CONTROLLABILITY OF ROOM AIR TEMPERATURE AND ADJUSTMENT OF CONTROLLER PARAMETERS

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ABSTRACT

The heating system and/or the air-conditioning system maintain thermal comfort conditions in a room space. The room air temperature control system is one subsystem of this integrated system. It differs from the other control loops, like heating coil or cooling coil control loop, being a stiff system. That means that the relation of longest time constant to the shortest is big. When room air temperature control is considered the main questions to be asked are

- What is the control variable? There are several possibilities, like inlet air temperature, inlet air volume flow rate, position of control valve of reheating coil or water radiator, etc. This arises also the question if cascade control or direct control should be used.

- Where should the controlled parameter be measured? Again there are different possibilities, e.g. direct room air temperature measurement, outlet air temperature measurement, mean value of certain room temperatures, etc.

In this paper the controllability of room air temperature and adjustment of control parameters is considered. The cases are (Fig. 1) cascade control of room air temperature when inlet air temperature or inlet air volume flow rate is the control variable and direct room air temperature control when valve position of reheating coil is the control variable.

The studies were made by simulation using TRNSYS-program (1).

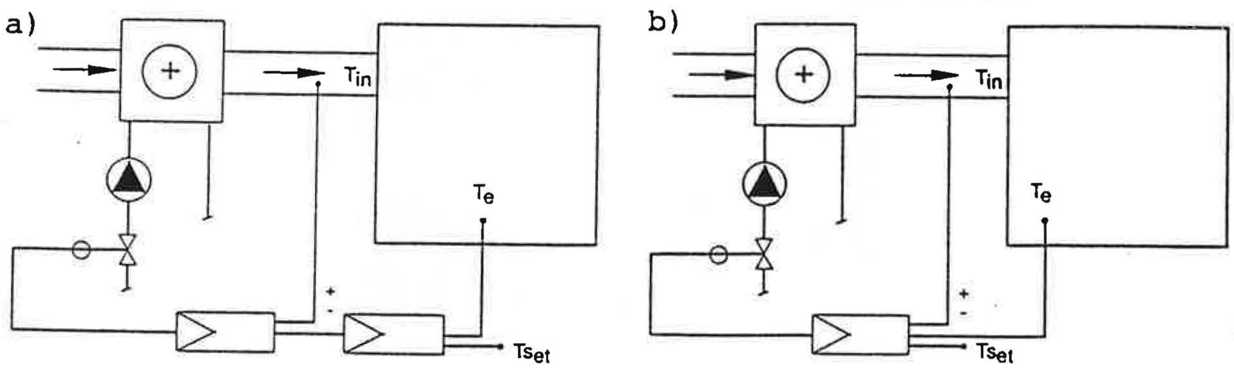

Figure 1. Studied room air temperature control modes a) cascade control, b) direct control.

CHARACTERISTIC CONTROLLABILITY FACTORS

The controllability of a dynamic system can be studied by examining the response of the controlled variable (e.g. room air temperature) to a step-change of the control variable (e.g. inlet air temperature or opening of control valve). The studies are made for an open-loop system.

The characteristic controllability factors are gain of the process K_v, time constant and lag time t_v. Control difficulty is defined $S=t_v/\tau$ (2). They can be determined from the step-response. The method is exactly valid to a linear first order system. The room air temperature control loop is neither linear nor of a low order. However, the method can be used to analyze the dynamic behavior of this subsystem when we introduce a new characteristic factor: time when the process achieves the steady state in the terms of controllability t_{ss}.

For a first order system the step response has achieved 98,2 % of its final value after the time 4τ(3). This is called time when process achieves the steady state in the terms of controllability, i.e. $t_{ss} = 4\tau$. When room air temperature is controlled by an air-conditioning system the time constant according to (3) is

$$\tau = 60/n \text{ [min]}, \qquad (1)$$

where

n is air volume flow rate/hour.

This value can be used as an approximation.

Figure 2 shows step responses of a room air temperature control loop with different air flow volume rates when a change of 6 °C was made to the inlet air temperature. The value t_{ss}=4 h has been used in this paper. The value is longer than what Eq. (1) gives. The characteristic controllability factors and further the controller parameters seem not to be very sensitive for t_{ss} varying from 15 min to 10 hours.

The system will achieve its new steady state after several days. After four hours from the change the room air temperature has changed 0,2-2 °C. The lag time cannot be exactly determined from the step response. It varies between 0,5-5 min (3). In this study t_v=3 min was used.

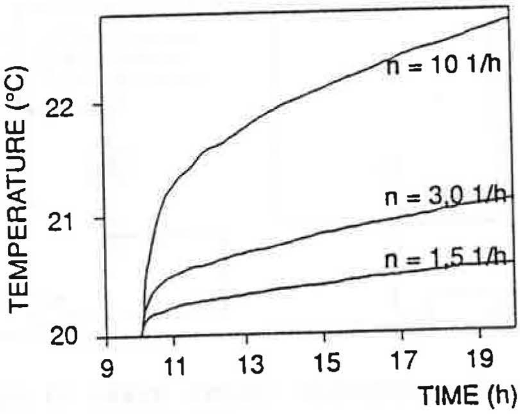

Figure 2. Step responses of room air temperature with different air volume flow rates.

Table 1 summaries the characteristic controllability factors of the cases (Fig. 1). The change in room air temperature grows when air volume flow rate grows. When an air-conditioning system with variable air flow rate is used the controller should be tuned according to the maximum air volume flow rate to ensure stability. Control difficulty S is small in all cases. On/off- or P-control law would be sufficient (2) but PI-control in used to avoid any control difference. In direct control the time constant is clearly longer than in cascade control.

Table 1. Characteristic controllability factors of the case systems of Figure 1.

Control mode	Step change	K_s [°C]	t_v [min]	τ[min]	S
Cascade control					
n=1,5 1/h	T_{in}:20->26 °C	0,99	3	40	0,075
n=3,0 1/h	-"-	1,95	3	37	0,081
n=10,0 1/h	-"-	5,07	3	32	0,094
T_{in}=16°C	n:1,5->3,0 1/h	1,48	3	41	0,073
T_{in}=16°C	n:1,5->10,0 1/h	1,17	3	37	0,081
Direct control					
n=3,0 1/h	H^*:0,2->0,5	3,77	3	56	0,054
n=3,0 1/h	H^*:0,5->0,8	5,23	3	56	0,054

ADJUSTMENT OF CONTROLLER PARAMETERS

Well known methods for adjusting the P-, PI- and PID-controller parameters are the Ziegler-Nichols (ZN) method and the Chien-Hrones-Reswick (CHR) method. The latter have presented method for adjusting an aperiodic or fast closed loop behavior. The PI-control law in analog form is

$$u(t)=K_P e(t)+K_I \int e(t)dt, \qquad (2)$$

where

u(t) is the control signal,
e(t) the control difference,
K_P the proportional gain,
K_I the integral gain.

Table 2 gives the PI-controller parameters of the room air temperature control loops of Figure 1 and Table 1.

CLOSED-LOOP CONTROL SYSTEM

The behavior of the closed loop control system was tested by changing the set point value of the room air temperature, by changing the inlet air temperature or volume flow rate and by putting internal heat load to the room. The both parameters of Table 3 were used. The Ziegler-Nichols method gives a good approximation for tuning the controller. The controller should be adjusted according to the step-response test that gives the greatest gain of the process K_s at all operation conditions. The cascade control leads to a more stabile closed-loop behavior than direct control. The cascade control is able to compensate disturbances, like changes in inlet air temperature to the reheating coil, before they affect the room air temperature.

Table 2. PI-controller parameters of the case systems of Figure 1 and Table 1.
Legend:
ZN is Ziegler-Nichols method
CHR is Chien, Hrones and Reswick method
$[K_p]=[1/°C]$
$[K_I]=[1/°C\ min]$

Control mode	Step change	ZN K_p	ZN K_I	CHR, aperiodic K_p	CHR, aperiodic K_I
Cascade control					
n=1,5 1/h	T_{in}:20->26°C	12,10	1,22	4,71	0,098
n=3,0 1/h	-"-	5,69	0,57	2,21	0,050
n=10,0 1/h	-"-	1,89	0,19	0,74	0,019
T_{in}=16°C	n:1,5->3,0 1/h	8,31	0,84	3,23	0,066
T_{in}=16°C	n:1,5->10,0 1/h	9,49	0,96	3,69	0,083
Direct control					
n=3,0 1/h	H^*:0,2->0,5	4,46	0,45	1,73	0,026
n=3,0 1/h	H^*:0,5->0,8	3,21	0,32	1,25	0,019

Figure 3 shows the inlet and room air temperature variations when an internal heat load of about 270 W/m^2 is brought to the room from 8-11 and 12-16 hours. The inlet air temperature may vary from 12 °C to 28 °C. The controller was tuned using Ziegler-Nichols method. The closed loop behavior is stabile.

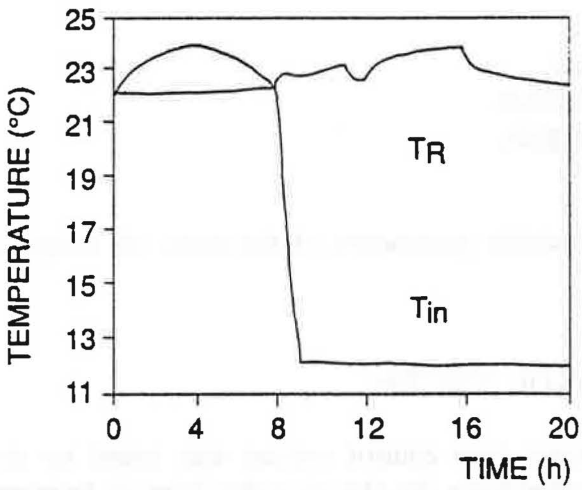

Figure 3. Inlet air temperature and room air temperature variations when an internal heat load of 270 W is brought to the room. Inlet air temperature may vary from 12 °C to 28 °C.

CONTROL OF TWO ROOMS

Simulations were made to a system of two rooms, one facing to the south and the other to the north. The rooms were served by the same air conditioning system. The following cases were examined

- Control according to the room facing to the south, internal heat load only in the south facing room.
- Control according to the room facing to the north, internal heat load only in the south-facing room.
- Control according to the mean value of the room air temperatures, both rooms have internal heat loads.

Dynamic control was used to let the room air temperature vary from 22 °C to 26 °C in summer and from 21 °C to 23 °C in spring and winter.

Figure 4 shows the room air temperatures and inlet air temperatures in the above mentioned cases. Inlet air volume flow rate is constant (3,0 1/h) and the simulations were made in spring weather conditions ($T_{u,min}$=-18 °C, $T_{u,max}$=+5 °C). The room air temperatures can be kept in the allowable range when the mean value of the two rooms is measured.

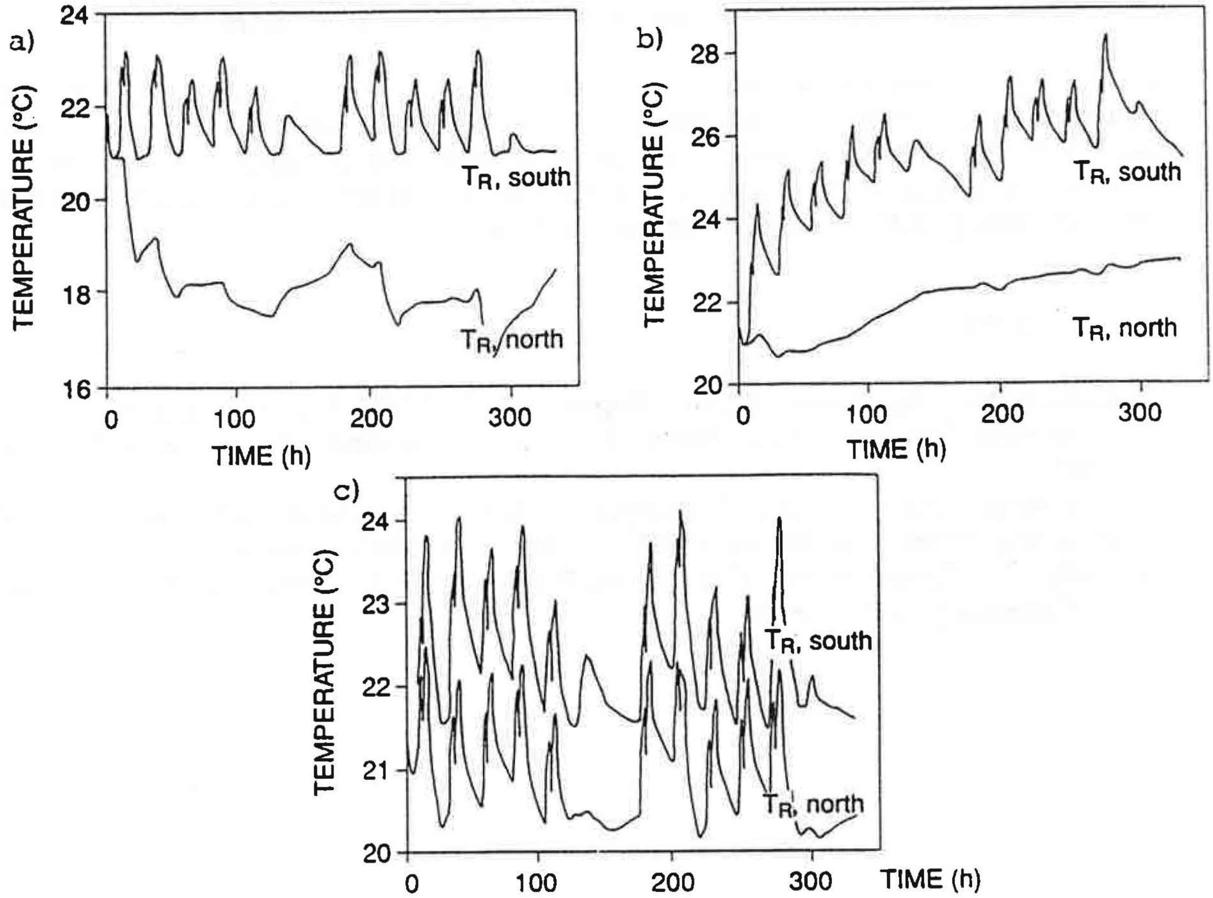

Figure 4. Room air and inlet air temperatures when the two-rooms system is controlled according to a) room facing to the south, b) room facing to the north, c) mean value of the room air temperatures.

CONCLUSIONS

In this paper the controllability of room air temperature and adjustment of control parameters is considered. The cases are cascade control of room air temperature when inlet air temperature or inlet air volume flow rate is the control variable and direct room air temperature control when valve position of reheating coil is the control variable.

When room air temperature control is considered the main questions to be asked and answered are: What is the control variable and where should the controlled variable be measured?

The cascade control leads to a more stabile closed-loop behavior than direct control. The cascade control is able to compensate disturbances, like changes in inlet air temperature to the reheating coil, before they affect the room air temperature. The control variable is thus either inlet air temperature or volume flow rate depending on the air conditioning system.

Simulation does not give an answer if it were better to measure room air temperature or exhaust air temperature because the room air is supposed to be fully mixed. However, when several rooms or zones are controlled according to one measurement it is better to share discomfort and measure the exhaust air temperature.

The Ziegler-Nichols method gives a good approximation for tuning the controller. The controller should be adjusted according to the step-response test that gives the greatest gain of the process K_s to ensure stability at all operation conditions. When an air-conditioning system with variable air volume flow rate is used the controller should be tuned according to the maximum air volume flow rate.

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