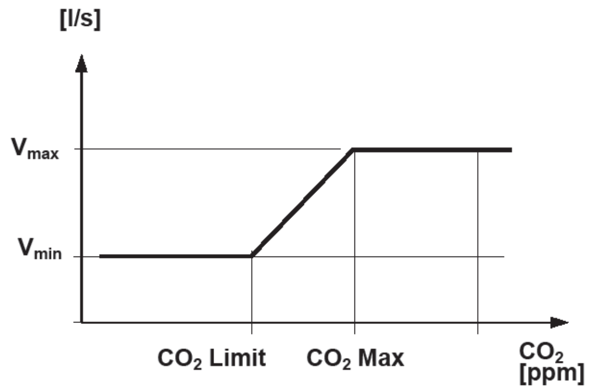


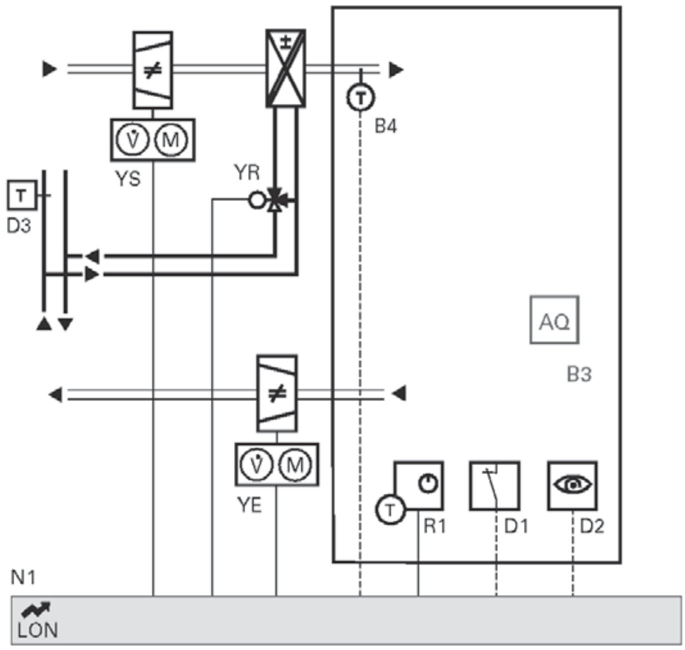

Fig. 29 IAQ control as a function of $CO_2$ content

The resulting volume setpoint is based on the temperature demand signal or the IAQ control signal, whichever is the greater.

## 5.2.1 Single-duct supply-extract air system with reheating or recooling coil

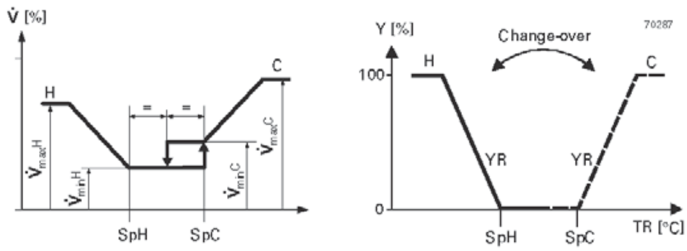
VAV05

- Supply air volume control
- Room temperature control
- IAQ control
- Reheating/air cooling coil or changeover coil
- Changeover signal via LON bus
- Room-supply air temperature cascade




**Plant diagram**

| | |
|---|---|
| R1 | Room unit with temperature sensor |
| B3 | IAQ sensor (room or duct) |
| B4 | Room or supply air temperature sensor |
| D1 | Window switch |
| D2 | Occupancy detector |
| D3 | Changeover signal via LON bus |
| YS | Supply air control |
| YE | Extract air control |
| YR | Reheating/air cooling coil |



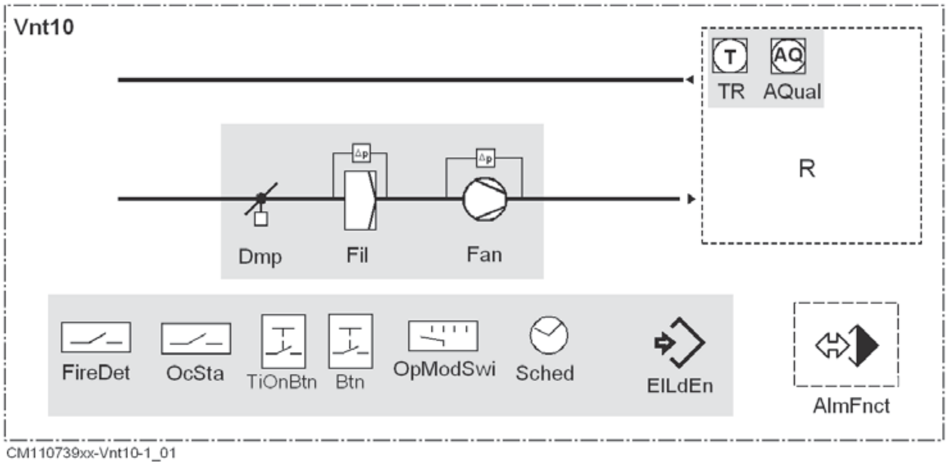

**Function diagrams**

| | |
|---|---|
| V | Volumetric flow |
| TR | Room temperature |
| SpH | Effective heating setpoint |
| SpC | Effective cooling setpoint |
| $V_{max}H$ | Max. volume, heating |
| $V_{min}H$ | Min. volume, heating |
| $_{max}C$ | Max. volume, cooling |
| $V_{min}C$ | Min. volume, cooling |
| Y | Output signal |
| YR | Reheating/recooling coil |
| H | Heating sequence |
| C | Cooling sequence |

## 5.3 DESIGO PX

### 5.3.1 Ventilation system for supply or extract air with air damper andsingle-speed fan

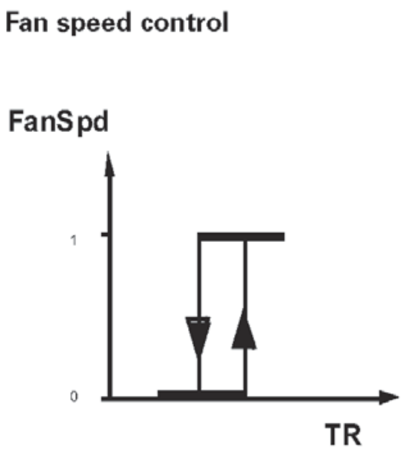
Application Vnt10

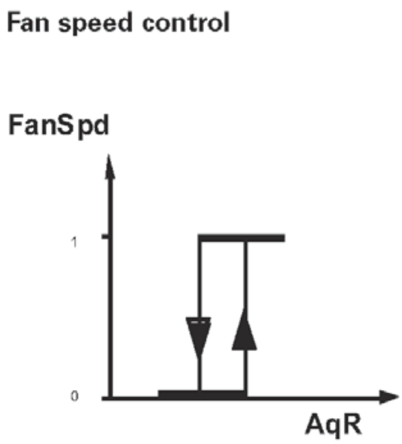



**Plant diagram**

| | |
|---|---|
| AlmFnct | Alarm function |
| AQual | IAQ sensor (option) |
| Btn | Button (option) |
| Dmp | Air damper (option) |
| ElLdEn | Enabling electrical load (option) |
| Fan | Fan (option) |
| Fil | Filter (option) |
| FireDet | Fire detector (option) |
| OcSta | Occupancy state (option) |
| OpModSwi | Operating mode selector (option) |
| R | Room |
| Sched | Time progam (option) |
| TiOnBtn | On button with overrun (option) |
| TR | Room temperature sensor (option) |

*Function diagram*

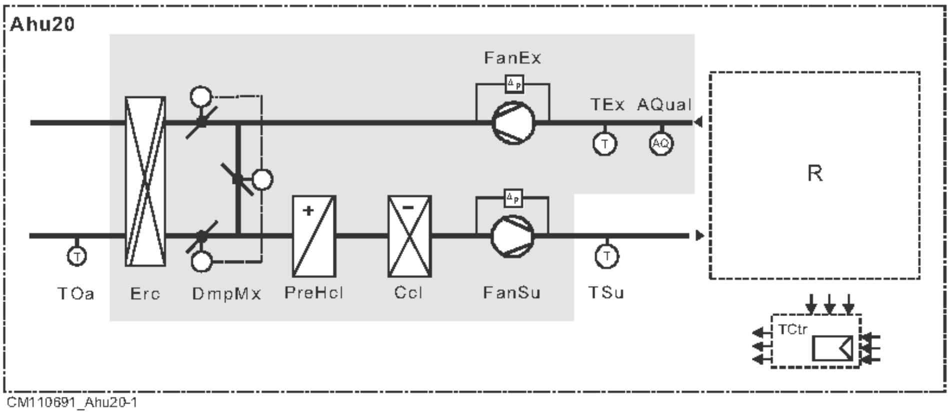



| | |
|---|---|
| TR | Room temperature |
| AqR | Indoor air quality |
| FanSpd | Fan speed |

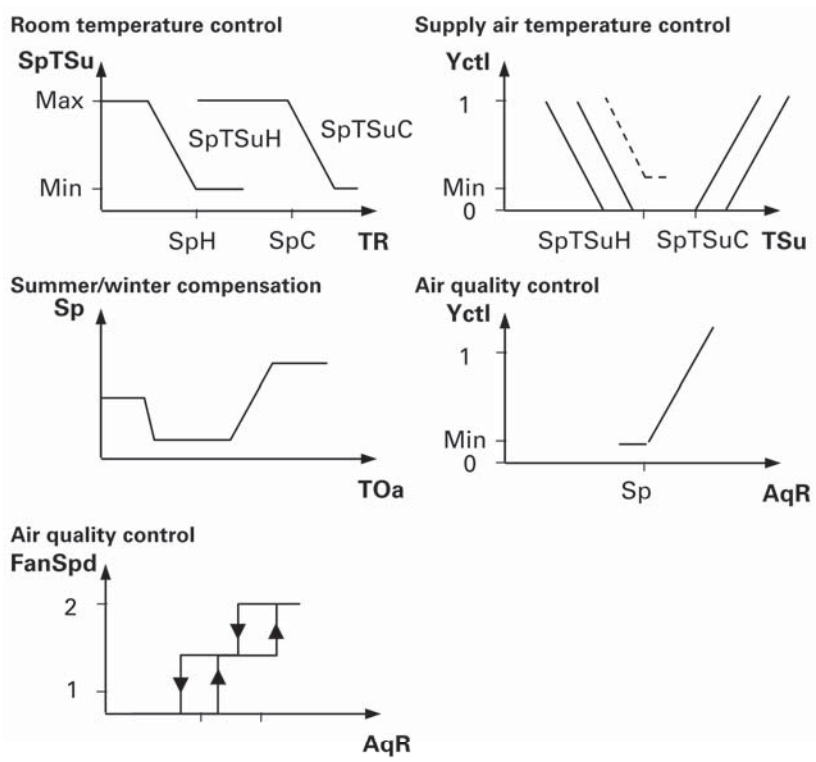
**5.3.2 Partial air conditioning system with mixing dampers, energy recovery, air heating coil, air cooling coil and multispeed fans**

Application Ahu20




**Plant diagram**

| | | | |
|---|---|---|---|
| AQual | IAQ sensor external compound {AQualCtl} | R | Room |
| Ccl | Air cooling coil | PreHcl | Preheating coil |
| DmpMx | Mixing dampers | TCtr | Temperature controller |
| ErcEne | Energy recovery | TEx | Extract air temperature sensor |
| FanEx | Extract air fan, 2-speed | TOa | Outside temperature sensor |
| FanSu | Supply air fan, 2-speed | TSu | Supply air temperature sensor |

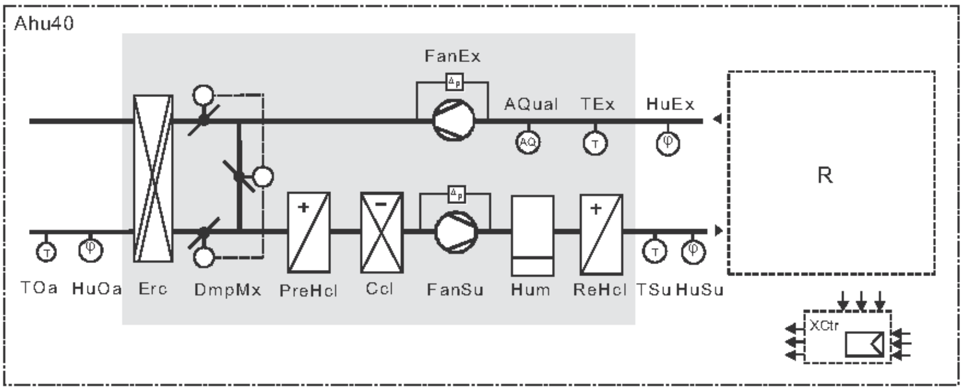



**Function diagrams**

| | | | |
|---|---|---|---|
| AqR | Indoor air quality | SpTSu | Supply air temperature setpoint |
| FanSpd | Fan speed | SpTSuC | Supply air temperature setpoint, cooling |
| Max. | Maximum | SpTSuH | Supply air temperature setpoint, heating |
| Min | Minimum | TOa | Outside temperature sensor |
| Sp | Setpoint | TR | Room temperature |
| SpC | Cooling setpoint | TSu | Supply air temperature |
| SpH | Heating setpoint | Yctl | Controller output |

## 5.3.3 Air conditioning system with mixing dampers, energy recovery, air heating coil, air cooling coil, air humidifier and multispeed fans

Application Ahu40

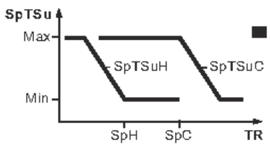



CM110691_Ahu40-1

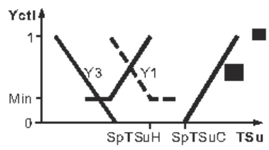
**Plant diagram**

| | | | |
|---|---|---|---|
| AQual | IAQ sensor (option) | HuOa | Outside air humidity sensor |
| Ccl | Air cooling coil (option) | PreHcl | Preheating coil (option) |
| DmpMx | Mixing dampers (option) | R | Room |
| Erc | Energy recovery (option) | ReHcl | Reheating coil (option) |
| FanEx | Extract air fan (option) | TEx | Extract air temperature sensor (option) |
| FanSu | Supply air fan (option) | TOa | Outside air temperature sensor |
| HuEx | Extract air humidity sensor | TSu | Supply air temperature sensor |
| HuSu | Supply air humidity sensor | XCtr | Temperature and humidity controller |

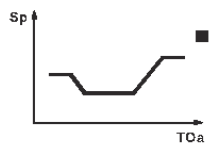
**Room temperature control**



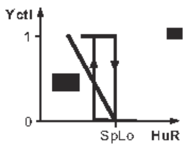

**Supply temperature control**



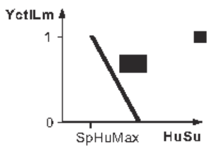

**Summer/winter compensation**



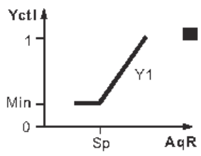

**Room humidity control**



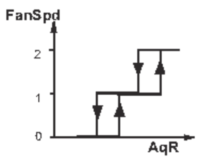

**Supply air humidity limitation**




**Indoor air quality control**




**Fan speed control**




**Function diagrams**

| | | | |
|---|---|---|---|
| AqR | Indoor air quality | SpLo | Lower setpoint |
| FanSpd | Fan speed | SpTSu | Supply air temperature setpoint |
| HuR | Room humidity | SpTSuC | Supply air temperature setpoint, cooling |
| HuSu | Supply air humidity | SpTSuH | Supply air temperature setpoint, heating |
| Max | Maximum | TOa | Outside temperature |
| Min | Minimum | TR | Room temperature |
| Sp | Setpoint | TSu | Supply air temperature |
| SpC | Cooling setpoint | Yctl | Controller output |
| SpH | Heating setpoint | YctlLm | Limitation controller output |

## 5.4 SED2 (demand-dependent control of variable speed fans)

### 5.4.1 Air handling unit with air heating coil, air cooling coil, filter and VSD-controlled supply and extract air fans



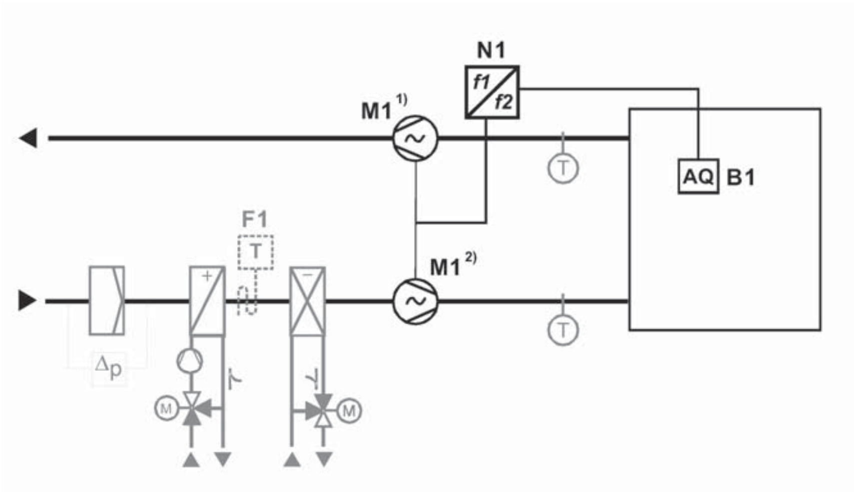
**Use**

- Office buildings
- Public buildings
- Theaters
- Schools and universities

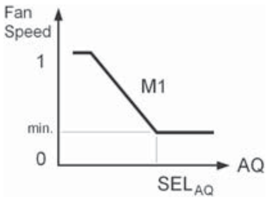
**Options**

- Frost protection unit for protecting the air heating coil
- Filter monitoring with differential pressure switch

*Plant diagram*



*Function diagram* **Demand-controlled fans**




| | |
|---|---|
| AQ | Indoor air quality |
| M1 1) | Supply air fan 1 |
| M1 2) | Supply air fan 2 |
| M1 3) | Supply air fan 3 |
| $SEL^{AQ}$ | IAQ setpoint |
| Min. | Minimum fan speed |

*Description of functions* **Basic functions**

- As the IAQ (measured in $CO_2$ or VOC by sensor B1) deteriorates, the fan speed is increased. When IAQ improves, the fan speed is reduced to its minimum, thus saving energy
- Switching on/off via digital input 1
- External alarm to digital input 2; in the event of alarm, the fan will be stopped
- Booster function via digital input 3 (rpm = 100%)
- Error message via relay output 1
- Indication of operation via relay output 2

**5.5 Synco$^{TM}$ 100**
**5.5.1 Ventilation system with air heating and air cooling coil**

Application sheet

ADCZ01 LM1 HQ
Synco$^{TM}$ 100 RLM162

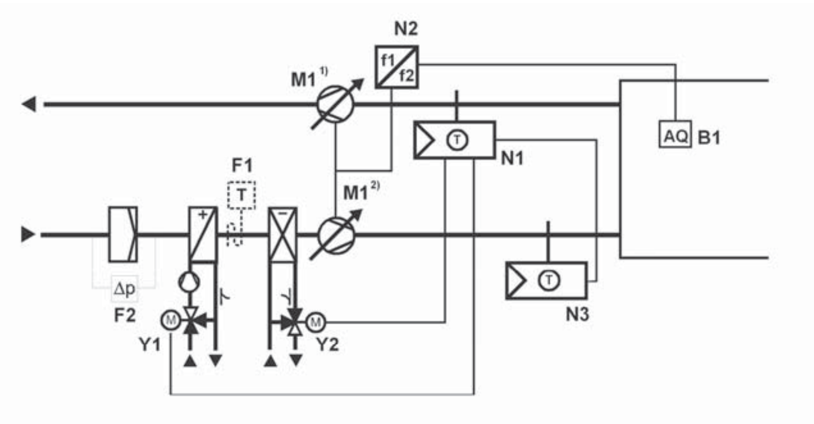
Extract air temperature control including minimum limitation of the supply air temperature and control of IAQ.

Ventilation system with air heating coil, air cooling coil, supply and extract air fan and filter.

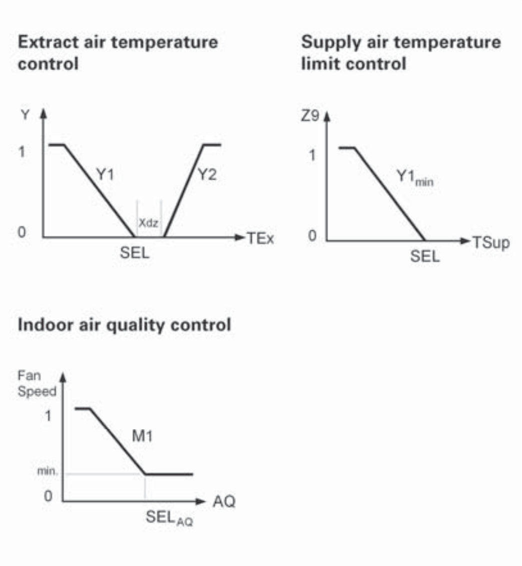
**Use**
- Office buildings
- Warehouses
- Sports halls
- Schools
- Theaters

**Options**
- Frost protection for air heating coil
- Filter monitoring with differential pressure switch

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| TSup | Supply air temperature |
| TEx | Extract air temperature |
| SEL | Setpoint |
| Z9 | Limit control input |
| Y1 | Heating coil |
| Y2 | Cooling coil |
| Y | Control signal |
| $Y1_{min}$ | Limit control signal (DC 0…10V) |
| Xdz | Dead zone |

| | |
|---|---|
| AQ | Air quality |
| M1 2) | Supply air fan |
| M1 1) | Extract air fan |
| $SEL_{AQ}$ | Air quality setpoint |
| B1 | Air quality sensor |
| Min. | Minimum fan speed |

## 5.5.2 Ventilation system with air heating and air cooling coil

Application sheet
Room temperature control including control of IAQ.

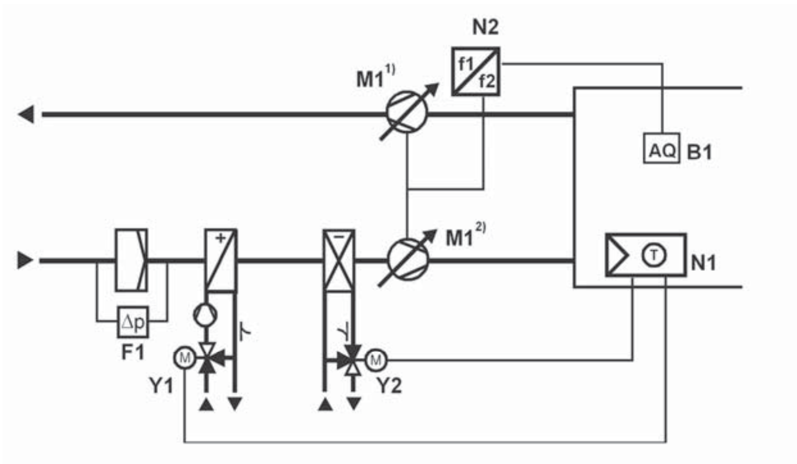
ADCZ02 LA1 HQ
Synco™ 100 RLA162

Ventilation system with air heating coil, air cooling coil, supply and extract air fan and filter.

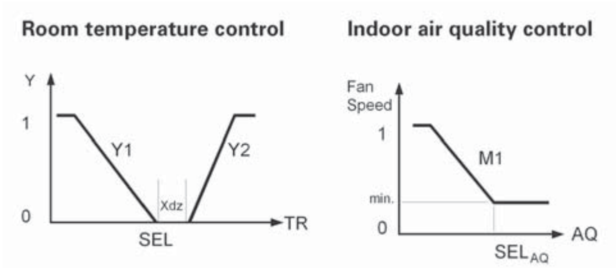
**Use**
- Office buildings
- Warehouses
- Sports halls
- Theaters

**Options**
- Filter monitoring with differential pressure switch

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| TR | Room temperature |
| SEL | Setpoint |
| AQ | Air quality |
| Y1 | Heating coil |
| Y2 | Cooling coil |
| Y | Control signal |
| M1 2) | Supply air fan |
| M1 1) | Extract air fan |
| B1 | Air quality sensor |
| Min. | Minimum fan speed |
| Xdz | Dead zone |

**5.6 Synco™ 200**
**5.6.1 Ventilation system with mixing dampers**

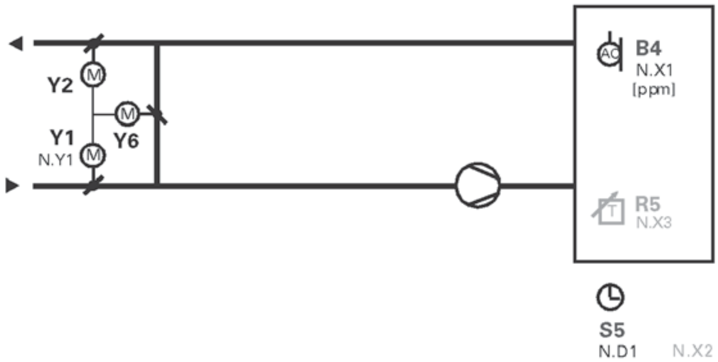
Application sheet
Control of IAQ

AZD01 LU2 HQ
Synco™ 200 RLU220

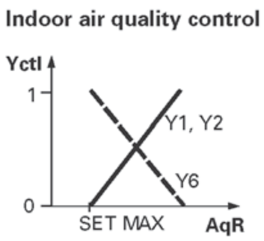
**Ventilation system with mixing dampers**
Ventilation system for spaces where the proportion of outside air is increased with deteriorating IAQ (measured in ppm) to avoid unwanted odors and to enhance comfort. Typical applications include kitchens, public areas, such as restaurants and bars, and buildings with an intermittently large number of occupants (e.g. theaters and cinemas).

**Options:**
- Absolute remote setpoint adjuster
- Additional external setpoint with maximum value selector

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| SET MAX | Setpoint |
| AqR | Indoor air quality |
| Yctl | Controller output |

## 5.6.2 Ventilation system with mixing dampers

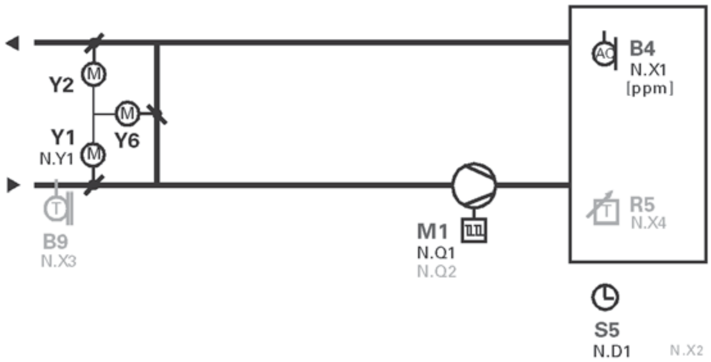
Application sheet
IAQ and fan control

AAZD02 LU2 HQ
Synco$^{TM}$ 200 RLU222

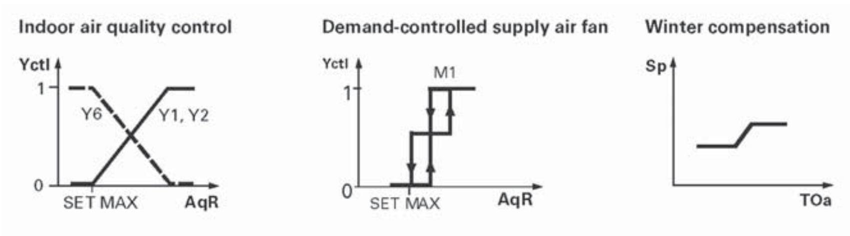
**Ventilation system with mixing dampers**
Ventilation systems for spaces where the proportion of outside air is increased with deteriorating IAQ (measured in ppm) to avoid unwanted odors and to enhance comfort. Typical applications include kitchens, public areas, such as restaurants and bars, and buildings with an intermittently large number of occupants (e.g. theaters and cinemas).

**Options:**
- Absolute remote setpoint adjuster
- Outside temperature-dependent functions
- Additional external setpoint with maximum value selector
- 2-speed fan

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| SET MAX | Setpoint |
| AqR | Indoor air quality |
| Yctl | Controller output |
| TOa | Outside temperature |
| Sp | Setpoint |

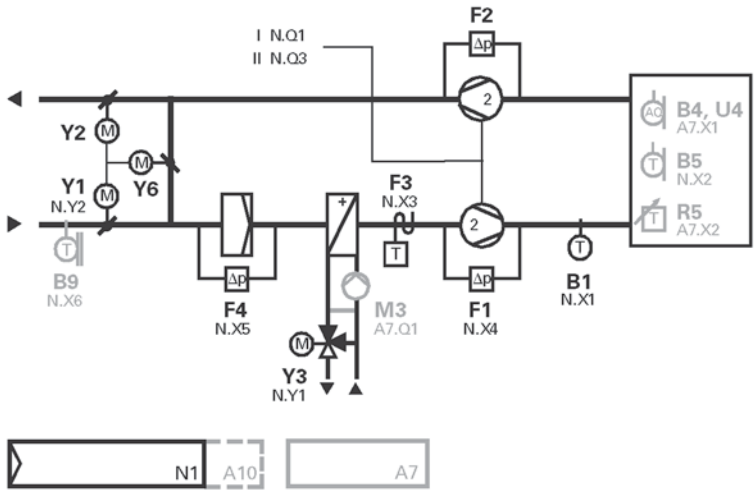
## 5.7 Synco™ 700
### 5.7.1 Ventilation system with mixing dampers and air heating coil

Application sheet
Room-supply air temperature cascade control

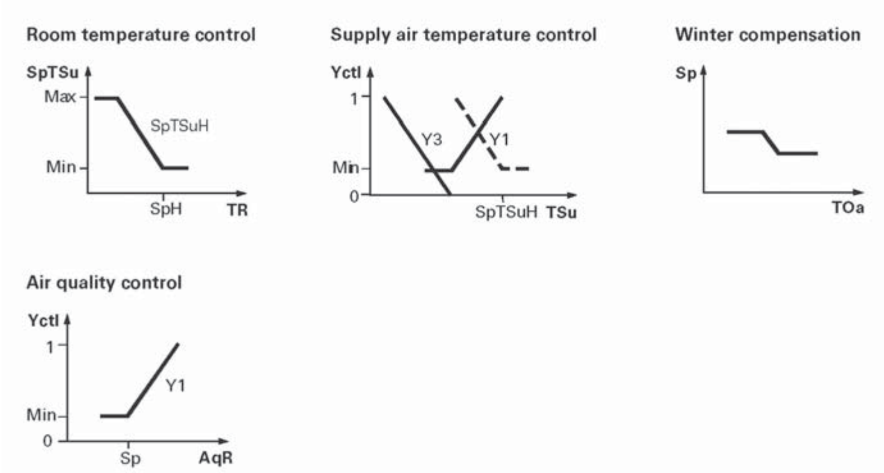


**Ventilation system with mixing dampers and air heating coil**

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| AqR | Indoor air quality |
| Max | Maximum |
| Min | Minimum |
| Sp | Setpoint |
| SpH | Heating setpoint |
| SpTSu | Supply air temperature setpoint |
| SpTSuH | Supply air temperature setpoint, heating |
| TOa | Outside temperature |
| TR | Room temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |

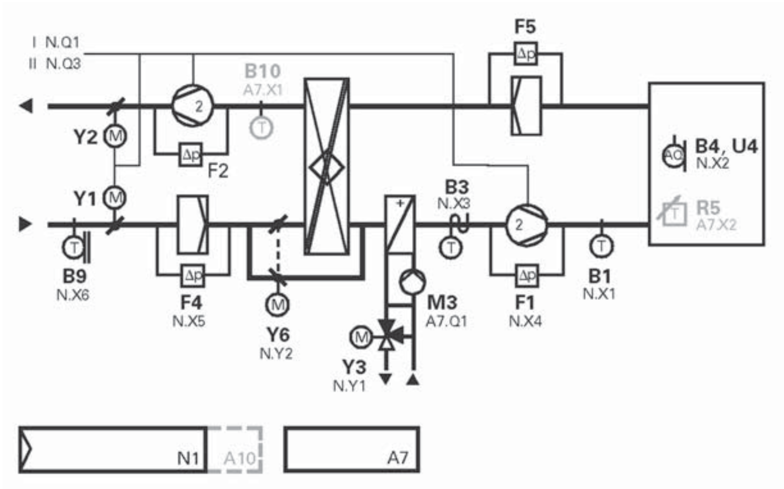
## 5.7.2 Ventilation system with plate heat exchanger and air heating coil

Application sheet
Supply air temperature control including control of IAQ.

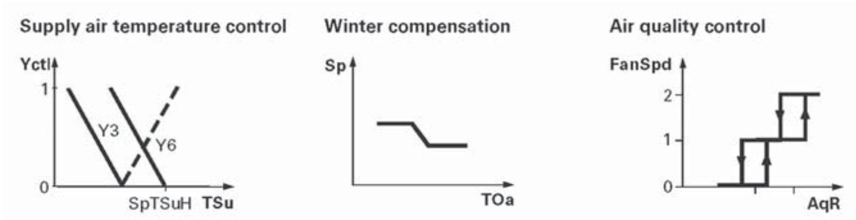
ADAE02 U1B HQ
Synco$^{TM}$ 700 MU710B

**Ventilation system with plate heat exchanger and air heating coil**

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| AqR | Indoor air quality |
| FanSpd | Fan speed |
| Sp | Setpoint |
| SpTSuH | Supply air temperature setpoint, heating |
| TOa | Outside air temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |

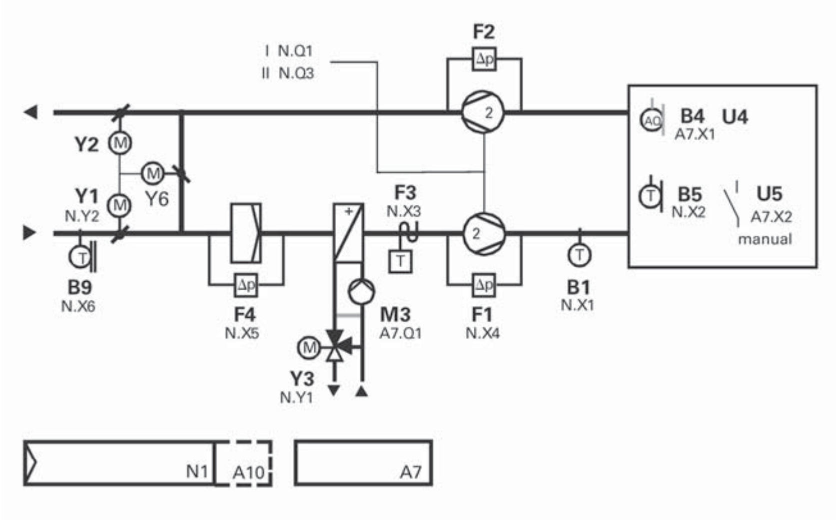
## 5.7.3 Ventilation system with mixing dampers and air heating coil

Application sheet
Room-supply air temperature cascade control.

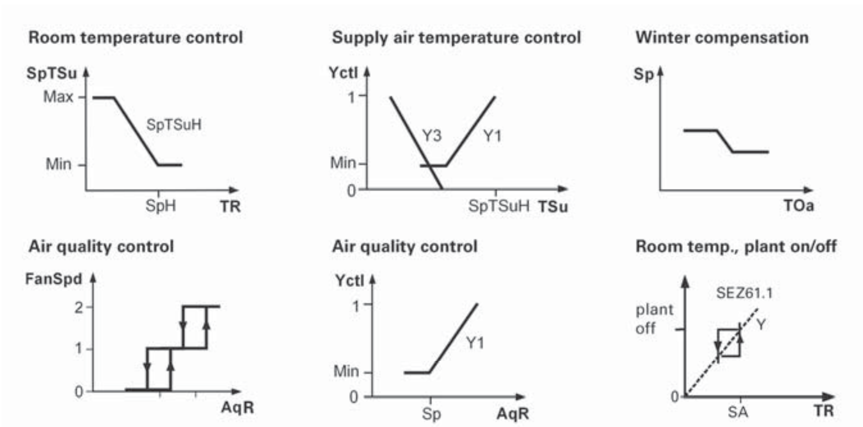
AEA006 U1B DE
Synco™ 700, RMU710B

**Ventilation system with demand control based on room temperature and IAQ, with air heating coil and mixing dampers**

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| Max | Maximum |
| Min | Minimum |
| Sp | Setpoint |
| SpH | Heating setpoint |
| SpTSu | Supply air temperature setpoint |
| AqR | Indoor air quality |
| SA | Switching interval |
| SpTSuH | Supply air temperature setpoint, heating |
| TOa | Outside temperature |
| TR | Room temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |
| FanSpd | Fan speed |

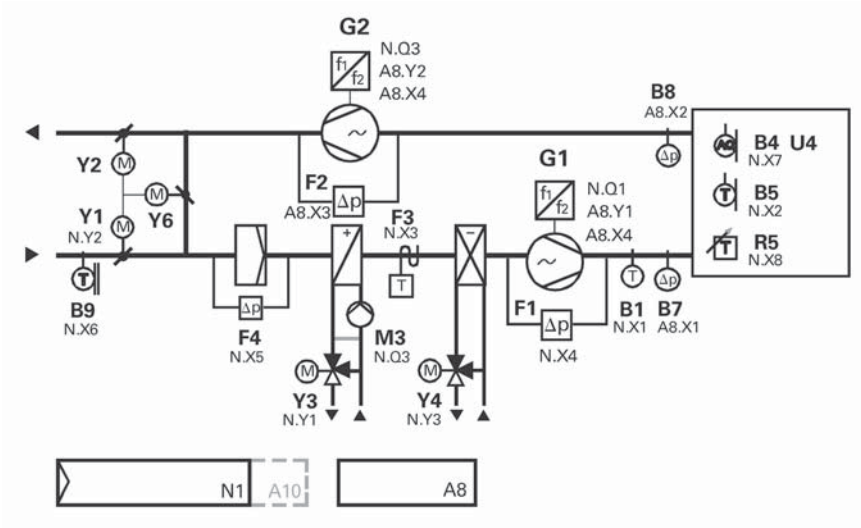
## 5.7.4 Partial air conditioning system with mixing dampers, air heating and air cooling coil

Application sheet
Room-supply air temperature cascade control.

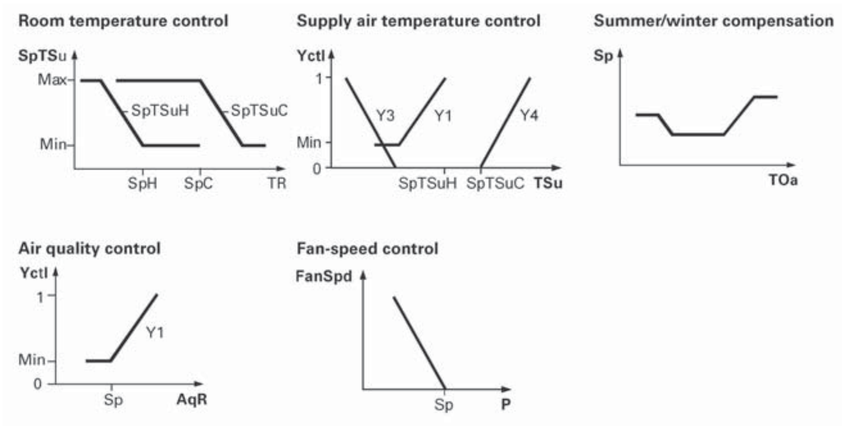
AEC001 U2B DE
Synco™ 700 RMU720B

**Partial air conditioning system with mixing dampers, air heating and air cooling coil**

*Plant diagram*




*Function diagrams*

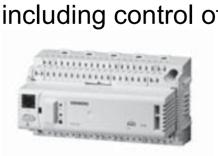



| | |
|---|---|
| Max | Maximum |
| Min | Minimum |
| Sp | Setpoint |
| SpC | Cooling setpoint |
| SpH | Heating setpoint |
| SpTSu | Supply air temperature setpoint |
| SpTSuC | Supply air temperature setpoint, heating |
| TOa | Outside temperature |
| TR | Room temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |
| AqR | Indoor air quality |
| FanSpd | Fan speed |

**5.7.5 Partial air conditioning system with plate heat exchanger, air heating and air cooling coil**

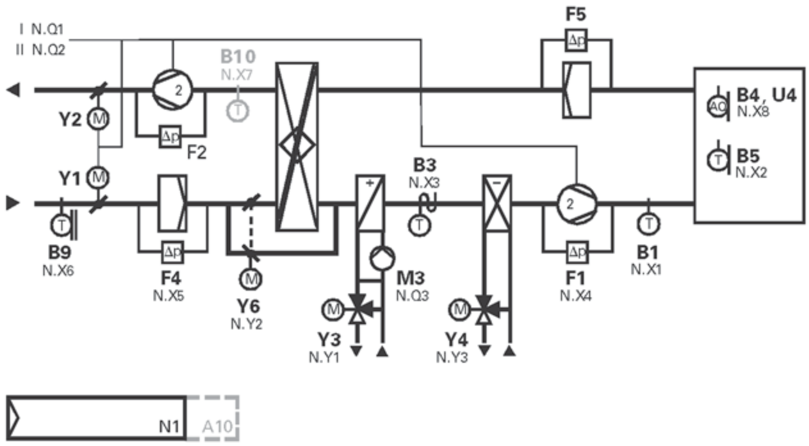
Application sheet
Room-supply air temperature cascade control including control of IAQ.



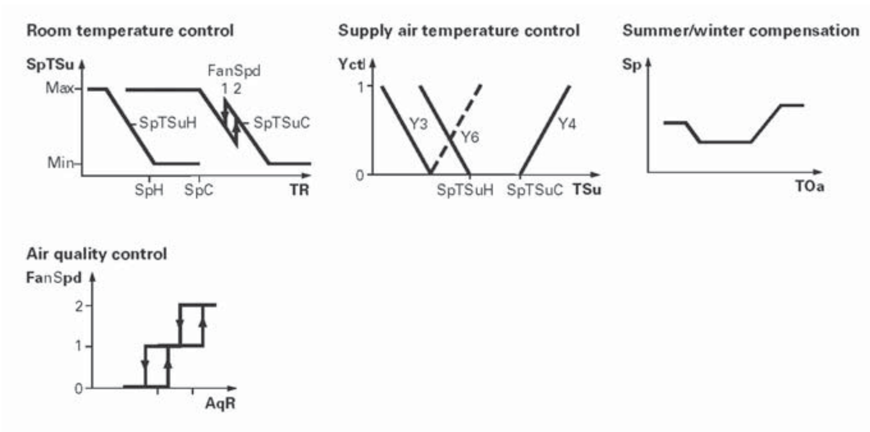


**Partial air conditioning system with plate heat exchanger, air heating and air cooling coil**

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| AqR | Indoor air quality |
| FanSpd | Fan speed |
| Max | Maximum |
| Min | Minimum |
| Sp | Setpoint |
| SpC | Cooling setpoint |
| SpH | Heating setpoint |
| SpTSu | Supply air temperature setpoint |
| SpTSuC | Supply air temperature setpoint, cooling |
| SpTSuH | Supply air temperature setpoint, heating |
| TOa | Outside temperature |
| TR | Room temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |

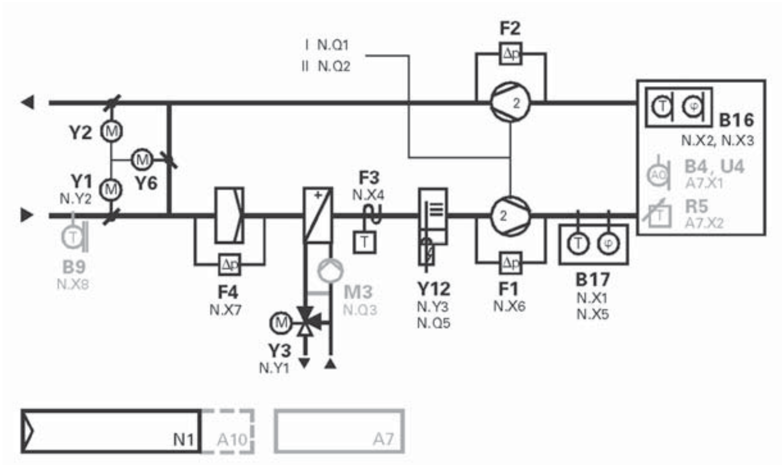
**5.7.6 Partial air conditioning system with mixing dampers, air heating coil and humidifier**

Application sheet
Room-supply air cascade control including humidity control.

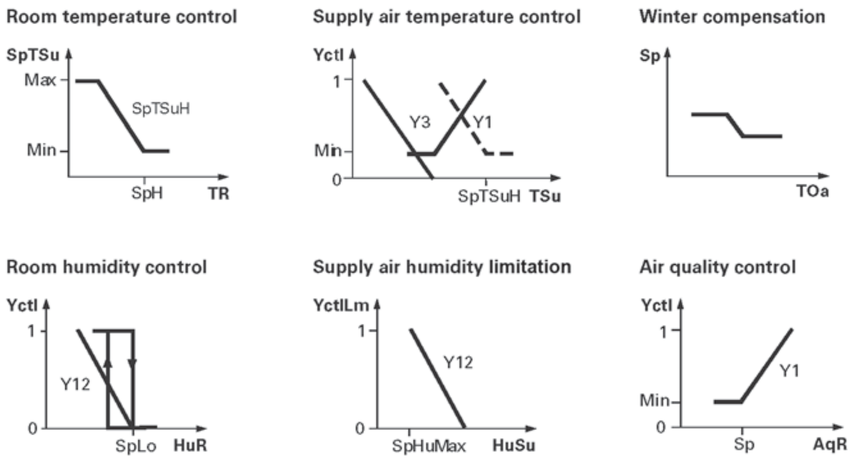
AEDB01 U2B HQ
Synco$^{TM}$700 RMU720B

**Partial air conditioning system with mixing dampers, air heating coil and air humidifier**

*Plant diagram*




*Function diagrams*




| | |
|---|---|
| AqR | Indoor air quality |
| HuR | Room humidity |
| HuSu | Supply air humidity |
| Max | Maximum |
| Min | Minimum |
| Sp | Setpoint |
| SpC | Cooling setpoint |
| SpH | Heating setpoint |
| SpHuMax | Maximum humidity setpoint |
| SpLo | Lower setpoint |
| SpTSu | Supply air temperature setpoint |
| SpTSuC | Supply air temperature setpoint, cooling |
| SpTSuH | Supply air temperature setpoint, heating |
| TOa | Outside temperature |
| TR | Room temperature |
| TSu | Supply air temperature |
| Yctl | Controller output |
| YctlLm | Controller output limit control |

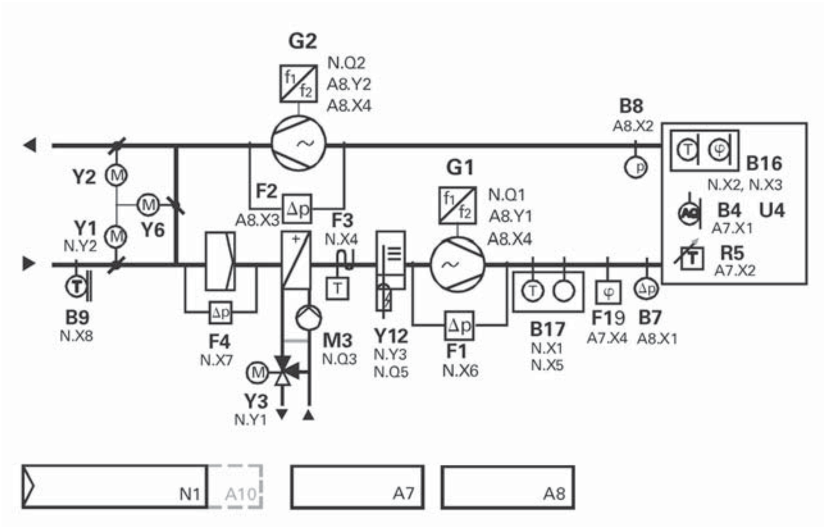
**5.7.7 Partial air conditioning system with mixing dampers, air heating coil and humidifier**

Application sheet
Room-supply air temperature cascade control including humidity control.

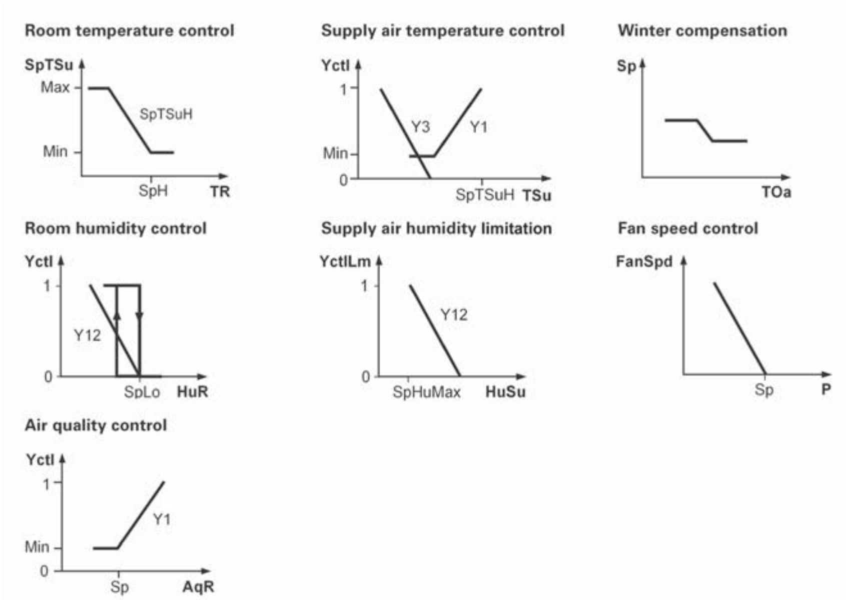
AEDB03 U2B DE
Synco™ 700, RMU720B

**Partial air conditioning system with mixing dampers, air heating coil and air humidifier**

*Plant diagram*




*Function diagrams*




| | | | |
|---|---|---|---|
| Max | Maximum | SpLo | Lower setpoint |
| Min | Minimum | TOa | Outside air temperature |
| Sp | Setpoint | TR | Room temperature |
| SpH | Heating setpoint | TSu | Supply air temperature |
| SpTSu | Supply air temperature setpoint | Yctl | Controller output |
| SpTSuH | Supply air temperature setpoint, heating | YctlLm | Controller output limitation |
| | | FanSpd | Fan speed |
| HuR | Room humidity | AqR | Indoor air quality |
| HuSu | Supply air humidity | | |
| SpHuMax | Maximum humidity setpoint | | |

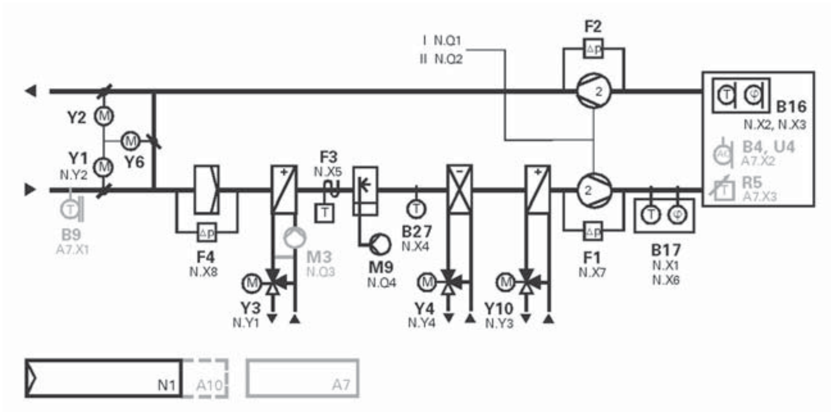
**5.7.8 Partial air conditioning system with mixing dampers, preheating coil, humidifier, air cooling and reheating coil**

Application sheet
Room-supply air temperature cascade control including humidity control.

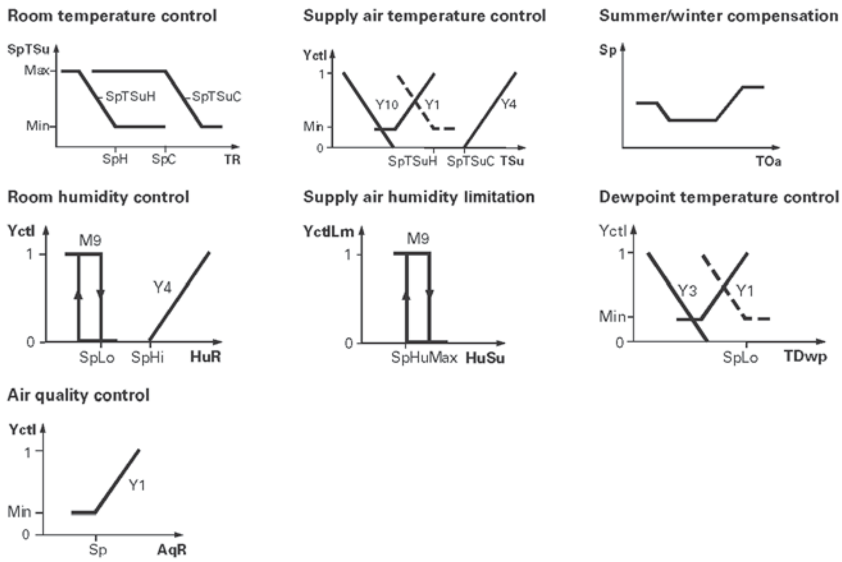
AEZH02 U3B HQ
Synco™700, RMU730B

**Partial air conditioning system with mixing dampers, preheating coil, air humidifier, air cooling and reheating coil**

*Plant diagram*




*Function diagrams*




| | | | |
|---|---|---|---|
| AqR | Indoor air quality | SpLo | Lower setpoint |
| HuR | Room humidity | SpTSu | Supply air temperature setpoint |
| HuSu | Supply air humidity | SpTSuC | Supply air temperature setpoint, cooling |
| Max | Maximum | SpTSuH | Supply air temperature setpoint, heating |
| Min | Minimum | TDwp | Dewpoint temperature |
| Sp | Setpoint | TOa | Outside temperature |
| SpC | Cooling setpoint | TR | Room temperature |
| SpH | Heating setpoint | TSu | Supply air temperature |
| SpHuMax | Maximum humidity setpoint | Yctl | Controller output |
| SpHi | Upper setpoint | YctlLm | Controller output limitation |

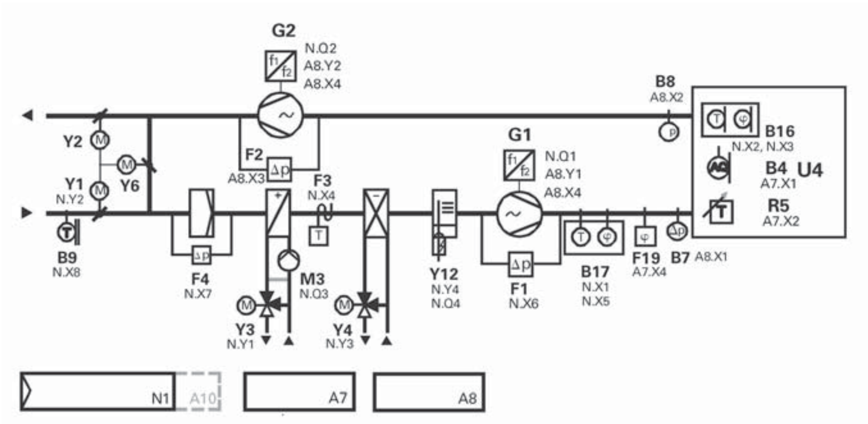
## 5.7.9 Air conditioning system with mixing dampers, air cooling coil, air heating coil and air humidifier

Application sheet
Room-supply air temperature cascade control
including humidity control

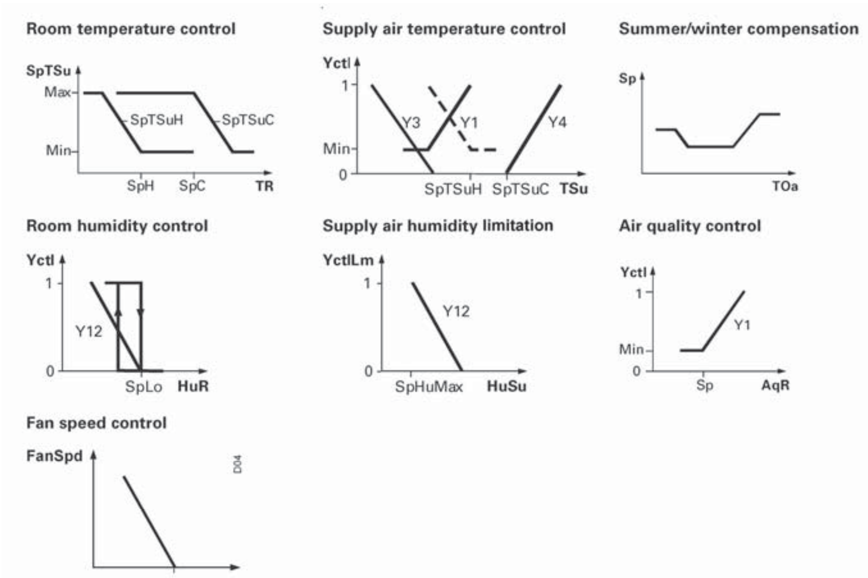
AEHB03 U3B DE
Synco$^{TM}$700, RMU730B

**Air conditioning system with mixing dampers, air cooling coil, air heating coil and air humidifier**

*Plant diagram*




*Function diagrams*




| | | | |
|---|---|---|---|
| AqR | Indoor air quality | SpTSu | Supply air temperature setpoint |
| HuR | Room humidity | SpTSuC | Supply air temperature setpoint, cooling |
| HuSu | Supply air humidity | SpTSuH | Supply air temperature setpoint, heating |
| Max | Maximum | TOa | Outside temperature |
| Min | Minimum | TR | Room temperature |
| Sp | Setpoint | TSu | Supply air temperature |
| SpC | Cooling setpoint | Yctl | Controller output |
| SpH | Heating setpoint | YctlLm | Controller output limitation |
| SpHuMax | Maximum humidity setpoint | FanSpd | Fan speed control |
| SpLo | Lower setpoint | | |

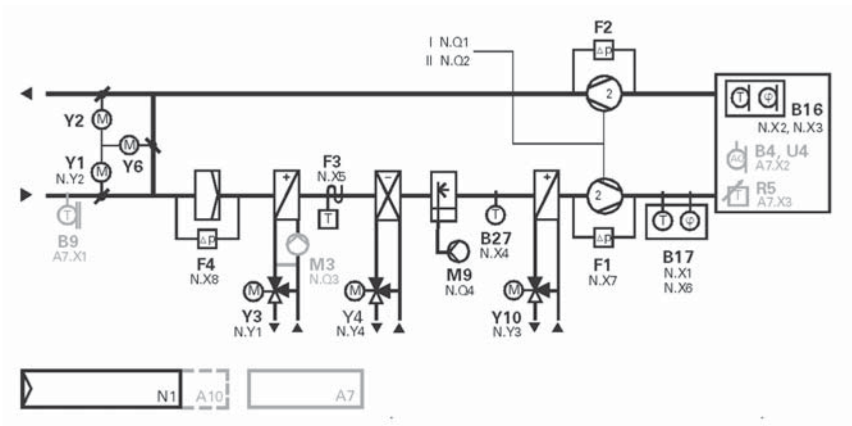
## 5.7.10 Air conditioning system with mixing dampers, preheating coil, air cooling coil, air humidifier, air dehumidifier and reheating coil

Application sheet
Room-supply air temperature
cascade control including humidity control

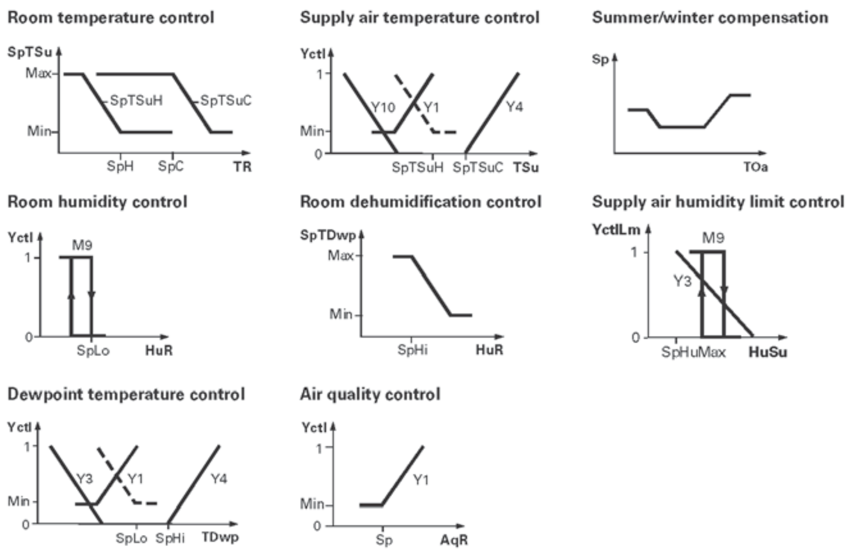
AEZH01 U3B DE
Synco™700, RMU730B

**Air conditioning system with mixing dampers, preheating coil, air cooling coil, air humidifier, air dehumidifier and reheating coil**

*Plant diagram*




*Function diagrams*




| | | | |
|---|---|---|---|
| AqR | Indoor air quality | SpTDwp | Dewpoint temperature setpoint |
| HuR | Room humidity | SpTSu | Supply air temperature setpoint |
| HuSu | Supply air humidity | SpTSuC | Supply air temperature setpoint, cooling |
| Max | Maximum | SpTSuH | Supply air temperature setpoint, heating |
| Min | Minimum | TDwp | Dewpoint temperature |
| Sp | Setpoint | TOa | Outside temperature |
| SpC | Cooling setpoint | TR | Room temperature |
| SpH | Heating setpoint | TSu | Supply air temperature |
| SpHuMax | Maximum humidity setpoint | Yctl | Controller output |
| SpHi | Upper setpoint | YCtlLm | Controller output limitation |
| SpLo | Lower setpoint | | |

# 6 Specification text for demand-controlled ventilation

*Summary*

Demand-controlled ventilation to ensure optimum IAQ and thermally comfortable indoor conditions in rooms with varying periods of occupancy and varying numbers of occupants.

And (detailed text to be added to summary):

*Detailed text*

The control program must cover the following functions:

- Demand switches/software for thermal comfort and IAQ
  - When the acquired room temperature is below the heating setpoint or above the cooling setpoint, the ventilation system will operate irrespective of IAQ
  - If the acquired room temperature is within the zero-energy zone (dead band) for thermal comfort, the ventilation system will only operate if IAQ is unsatisfactory
  - In full air conditioning systems, the same principles are also applied to humidity
  - Basic ventilation may be necessary, however, to remove indoor air pollution originating in the building material, or to maintain static pressure ratios

- The IAQ control loop serves to minimize energy consumption, operating and maintenance costs whatever the load, especially with low loads
- Option 1: The $CO_2$ concentration is determined using a selective optical infrared sensor with an integrated reference light
- Option 2: IAQ is determined using a combined $CO_2$/VOC sensor consisting of an optical infrared sensor with an integrated reference light source for $CO_2$ measurement and a heated tin-dioxide semiconductor element for VOC measurement.
  A microprocessor control system processes the $CO_2$ and VOC signals to produce a ventilation demand signal. This demand signal is the result of selecting the higher of the two values from the $CO_2$ and VOC sensors. A self-adaptive algorithm compensates for environmental influences. In the control system, the cut-in point of the VOC signal can be corrected daily in a self-adaptive process based on the quality of the outside air, via software, to adapt the VOC signal to take account of the type of room usage.

- The control strategy of the combined sensor/controller consists of the following functions:
  - Time program as defined by the customer, to shut down the plant when the building is not in use
  - Time program for preventilation to air the rooms before the start of occupancy, with plant protection features when running on outside air only
  - Buttons for manual control options to set duration and preventilation function
  - Continued ventilation at the end of the occupancy period for an adjustable maximum overrun time, with “hold” circuit and shutdown when the IAQ setpoint is reached for the first time
  - Demand-controlled ventilation with automatic changeover to Comfort mode via PID controller during the building-in-use period, combined with other temperature and humidity strategies, adapted to the plant components available

– Standard option for connection of occupancy detectors for automatic changeover to standby, acting on temperature, humidity and IAQ
– Control sequences for mixed air mode using recirculated air, and 2-speed control, optionally single-speed control or operation via VSD depending on plant components, with changeover determined by parameters

**Option 1: Room version**
Sensor housing and mounting plate for sensor element can be separated for separate mounting. The sensor element and the electronic components can be installed and removed without disconnecting wiring.

**Option 2: Duct version**
The measuring cell is completely sealed from interface electronics and the connection terminals to prevent air from outside the duct influencing the measurement. Alignment of sensor housing relative to the air flow is not required.

# 7 Technical articles


[1] VDMA -Einheitsblatt 24773: Bedarfsgeregelte Lüftung – Begriffe, Anforderungen, Regelstrategien, March 1997

[2] Bedarfsgeregelte Lüftung – Automatisierungskonzept mit Zukunft; TAB Technik am Bau 6/1997, Simon Meier, Siemens Building Technologies

[3] Indoor Air Conferences: Indoor Air'78, Kopenhagen; Indoor Air'81, Amherst; Indoor Air'84, Stockholm; Indoor Air'87, West Berlin; Indoor Air'90, Toronto; Indoor Air'93, Helsinki; Indoor Air'96, Nagoya; Indoor Air'99, Edinburgh; Indoor Air'02, Monterey: Full conference proceedings available from booksellers. Other conferences on the subject of air quality: Roomvent/Healthy Buildings. These conferences also take place every three years. Full conference proceedings available from booksellers

[4] Olf und decipol – die neuen Masseinheiten für die empfundene Luftverschmutzung, Gesundheitsingenieur – Haustechnik – Bauphysik – Umwelttechnik 109 (1988), S. 216-219, P.O. Fanger

[5] A Trained Panel to evaluate Perceived Air Quality Ph. Bluyssen, H. Kondo, J. Pejtersen, L. Gunnarsen, G. Clausen, P.O. Fanger

[6] Air Quality Guidelines for Europe; WHO Regional Publications, European Series No. 23, World Health Organisation WHO, Regional Office for Europe, Copenhagen

[7] Luftschadstoffe in Innenräumen: Exposition und gesundheitliche Auswirkungen Bericht über eine WHO-Tagung, WHO, EURO-Berichte und Studien 78

[8] Air Pollution Sources in Offices and Assembly Halls, Quantified by the Olf Uniit Energy and Buildings 12 (1988), S. 7-19. P.O. Fanger, L. Lauridsen, Ph. Blussen, G. Clausen

[9] Raumluftqualität und Lüftung in Schweizer Bauten, Schriftenreihe des Bundesamtes für Energiewirtschaft Studie Nr. 44, J. Schlatter und H.U. Wanner

[10] Minimum Ventilation Rates and Measures for Controlling Indoor Air Quality, Technical Note AIVC 26, October 1989

[11] Bedarfsgeregelte Lüftung – Derzeitiger Kenntnisstand (Juni 1989) Internationale Energie-Agentur IEA, Dr. W. Raatschen, Dornier GmbH, Friedrichshafen

[12] Sensoren für eine Bedarfsgeregelte Lüftung – Hintergrundinformation zum VDMA Einheitsblatt 24 772 CCI 4/1991, Simon Meier, Siemens Building Technologies

[13] Mischgassensoren als Führungsgrösse für Bedarfsgeregelte Lüftungen HeizungKlima 4/1992, Simon Meier, Siemens Building Technologies

[14] Bedarfslüftung – ein grosses Energie-Sparpotential liegt brach Heizung Lüftung Haustechnik HLH 9/1994, S. 459-465, Simon Meier, Siemens Building Technologies

[15] Bedarfslüftung: Komfort bei reduzierten Kosten Technik am Bau TAB 10/1995, Simon Meier, Siemens Building Technologies

[16] Sensoren für IAQ: Mischgasfühler? Ja! – $CO_2$-Fühler? Ja! CCI 13/1995, Simon Meier, Siemens Building Technologies

[17] 5-Stern-Luft in Restaurant – mit Bedarfslüftung Heizung und Lüftung 4/1994, S. 26-29, Simon Meier, Siemens Building Technologies

[18] Economizer tx2 – h,x-geführte Regelung Brochure – Siemens Building Technologies – Order No.: CB 20199

[19] Olfaktorische Behaglichkeit – ein neuer Ansatz für die empfundene Raumluftqualität KI Luft- und Kältetechnik 2/2003, Diotima von Kempski
[20] REZ Raumluft-Essenzen-Zugabe – ein kleiner Leitfaden über Grundlagen und Anwendungsmöglichkeiten, Fachwissen aktuell, Promotor-Verlag, 1999, Diotima von Kempski
[21] Air and Well Being – A Way to more Profitability, Tagungsband der Healthy Buildings-Konferenz 2003, Singapore, Juli 2003, Diotima von Kempski
[22] REZ Raumluft-Essenzen-Zugabe und Raumluftqualität – ein Widerspruch oder eine notwendige Ergänzung? Wohnungsmedizin und Bauhygiene, April 2001, Diotima von Kempski
[23] Raumluftqualität – Belastung, Bewertung, Beeinflussung, Verlag C.F. Müller Karlsruhe, 1993, ISBN 3-7880-7451-5, J. Witthauer, H. Horn, W. Bischof

# 8 Guidelines and standards

| Country | General | | | Individual office | | Open plan office | | Conference rooms | | Classroom auditorium lecture hall | | Restaurant | | Shops | | Corridors | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | $CO_2$ (ppm) | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | Based on no. of people $m^3/h$ per person | Based on area $m^3/h*m^2$ | |
| Austria | 20–70 (30–105 | | 1000 | | | | | | | | | | | | | | | [ÖN6000-3] |
| Europe IDA 1 | >54 (>108) | not appl. | ≥ 400* | | | | | | | | | | | | | | | [EN13779] |
| IDA 2 | 34–54 (72–108) | >2.5 | 400–600* | | | | | | | | | | | | | | | |
| IDA 3 | 22–36 (43–72) | 1.3–2.5 | 600–1000* | | | | | | | | | | | | | | | |
| IDA 4 | <22 (<43) | <1.3 | <1000* | | | | | | | | | | | | | | | |
| Germany | | | 1000–1500 | 40 (60) | 4 | 60 (80) | 6 | 20 (40) | 10–20 | 30 (50) | 15 | 30 (50) | 8 | 20 (40) | 3–12 | | | [DIN 1946-2] |
| Switzerland | 12–15 25–30 (30–70) | 0.3 $h^{-1}$ | 1000 1500 | | | | | | | | | | | | | | | [SIA382/1] |
| UK | | | | | (4.7) | | (4.7) | (43)–(90) | (22) | | | | | (18)–(29) | (11) | | 4.7 | [BS5720:1979] |
| USA | | | 700* | 36 | | 36 | | 36 | | 29 | | 36 | | 29 | 3.6–5.4 | | 0.9 | [ASHRAE62] |

Table 7 Overview of ventilation standards
* Above outside level
( ) If smoking is permitted, the values inside parantheses have to be considered
IDA 1: High indoor air quality
IDA 2: Medium indoor air quality
IDA 3: Moderate indoor air quality
IDA 4: Low indoor air quality

*Citations from standards*

*Austria [ÖN6000-3]*

This Austrian standard draws only on the $CO_2$ concentration to determine the minimum outside air flow rate per person. The minimum outside air flow rates are based on a volume percentage of $CO_2$ in the outside air of 350 ml/$m^3$ = 350 ppm, and an admissible maximum $CO_2$ concentration of 1,000 ppm in the indoor air.

Note: The minimum outside air flow rates specified vary according to the physical activity anticipated in the space.

In rooms where smoking is permitted, the minimum outside air flow rates in the table must be increased by a factor of at least 1.5.

*Germany [DIN 1946-2]*

The minimum outside air flow rates shown in the table for the various types of space must be observed. In each case, the higher value applies. In rooms with additional, undesirable sources of odor (e.g. tobacco smoke), the minimum outside air flow rate per person must be increased by 20 $m^3/h$.
For pollution of the indoor air through human bio-effluents, the $CO_2$ content of the air can be used as a yardstick for comparison. The $CO_2$ content of the air must not exceed 0.15% = 1,500 ppm (concentration by volume). The recommended value is 0.1%.

*Great Britain [BS 5720:1979]*

Outside air supply is required to maintain an acceptably non-odorous atmosphere (by diluting body odors and tobacco smoke) and to dilute the carbon dioxide exhaled. This quantity may be quoted per person and is related to the occupational density and activity within the space. The proportion of outside air introduced into a building may be varied to achieve economical operation.
Consideration should be given to changes in building load and the system should be designed such that maximum operational efficiency is maintained under part load conditions.

A table is given with typical examples of air-conditioned spaces like offices, shops, restaurants, etc., and detailed values in $dm^3/s$ per person and/or $dm^3/s$ per area are given.

*Switzerland [SIA382/1]*

The outside air flow rates in non-smoking areas are based on comfort requirements. Ventilation systems should generally be sized such that an indoor $CO_2$ concentration of 0.10% = 1,000 ppm (corresponding to a difference of 0.06 to 0.07% between the indoor and outside air) can be maintained. This requires an outside air flow rate of 25 to 30 $m^3$ per person per hour. From the point of view of hygiene, a $CO_2$ concentration of 0.15% (corresponding to a difference of 0.11 to 0.12% compared with the concentration in the outside air) is perfectly acceptable, and this can be maintained with a flow rate of 12 to 15 $m^3$ per person per hour.

Surveys have shown that with a $CO_2$ concentration of 0.15%, 85% of room users judge IAQ to be satisfactory.

In rooms where smoking is permitted, a flow rate of approximately 30 to 40 $m^3$ per person per hour is necessary to avoid acute physical discomfort, and approximately 60 to 70 $m^3$ per person per hour to avoid annoyance.

In unoccupied or only partly occupied rooms, it is advisable for health reasons to maintain an air exchange rate of at least 0.3 $h^{-1}$ or to ensure adequate boost ventilation (purge) before the room is used.

*USA [ASHRAE62]*

IAQ should be considered acceptable if the ventilation rates shown in the table are maintained and provided that the quality of the outside air introduced is acceptable.

Human beings in the building emit $CO_2$, water vapor and pollutants including biological aerosols and volatile organic substances. The comfort criteria (odor) in relation to human bio-effluents are fulfilled when ventilation results in an indoor $CO_2$ concentration of less than 700 ppm above the concentration in the outside air.

Note: The ASHRAE standard contains a very detailed table of all possible types of room, in each case providing the anticipated maximum occupancy and the required air flow rate per person per hour, or the flow rate in relation to area. In addition, the relationship between the ventilation rate and the indoor $CO_2$ concentration is illustrated in detail.

*Europe [EN 13779]*

**New European standard "Ventilation for non-residential buildings"**

The new European standard EN 13779 "Ventilation for non-residential buildings – performance requirements for ventilation and room conditioning systems" was approved by CEN (Comité Européen de Normalisation) on January 16, 2004.

The national standards organizations of the following countries are bound to implement this European standard:

Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Switzerland, and the United Kingdom

The new standard differentiates between four indoor air quality (IDA) categories:

| | |
|---|---|
| **IDA** 1 | High indoor air quality |
| **IDA** 2 | Medium indoor air quality |
| **IDA** 3 | Moderate indoor air quality |
| **IDA** 4 | Low indoor air quality |

Table 8 The four indoor air quality categories as defined by the new standard EN 13779

**How are the indoor air quality (IDA) categories defined?**

For practical applications, the standard specifies five methods to quantify the category of indoor air quality. The actual values are given in Table 9.

1. Direct classification by $CO_2$ level is considered to be well established for occupied rooms where smoking is not permitted and pollution is mainly caused by human metabolism.

2. Direct classification by the perceived indoor air quality in decipols
   This method is not yet fully accepted and difficult to use in practice.

3. Indirect classification by the rate of outside air per person:
   This is a well-based practical method for all situations where the rooms serve for typical human occupancy. These values are often used to design the system. The rates of outside air (supplied by the ventilation system) per person in case of normal work in an office or at home with a metabolic rate of about 1.2 met are given in Table 9.
   If possible, the design should be done on real data of human occupancy for the project. However, if no values are declared, the standard specifies typical values in Table 10.

4. Indirect classification by the air flow rate per floor area:
   This method can in some cases be used to design a system for rooms which are not for human occupancy and which do not have a clearly defined use (e.g. storage rooms).

5. Classification by concentration levels for specific pollutants:
   This method of classification is suitable for situations with significant emissions of specific pollutants.

| Category | $CO_2$ level above level of outside air (ppm) | | Perceived indoor air quality (decipol) | | Perceived indoor air quality (% dissatisfied) | | Rate of outside air per person* ($m^3$/h person) | |
|---|---|---|---|---|---|---|---|---|
| | Typical range | Default value | Typical range | Default value | Typical range | Default value | Typical range | Default value |
| IDA 1 | ≤400 | 350 | ≤1 | 0.8 | ≤15 | 12.7 | >54 | 72 |
| IDA 2 | 400-600 | 500 | 1.0 – 1.4 | 1.2 | 15 – 20 | 17.6 | 36 – 54 | 45 |
| IDA 3 | 600-1000 | 800 | 1.4 – 2.5 | 2.0 | 20 – 30 | 25.6 | 22 – 36 | 29 |
| IDA 4 | >1000 | 1200 | >2.5 | 3.0 | >30 | 33.3 | <22 | 18 |

Table 9 The different categories of indoor air quality with their respective classifications.

Direct classification: By $CO_2$ or perceived indoor air quality
Indirect classification: By rate of outside air per person
From EN 13779 and CR1752.
* All values are given for non-smoking areas. For smoking areas, multiply by 2

If possible, the design should be based on real values of human occupancy for the project. However, if no values are declared, the data in Table 10 are recommended:

| Kind of use | Net floor area in $m^2$ per person | |
|---|---|---|
| | Typical range | Default range |
| Landscaped office room | 7 – 20 | 12 |
| Small office room | 8 – 12 | 10 |
| Meeting room | 2 – 5 | 3 |
| Department store | 3 – 8 | 4 |
| Classroom | 2 – 5 | 2.5 |
| Hospital ward | 5 – 15 | 10 |
| Hotel bedroom | 5 – 20 | 10 |
| Restaurant | 1.2 – 5 | 1.5 |

Table 10 Design assumptions for floor area per person

The following categories for control of IAQ are defined in the standard:

| Category | System status |
|---|---|
| IDA – C1 | No control |
| IDA – C2 | Manual control by switch |
| IDA – C3 | According to a given time schedule |
| IDA – C4 | Occupancy control: According to presence (light switch, infrared sensor) |
| IDA – C5 | Presence control according to the number of people |
| IDA – C6 | Direct control by sensors measuring indoor air parameters ($CO_2$ or VOC) |

Table 11

**Related to IAQ**
**The standard requests explicitly that the client and the planning engineer should agree on and specify:**

- The desired IAQ for the user of the building, that is, IDA 1, IDA 2, IDA 3 or IDA 4
- The method of classification the client wants to be applied (see text box "IDA categories")
- The use of each room
- Human occupancy (the number of people that can be in the room for a longer period of time). In addition, the activity has to be declared. The occupancy level should be given as a schedule. If these values are not declared, the values in Table 10 are recommended
- Outside air flow rates per room. If nothing is declared, the rate of outside air per person for category IDA 2 should be used (refer to Table 9)
- Type of control of the indoor environment (IDA-C1 to IDA-C6)

*Comments and interpretation*

It is obvious that the easiest way to make sure that the building is operated in line with this standard, is to use $CO_2$-based demand-controlled ventilation.

Although the standard does not make that statement explicitly, you can read it between the lines because it calls classification of the air by $CO_2$ level "direct". Other methods to classify the air are termed "not yet fully accepted", "difficult to use in practice" or "indirect" and "used for system design". In addition, the standard calls $CO_2$- or VOC-based demand control "direct" but none of the other methods. By using direct control by sensors measuring indoor air $CO_2$ concentration (method IDA – C6), the indoor air quality category (IDA) can always be guaranteed and documented for the user and the operator of the buildings. This is even true if the design assumptions of occupancy were incorrect (refer to Table 10). $CO_2$-based demand-controlled ventilation is compensating for this and guarantees economical operation in line with the agreed IAQ.

It is expected that this new standard, which will be valid throughout Europe, will create additional request for demand-controlled ventilation.


*[AIVC]* A Review of International Ventilation, Air Tightness, Thermal Insulation and Indoor Air Quality Criteria, M.J.Limb, International Energy Agency, Document AIC-TN55, 2001

*[ASHRAE62]* ANSI/ASHRAE Standard 62-2001, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2001

*[ASTMD6245]* ASTM D6245-98(2002)
Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation

*[BS 5720:1979]* British Standard BS5720. 1979, Code of Practice for Mechanical ventilation and air conditioning in buildings

*[CR1752]* Ventilation for buildings – Design criteria for the indoor environment, CEN REPORT, Dec. 1998

*[DIN1946-2]* DIN 1946 – Part 2, Heating, ventilation and air conditioning – Requirements relating to health (VDI code of practice), Deutsches Institut für Normung e.V. 1994, Berlin

*[EN 13779]* European Standard, Ventilation for non-residential buildings – Performance requirements for ventilation and room conditioning systems, CEN, Brussels, September 2004

*[ÖN6000-3]* Austrian standard: Ventilation systems: Basic regulations, hygiene and physiological requirements for occupied spaces

*[SIA382/1]* Swiss standard: Technical requirements for ventilation systems, 1992, Schweizerische Normen Vereinigung, Zürich 1992

*[VDI4300-9]* Draft code of practice: Measuring indoor air pollution – Strategy for the measurement of carbon dioxide ($CO_2$)

# 9 Glossary

*Acceptable IAQ*
This refers to air which does not contain any known harmful substances in harmful concentrations, and which is accepted without complaint by a large majority (80% or more) of the people exposed to it.

*Air conditioning system*
See "Air handling systems".

*Air handling systems*
These cover ventilation systems (heating with or without heat recovery), partial air conditioning systems (heating and humidification and/or cooling, with or without heat recovery), and (full) air conditioning systems (all four processes with or without heat recovery).

*Air vitalizing system*
A proprietary system in which natural olfactory substances are mixed with the supply air of an air handling system by the addition of essential oils. Technical and aromachological parameters must be adhered to in this process.

*$CO_2$ sensor*
Measures the concentration of $CO_2$ in the indoor air or extract air in ppm. A typical value for the concentration in the outside air is 350 to 500 ppm. Typical room setpoint: 1,000 to 1,500 ppm. MAC value/OEL: 5,000 ppm.
Measuring principles: Optoacoustic and pyroelectric sensors. Optoacoustic sensors have a defined, stable zero-point.

*Comfort band, comfort zone*
The room temperature and humidity zone within which there is no need for heating/cooling or humidification/dehumidification. For example: 22 °C ± 2 °C; 45% r.h. ±15% r.h., or in the case of IAQ, a $CO_2$ concentration of less than 1,500 ppm. 1,000 ppm corresponds to an outside air flow rate of 25 $m^3$/h per person, and 1,500 ppm to 15 $m^3$/h per person.

*decipol (dp)*
The perceived IAQ may also be expressed in decipol (dp), where 1 dp is the air quality in a space with the pollution source of one olf ventilated by 10 l/s of clean air.

*Demand switches*
Throughout the period when a building is potentially in use (as defined by a time schedule), the air handling system is only switched on if there is a measured demand (heating/cooling demand, air renewal demand, demand for humidification/dehumidification, etc). On/off controllers operate as demand switches. All the demand signals have an equal weighting. If the measured variables are within the associated comfort zone (dead band), the air handling system will be switched off.

*Demand-controlled ventilation*
In a demand-based ventilation system, the air renewal demand is measured continuously by IAQ sensors ($CO_2$ or VOC sensors), and a controller continuously adjusts the amount of outside air delivered to the room so that it matches the actual (measured) demand. This approach goes significantly further than time switch control. The air handling system is enabled on the basis of the signals from demand switches. Since no additional controlled devices are required for demand-controlled ventilation, it is easy to upgrade existing systems.

*Economizer tx2*
Control strategy used to optimize the use of energy for the thermal treatment (heating/cooling, humidification/dehumidification) of indoor air. As these four processes are cost-intensive to a varying degree, the sum of the weighted demand signals is minimized.

*h,x chart* — A type of psychrometric chart which can be used to determine all the thermodynamic properties of moist air without calculation.

*Indicator substance* — The $CO_2$ content of the indoor air is an indicator of the pollution caused by the people in the room, provided that smoking is not permitted and that there are no other sources of indoor air pollution present. Tobacco smoke is another indicator substance.

*Indoor air quality (IAQ) sensor* — Sensor used to measure the quality of the air in rooms and extract air ducts. If the people in a room are the primary source of air pollution, the concentration of $CO_2$ is the most suitable reference variable for demand-controlled operation of the air handling system. Ideal applications are museums, lecture halls, theaters, cinemas and open plan offices. Tobacco smoke can only be measured by VOC sensors.

*MAC value* — Maximum acceptable concentration. This concentration of a substance legally permitted in the workplace is also known as the occupational exposure limit (OEL). The MAC is sufficiently low that it will not affect the health of people who are exposed to it for 8 hours. For $CO_2$: 5,000 ppm.

*Metabolic rate (M)* — Rate of energy production of the human body. The metabolic rate varies with the activity. It is expressed in the met unit or in $W/m^2$ (1 met = 58.2 $W/m^2$). One met is the energy produced per unit surface area of a sedentary person at rest. The surface area of an average person is about 1.8 $m^2$ [CR 1752].

*Olf* — The air pollution created by a standard person (average sedentary adult office worker feeling thermally neutral).

*olfactory/olf action* — Olfactometry makes use of the highly sensitive human sense of smell to detect and analyze odors. While it has been possible to classify other sensory perceptions in a generally valid way, this has not proved possible with odors. Nevertheless, repeated efforts have been made to establish a practicable model by the use of panels of judges [5].

*Partial air conditioning system* — See ”Air handling systems”.

*Perceived IAQ* — Is defined as the percentage of dissatisfied people. This means people predicted to perceive the air as being inacceptable just after entering a space.

*ppm* — Parts per million. Measured variable used to quantify the $CO_2$ concentration.

*Sensor location* — To ensure good IAQ, the sensor must be sited in a position where it is exposed to the main sources of odor but, at the same time, it must be placed where it will be exposed to the effects of the ventilation system. In this context, it is important to note that odors are spread not only by air currents, but also by diffusion.

*Symaro* — Siemens range of building sensors.

*Synco* — Siemens range of controllers.

*Ventilation system* — See ”Air handling systems”.

*VOC* VOC = Volatile Organic Compounds.

*VOC sensor* VOC sensors measure the presence of combustible gases and vapors in the indoor air (tobacco smoke, body odor, emissions from materials in the room). These sensors are best used in applications such as restaurants, conference rooms, and sports and meeting halls.

*VOC sensors* See ”Mixed-gas sensors”.

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