Automatic control of air supply

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Control of ventilation systems has to be tailored in order to achieve a proper indoor environment and comfort. Design criteria and equations for calculation are described. The main methods of automatic control of air supply: air supply temperature control at constant supply air temperature; control of minimum limitation of supply air temperature and maximum limitation of supply air humidity; cascade controlling for space areas where the temperature is desired to be constant, and a minimum limitation of supply air temperature are presented.

Key words: air supply systems, automatic control

1. INTRODUCTION

All the major manufacturers of controlling equipment pay serious attention to improve and develop state of the art equipment for more compatible and flexible applications. This is part of the competition between factories.

The challenge for indoor environment experts is not to provide the proper equipment to do the job, but to do the right thing with the available equipment.

Many scientists have therefore been quiet busy to find solutions for accurate controlling of indoor environment, especially when you have a certain distance between the sensor and the climate system. Methods for classification of controlling equipment have been another main challenge for many scientists. The controlling theories are discussing the dynamic property, which includes indoor climate systems and the mathematical and numeric methods behind, describes and analyses the reactions of new systems. The static property for controlled devices is given by means of a static characteristic. This characteristic is given as an equation or a diagram, focusing on the dependence between the controlled climate condition and the controlling signal, which apply during stationary conditions, *e.g.*, in ventilation systems. These systems are designed to improve a comfortable indoor environment with a low health risk for the occupants.

Relations between hypersensitivity reactions and materials have been proved and examples of these materials are formaldehyde, nitrogen, dioxide, tobacco smoke, total volatile organic compounds (TVOC) and dust-mites. The factors that influence the indoor environment are more complex and have a different composition than a few years ago. Synthetic fibres and artificial materials which emit dust and chemicals, and an inappropriate use of rooms and space are generating a great potential for a bad indoor environment. Together with temperature and humidity this scenario causes the growth of fungi and microorganisms.

Indoor climate has traditionally not been on the agenda either in buildings or in industrial complexes. The air quality has been difficult to identify and to control and of course the cost to evacuate used air and replace it by new air has been an investment on top of all other expenses. So the most easiest way to solve these problems was to ignore them. Investigation and studies in West European countries prove that the indoor environment very often does not meet the standards required to keep a proper air quality. The reasons are many, from lack of competence in designing air handling systems to poor maintenance and operation routines.

Air handling systems consist of a number of different parts and pieces connected together in different auxiliary systems, whose task is to deliver high quality air to occupied zones. The controlling system is probably the most complex one of these auxiliary systems, and experience is telling us that the reason for an unappropriate indoor air condition very often is fault and lack of professional commissioning and operation procedures. Poor indoor environment causes many serious diseases in bronchi, and many research and development programmes

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are working continuously to improve techniques and methods for a better indoor environment.

Controlling technology is one of these techniques, which is strictly important to have a properly designed, accurately commissioned, perfectly maintained and professionally operated air supply [1].

2. DESIGN CRITERIA FOR GOOD INDOOR ENVIRONMENT

To define the purpose of the prestandard mentioned over we will clarify the following definition:

1. Draught: The unwanted local cooling of the body caused by air movement and temperature.

The draught rating factor in percent is given by the equation:

$$D = (34 - t_a)\,(t_m - 0.05)^{0.62}\,(0.37 \times \mathrm{Tu} + 3.14), \quad (1)$$

there –
D = draught rating (%)
t_a = local air temperature in °C
t_m = local mean temperature in °C
Tu = local turbulence intensity in %

2. External work: The energy consumed by mechanical devices. External work can also be expressed as a fraction of metabolic energy production, where the fraction value defines the mechanical efficiency. For most activities external work can be disregarded.

3. Humidity, absolute: The absolute amount of water vapour in the ambient air expressed in g/kg or m^3 dry air. It can also be expressed by the partial water vapour pressure (P_v) in Pa or by the dew-point (t_d) in °C.

4. Humidity, relative: The mass of water vapour in the air by volume divided by mass of water vapour by volume at saturation at the same temperature.

5. Insulation, clothing: The resistance to sensitive heat transfer provided by a clothing ensemble (*i.e.* more than one garment). It is described as the intrinsic insulation from the skin to the clothing surface, not including the resistance provided by the air layer around the clothed body. It is expressed in the clo unit in m^2 x K/W (there *K* – degree Kelvin). 1 clo = 0.155 m^2 x K/W.

6. Insulation, garment (1_{clu}): The increased resistance to sensible heat transfer obtained from adding an individual garment over the nude body. It is the effective increase in overall insulation attributable to the garment and is expressed in the clo unit or in m^2 x K/W.

7. Metabolic rate (M): The rate of the energy production of the 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. Predicted mean vote (PMV): PMV is an index that predicts the mean value of the thermal sensation votes of a large group of persons on a 7-point scale.

8. Predicted percentage of dissatisfied (PPD): The PPD is an index that predicts the percentage of a large group of people who are likely to feel thermally dissatisfied for body as a whole, *i.e.* feel either too warm or too cool.

9. Temperature, mean radiant (t_r): The uniform surface temperature of an enclosure in which an occupant would exchange the same amount of radiant heat as the actual non-uniform enclosure.

10. Temperature, operative: (t_0) the uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment.

11. Thermal comfort: The condition of mind that expresses satisfaction with the thermal environment.

12. Velocity, relative air (V_{ar}): The air velocity relative to the occupant, including body movements.

13. Ventilation effectiveness (ε_v): A measure of the relationship between the pollutant concentration in the exhaust air and the pollutant concentration in the breathing zone.

To achieve a proper ventilated area, all the definitions mentioned above have to be considered, depending on the ventilation characteristics.

The effectiveness of the ventilation in percentage can be calculated by the equation:

$$\varepsilon_v = \frac{C_e - C_s}{C_i - C_s}; \quad (2)$$

there –
ε_v = ventilation effectiveness in (%)
C_e = concentration of pollution in the exhaust air (%)
C_s = concentration of pollution in the supply air (%)
C_i = concentration of pollution in the breathing zone (%)

Also, the required ventilation rate can be calculated as a tool to decide the ventilation system and controlling equipment.

$$Q_c = 10 \times \frac{G_c}{C_{ci} - C_{co}} \times \frac{1}{\varepsilon_v}, \quad (3)$$

there –
Q_c = ventilation rate required for comfort (l/s)
G_c = sensory pollution load of olf (1 olf is the emission of pollutants from an adult still sitting with thermal comfort with the environment around)

C_{ci} = desired perceived indoor air quality in decipol (1 dc is the resulting level of pollution caused by 1 olf in a room which is ventilated by clean air supply of 10 l/s)
C_{co} = perceived outdoor air quality at air intake in decipol
ε_v = ventilation effectiveness (%)

As so many factors are affecting the ventilation requirement, a sophisticated controlling system has to be tailored in order to achieve air supply with a proper inlet temperature, humidity and a proper rate of contamination.

Facing the fact that these parameters have an individual influence on humans, air ventilation control is probably the most complicated automation system in buildings in order to satisfy the requirement which is necessary for a proper indoor environment.

Different ventilation systems need different controlling devices. Ventilation of sports halls is different from ventilation of offices, and ventilation of hospitals is different from ventilation of schools. Common for them all is that the ventilation system is designed to evacuate polluted air and replace it by fresh, heated, humidified and filtered air. Only sophisticated automatic controlling systems are able to manage this work.

Control systems for air-handling units

Control of ventilation systems is managed by different controlling loops, *e.g.* supply air controlling loop, room temperature control loop or variable air volume controled by pressure difference. Additionally, a number of combined and tailored solutions can be designed for an individual controlling requirement in order to achieve a proper indoor environment and comfort.

Control of ventilation systems is mainly based on an open loop control or closed loop control applications. The difference between those two controlling applications is that the open loop control is controlling the supply air based on the outdoor temperature and the closed loop control is heating the supply air, based on deviation from a set value.

Designing the controlling characteristics

A controlling system consists of a number of dynamic elements which fit together in a controlling loop. Then static and dynamic properties are determined by the individual elements.

To achieve a proper control of an air ventilation unit, the first idea is laying the base for a good and reliable system design. During the first phase of planning the design of the climate-control is determined with regard to the static and dynamic properties. At this level it is simple to modify the system design and to choose the individual components for a proper outcome.

Controllability of controlling systems

The controllability has been developed by Ziegler and Nichols, based on an empirical method. This method has been further developed by A. Grindal in order to adapt it to controlling the air handling systems [2]. The method allows to set the values of the system design and guidelines for classifying the controlled objects.

3. METHODS TO ACHIEVE LEGISLATIVE INDOOR ENVIRONMENT

The model below displays the supply air controlling application with a constant supply air temperature compensated by the outdoor temperature, constant sliding. The application for this model is ventilation of space area where the supply air temperature keeps constant by heating or cooling of the supply air. The comfort and energy saving for cooling the room temperature can be increased continuously with the rise of outdoor temperature (summer compensation). Controller N1 (Fig. 1) which is supplied with two output connections compares the measured supply air temperature by the sensor B1 with the desired set point temperature. By deviation the controller readjusts the heat valve Y1 or the cooling valve Y2 until the desired temperature is achieved.

The summer season gives the possibility to accept a higher than normal indoor temperature. Energy can be saved by less cooling. In areas with a high activity rate, this controlling application is preferable (Fig. 2).

If the ventilation is designed to cover transmission heat losses totally or partly, in addition to the heat which is produced by the ventilation itself, the supply air temperature can increase continuously decreasing the outdoor temperature (winter compensation) (Fig. 3).

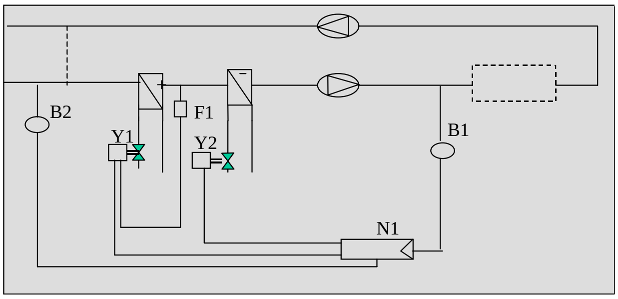

Fig. 1. Air supply temperature control at a constant supply air temperature

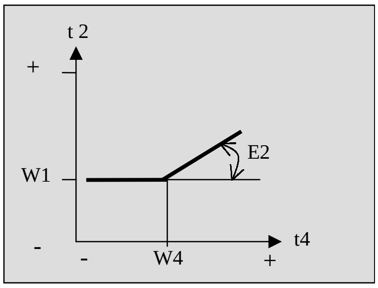

Fig. 2. Summer temperature compensation graph

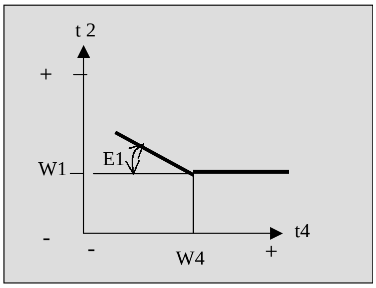

Fig. 3. Winter temperature compensation graph

The application in Fig. 4 is performed by a minimum limitation of supply air temperature and maximum limitation of supply air humidity. Humidification in a ventilation system is not recommended in general, but in some particular indoor environments the application of this controlling model is required.

Controller N1 has two output connections which compare the measured temperature at sensor B1 (alternatively at B3) with the requested temperature. At a deviation, the controller readjusts the heat valve Y1 or via the priority dispenser N3 readjusting the cooling valve Y2. The humidity controller N2 compares the measured humidity at sensor B2 (alternatively at sensor B3) with the requested humidity value. At a deviation, the controller readjusts the valve for the humidifier Y3 via the priority dispenser N3, the cooling valve Y2.

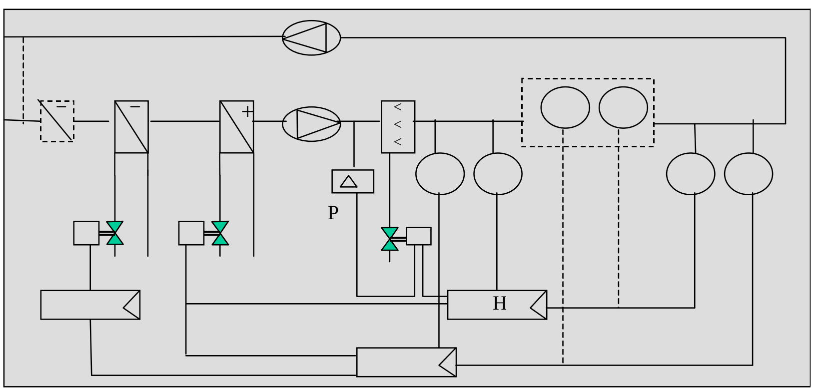

Fig. 4. Control of room temperature and humidity

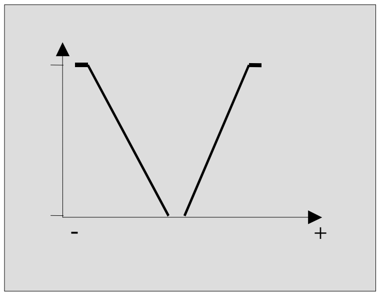

Fig. 5. Temperature control by a sequential control of heating and cooling in order to achieve a proper indoor environment

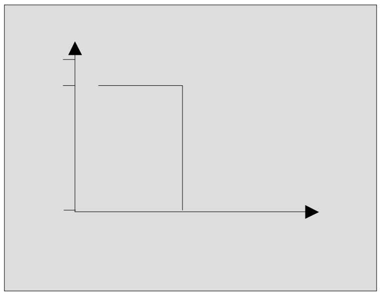

Fig. 6. Maximum limitation of supplied air humidity caused by the sensor in the room or in the outlet air duct

To provide a proper air mixture in supplied air, the maximum limitation of humidity is required.

Humidification is, generally speaking, not desirable because of the growth of fungi and microorganisms in the ventilation system. In areas where humidification of the indoor air is required special actions have to be taken.

The application in Fig. 7 is a ventilation system designed for space areas where the temperature is desired to be kept constant by heating or cooling the supplied air and a minimum limitation of supply air temperature is required.

Room temperature requirement by cascade controlling and a minimum limit of air supply temperature has a P + PI function (Proportional – Integral) P for controlling the room temperature and PI for controlling the air supply temperature. The required temperature of air supply is determined by deviations of the room temperature. Controller N1 (Fig. 7) for cascade controlling is measuring the room temperature at sensor B1a (alternatively at sensor B1b) and sensor B2. If the room temperature deviates from the requested value, the controller displaces the requested value for the air supply temperature, equal to the deviation and the influence of the cascade.

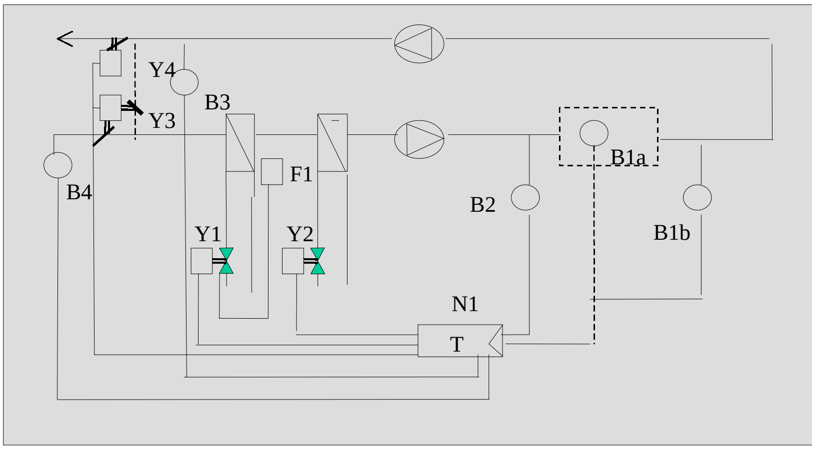

Fig. 7. Room temperature requirement by cascade controlling

The controller adjusts the heat valve Y1 or the cooling valve Y2 until the required value of air supply is achieved.

The damper sequence Y3/4 is a broken line and will normally not be part of the energy supply process because of its negative influence on the indoor environment (Fig. 8).

Control of dampers is efficient beyond the building operation hours, but is not recommended when people are present. To avoid draught from the air ducts, damper control is very efficient.

The cascade function gives a slipping passage from heating to cooling demand and keeps the room temperature constant.

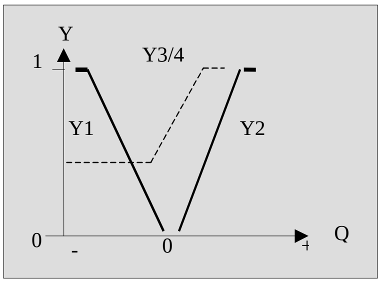

Fig. 8. Controlling sequence of the temperature, mainly using a heating and cooling valve

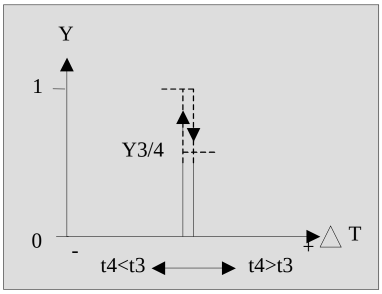

Fig. 9. Energy efficiency sequence control of the dampers

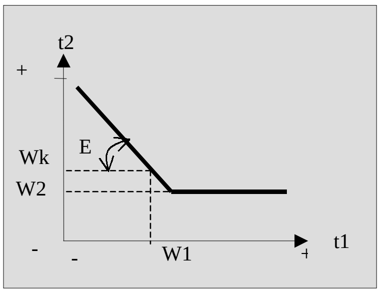

Fig. 10. Room/supply air cascade with a minimum limitation of supply air temperature

4. CONCLUSIONS

Automatic control of air quality includes temperature, humidity and air volume treatment. These parameters are sequentially controlled mainly by controllers or building automation systems.

A proper air quality also includes filter systems and CO sensor equipment, but this is normally not part of the controlling loops designed to deliver the desired air volume with a defined temperature and humidity. Controlling these functions needs separate and independent systems, which can be integrated in the total design if required.

Natural ventilation or mechanical air outlet systems are still the main technology to evacuate air from living zones. In these systems the inlet air is supplied by dampers in the wall or in the window frames.

Diseases and infections in human bronchi are increasing worldwide, and the indoor environment as one of the reasons is given great attention by consultants, contractors, manufactures and scientific personnel in order to reduce the damage of human health.

The climate conditions in buildings are getting high priority wordwide. This gives the scientists and designers an opportunity to improve the technology to succeed in a better indoor environment. One of the most suitable data simulation programs for climate systems is the HVAC-Dynamic programme developed in Norway for professional and training purposes.

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ORO TIEKIMO AUTOMATINIS REGULIAVIMAS

S a n t r a u k a

Oro tiekimo automatinio reguliavimo sistemos yra skirtos komfortinėms sąlygoms patalpoje palaikyti. Straipsnyje išryškintas problemos aktualumas, įvardyti pagrindiniai veiksniai, turintys įtakos patalpos vėdinimo efektyvumui, skaičiavimo formulės. Pateiktos reguliavimo sistemų charakteristikos bei nurodyti sistemų projektavimo ypatumai. Straipsnyje pateikiami ir nagrinėjami pagrindiniai oro tiekimo sistemų valdymo metodai: tiekiamo oro temperatūros valdymas užtikrinant pastovią tiekiamo oro temperatūrą; valdymas, ribojantis minimalią tiekiamo oro temperatūrą ir maksimalią drėgmę; kaskadinis valdymas su minimalios tiekiamo oro temperatūros apribojimu.

Raktažodžiai: oro tiekimo sistemos, automatinis reguliavimas

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АВТОМАТИЧЕСКОЕ РЕГУЛИРОВАНИЕ ВОЗДУХОСНАБЖЕНИЯ

Р е з ю м е

Для поддержки комфортных условий в помещении используется автоматическое регулирование воздухоснабжения. В статье выявлена актуальность проблемы, представлены основные факторы, влияющие на эффективность вентиляции помещения, расчетные формулы. Указаны характеристики систем регулирования и особенности проектирования этих систем. В статье представлены и анализируются основные методы контроля систем воздухоснабжения: регулирование температуры поступающего воздуха (с обеспечением постоянства температуры поступающего воздуха); регулирование с ограничением минимальной температуры поступающего воздуха и максимальной влаги; каскадное регулирование с ограничением минимальной температуры поступающего воздуха.

Ключевые слова: системы воздухоснабжения, автоматическое регулирование