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SUPERVISORY CONTROL OF VARIABLE AIR VOLUME (VAV) AIR-CONDITIONING SYSTEM

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INTRODUCTION

The mathematical optimization of an air conditioning process provides that it is possible to find a cost function to be minimized. System functions and constrains have to be determined. The heat and moisture balance functions of room and components are examples of the system functions. It is not, however, possible to describe the effect of indoor air quality to working efficiency and to the cost function. Thus, some approximations to fal optimization should be introduced.

In the study (1) a dynamic control of the room air temperature and humidity has been used, i.e. they are allowed to vary in a fixed range. The set values for the inlet air are controlled according to these values. In varying load and outdoor air conditions the air-conditioning system should produce the desired set values with minimum use of energy. Logical decision making can be used to share the heating/cooling power between the central air handling unit and possible zone/room units in a way that the needed power will be brought into the room. In addition, a method is needed to choose the unit processes of the central air handling unit. Bork (2) and Kreslin (3) have used the same approach.

SUPERVISORY CONTROL OF AIR-CONDITIONING SYSTEMS

Processing of inlet air can be done either in the central air handling unit or it can be shared to zone or room units. The more the system is decentralized the more difficult it is to optimize the system operation. The first set values comes from the room space whose conditions have to be controlled accurately. A certain heating or cooling power is needed in that room space. It is also possible that the inlet air should be humidified or dehumidified. The air coming to the room unit has to make possible the operation of the room device: A certain air volume flow rate (q_v) is needed in the room space in a certain state (t_{in}, x_{in}, p). The next need comes from the zone level. Again, a certain air volume flow rate ($q_{in,z}$) is needed in a certain condition ($t_{in,z}$, $x_{in,z}$, p_z) to ensure proper operation of the zone units. This determines the outlet air condition of the central air handling unit. The optimum set of unit processes depends on three state values: inlet air, outdoor air and exhaust air conditions. When the relations of these states change, the optimal set of unit processes of the central air handling unit changes, as well.

was 50 dm³/s and minimum 10 or 30 dm³/s. The dynamic set point range of indoor air temperature was in winter time 20 - 21 °C and in summer time 21 - 22 °C, 22 - 23 °C or 23 - 24 °C.

Table 1. Dimensioning loads (W) of the simulated office rooms (7,2 m^2) facing different facades.

Facade	South	North	East	West
Cooling power	360	294	344	351
Heating power	142	151	150	150

Free cooling was used in the following way: at 4.00 p.m. the system was stopped and at 3.00 a.m. it was started again, if cooling power was needed and if outdoor air could be used for cooling. Maximum air volume flow rate was used. When the mean value of room air temperature goes more than 2 °C under the daytime set point the free cooling will be stopped. Another need to stop free cooling is the outdoor air conditions, i.e. if there is not any cooling capacity available. At 8.00 a.m. the system starts to operate with normal daytime set values. In winter time the air-conditioning system is used to heat the room spaces with return air. A part of the inlet air is whence taken from outside so that at least the minimum fresh air fraction is met.

VAV-System without Reheating in Rooms

Figure 2 shows the duration of room air temperatures in January and June (t_{in} = 12 - 28 °C, $q_{v,max}$ = 40 dm³/s and $q_{v,min}$ = 10 dm³/s). In rooms with the higher internal heat load (372 W) the temperature rises even up to 26 °C, because the set value for the central air handling unit is determined according to the room facing to the north without any internal heat loads. In rooms having the north-facing lower internal heat load (72 W) the temperature control performs properly. In other rooms the temperature rises about 1,5 °C during the working hours. The temperature level is quite stabile being in south-facing rooms about 24 °C. In the cooling season in June the room air temperatures vary from 19,5 to 24,5 °C. Because of sun radiation the temperatures in the south-facing rooms having only occupant loads (72 W) are about 3 °C higher than in the north-facing rooms. The relative humidity in the south-facing rooms is in January about 10 - 20 % and in June 35 - 60 %.

In the above mentioned case the set values for the central air handling unit were determined by one room air temperatures. Another possibility could be to use the mean value of the room air temperatures or to give a higher weighing to some rooms. The division of the building to separately controlled zones would make the results better.

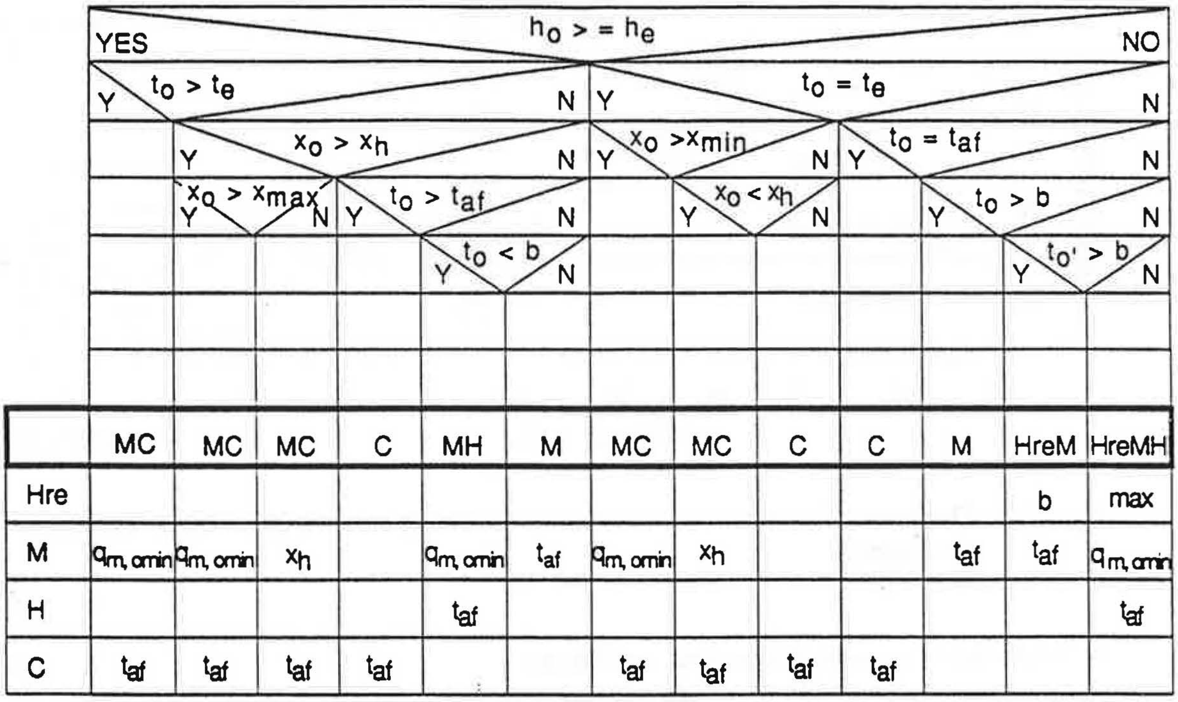

Figure 1. Supervisory control algorithm for a VAV-air-conditioning system with reheating cooling mode.

Simple mathematical models for heat recovery device (temperature efficiency), mixing box (outlet air temperature), humidifier (maximum humidification degree) and cooling coil (bypass factor) are needed to implement the algorithm. The supervisory control algorithm is dependent on the air-conditioning system. References (1, 2 and 3) give a set of supervisory control algorithms for different air-conditioning systems. In this paper supervisory control strategies of VAV - air condition systems are discussed.

SIMULATION RESULTS

Supervisory control and the operation of VAV-systems are studied in an office building having 40 rooms facing (each 7,2 m^2) to the south and 40 rooms facing to the north. Two different profiles 72 W (only occupants) and 372 W (occupants, lightning, equipment) for internal heat loads were used occuring from 8.00 a.m. to 4.00 p.m. Three-glazing windows with venetian blinds were used. Table 1 shows the design loads of the rooms. TRNSYS-program (4) was used in simulations. The supervisory control algorithm of Fig. 1 was programmed and added to the TRNSYS-component library.

The minimum inlet air temperature and minimum air volume flow rate were varied. The inlet air temperature was allowed to vary from 12 °C to 28 °C or from 15 °C to 25 °C. The maximum air volume flow rate in the first case was 40 dm^3/s and minimum 10, 20 and 30 dm^3/s. In the second case the maximum air volume flow rate

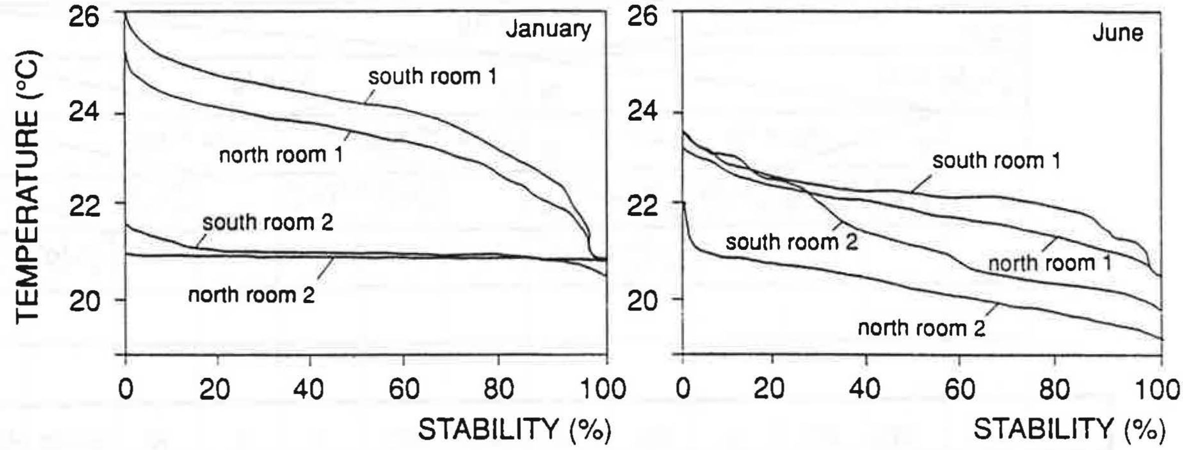

Fig. 2 Duration of room air temperatures in January and June. VAV-system without reheating.

A VAV-System with Reheating in Rooms

The room air temperatures can be controlled independently in a VAV-system with reheating. The set values for the central air handling unit are determined according to the maximum cooling power or minimum heating power needed in room spaces. The room air temperatures can be controlled by the air volume flow rate or reheating. In Figure 3 the duration of room air temperature is given when the dynamic set value range is 20 -21 °C (t_{in} = 12 - 28 °C, $q_{v,max}$ = 40 dm^3/s and $q_{v,min}$ = 10 dm^3/s).

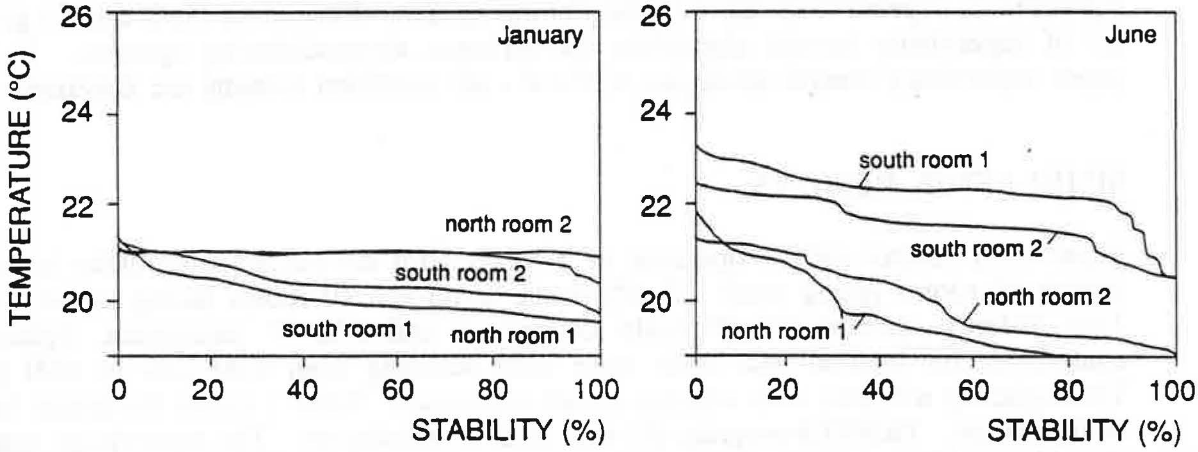

Fig. 3 The duration of room air temperatures in January and June. VAV-system with reheating.

The same dynamic set value range for room air temperature were used as for the VAV-system without reheating, i.e. 23 - 24 °C. The room air temperature goes up to 24,5 °C at its maximum. The relative humidity in the south-facing rooms is 15 - 20 % in January. That is a slightly higher value than that in a VAV-system without reheating. In July the relative humidity varies from 35 to 60 %.

If minimum value of the inlet air temperature is let to increase (at the same time the maximum air volume flow rate grows) the cooling energy consumption is slightly decreased. If a relative value 1 is given for the case 12 °C < t_{in} < 28 °C and $q_{v,min}$ = 10 dm^3/s then in the case 15 °C < t_{in} < 25 °C that is 0,86. However, the fan energy grows at the same time being in the second case 1,64 times higher than in the first case.

A VAV-System with Reheating and Humidifier in the Central Air-handling Unit

The humidity control strategy is the following. The room controller tries to keep the absolute humidity of the room air in its set point. A PI-control algorithm defines the set value for the inlet air humidity, i.e. cascade control is used.

The adding of the humidifier to the central air handling unit has no effect on room air temperature control. In winter time the temperature range is 20 - 21 °C and in summer 23 - 24 °C (t_{in} = 12 - 28 °C, $q_{v,max}$ = 40 dm^3/s and $q_{v,min}$ = 10 dm^3/s) as desired.

In winter the humidity of a south-facing room without internal heat loads varies from 30 to 40 %. In summer time the range is from 35 to 55 %.

In summer if the cooling coil is used to control the air humidity, as well, more cooling energy is used compared with the case without humidity control. If the set value range of room air humidity is low (35 - 40 %) cooling is needed continuously in summer. When the absolute humidity of the inlet air is lower than that of the outdoor air the cooling coil is used for dehumidification. That rises energy consumption. In the simulated case study 21546 kWh cooling energy was used. That is 3,6 times the figure of case without humidity control in summer conditions.

Energy Consumption of different VAV-Systems

The energy consumption of an VAV-air-conditioning system depends significantly on the configuration of the system. The energy consumption of a VAV-system without reheating (12 °C < t_{in} < 28 °C and 10 dm^3 < q_v < 40 dm^3, mixing, no heat recovery) were 50073 kWh heating energy, 2894 cooling energy and 29658 kWh fan energy. The corresponding figures for a VAV-system with reheating in each room were 45181 kWh heating energy, 5969 kWh cooling energy and 33493 fan energ. The reheating coils used 42 % of the heating energy.

In a VAV-system with reheating and humidifier in the central air handling unit the energy consumption figures were 48591 kWh heating energy, 21546 kWh cooling energy and 40796 kWh fan energy. The set value range for the relative humidity was 32 - 50 %. The reheating coils used 34 % of the heating energy. The use of heat recovery with nominal temperature efficiency of 50 % decreases the energy consumption by 30 -40 %.

The set value range of the inlet air temperature (12 - 28 °C or 15 - 25 °C) does not affect the energy consumption of the air-conditioning system remarkably (if the maximum air volume flow rate is dimensioned according to the heating and cooling power needed). However, the minimum air volume flow rate has an effect on the energy consumption. By growing the minimum air volume flow rate the energy consumption grows, as well.

CONCLUSIONS

The supervisory control has two functions: to minimize energy consumption and to ensure operation conditions for the unit processes. Supervisory control can take into account set value changes caused by different operation modes of the building (free cooling, optimum start/stop, etc.). Supervisory control algorithms depend on the air-conditioning system.

If individual control is desired a decentralized air-conditioning system should be used. When a VAV-system without reheating is used the central air-handling unit can produce air either just to heat or cool the rooms. In that case the set values have to be chosen according to the room space the central air-handling unit will be controlled. In that case the conditions in other rooms cannot be controlled accurately. When a reheating coil for each room is used the room air temperatures can be controlled quite well, the maximum difference being 0,5 °C. The central air-handling unit is in this case controlled according to the room asking for the lowest inlet air temperature.

In the Finnish weather conditions heat recovery (and/or mixing) is used most time of the year. Often heat recovery can produce the necessary heating power. Only in the cold winter time heating is used. When humidification is used heat recovery can not cover the heating demand alone.

REFERENCES

(1) Heimonen, I.,Supervisory control of air-conditioning systems in office buildings, MSc(Tech) thesis, Helsinki (1989). (In Finnish)

(2) Bork, P. Energieeinsparung bei Luftungs- und Klimaanlagen mit Hilfe verbesserter Automatisierungskonzepte. Automatisierungstechnische Praxis atp. 28 Jahrgang. Heft 4/1986.

(3) Kreslin, A.J. Model for an ideal air-conditioning system, Ventilation and air-conditioning of industrial and agricultural buildings. Riika (1981). (In Russian, translated into Finnish).

(4) Engineering Experiment Station Report 38-12, TRNSYS, A Transient System Simulation Program. Solar Energy Laboratory, University of Wisconsin-Madison (1988).