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Onoff control of room air temperature - effect of sensor timeconstant, onoff difference and location

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ONOFF CONTROL OF ROOM AIR TEMPERATURE - EFFECT OF SENSOR TIMECONSTANT, ONOFF DIFFERENCE AND LOCATION

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Abstract

Onoff control of roomair temperature is rather common. Different temperature sensor time constants, onoff differences and locations are studied in simulation of models and in fullscale experiments.

Table of contents

1 Introduction

The main purpose with this report is to study how onoff control of room air temperature depends on the following three items:

temperature sensor timeconstant
temperature sensor onoff difference
temperature sensor location

This will be done for a certain room, which is heated by air. The outdoor air is heated by an electric airheater, which is onoff controlled by the room air temperature. A short description of the room is made in section 2.

Models to be used in simulations are determined in section 3.

The simulation studies of onoff control are given in section 4.

Fullscale experiments are documented in section 5.

Finally some comparisons and conclusions are made in section 6 between the simulated and fullscale onoff control experiments.

2 The process

The room is an experiment room, which has been developed by the Department of Building Science, Lund Institute of Technology. The room has a length of 4.5 m, a width of 3.6 m and a height of 3.0 m. It is connected to outdoor air through a window and a front wall.

The airheater consists of three resistance bars inserted in the air stream. A fan blows the air into the room in three inlets at the window. The fan capacity is about 600 m^3/h. The airheater effect was 2080 W in the experiments.

The location of the termistor temperature sensors are shown in figure 2.1. The room air temperature sensors were mounted 1.5 m from the floor and 20 mm from the walls, if mounted at the wall.

A process computer together with a coupler/controller system were used to logg and control the room air temperatures.

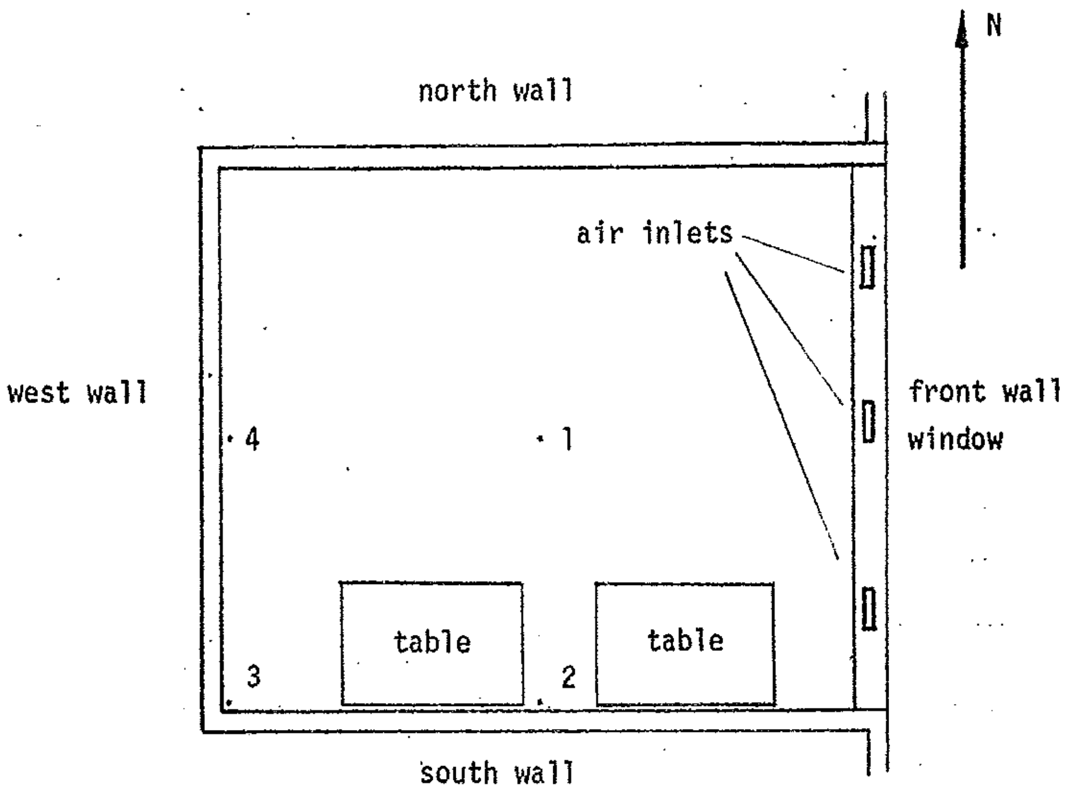

Figure 2.1 Room and room air temperature sensor locations (1-4) seen from above.

3 Determination of models

3.1 Identification experiment

The effect has been turned on and off according to a PRBS sequence with the following data

PRBS order	7
PRBS basic period	4 min
sampling interval	1 min
experiment length	500 min

The outdoor air temperature, the PRBS sequence, the inlet air temperature and the room air temperature are shown in figure 3.1.

3.2 Model and identification method

Using the experimental data described above, the dynamics from the control signal to air heater (denoted by u(t)) to the room air temperature (denoted by y(t)) was modelled as follows. First the coefficients of a difference equation

$$y(t) + a_1 y(t-1) + \ldots + a_n y(t-n) =$$

$$= b_1 u(t-k-1) + \ldots + b_n u(t-k-n) + v(t)$$

were determined using a least squares criterion. The model parameters a_i and b_i are thus found by minimizing the loss function

$$V = \sum_{t=1}^{N} v(t)^2$$

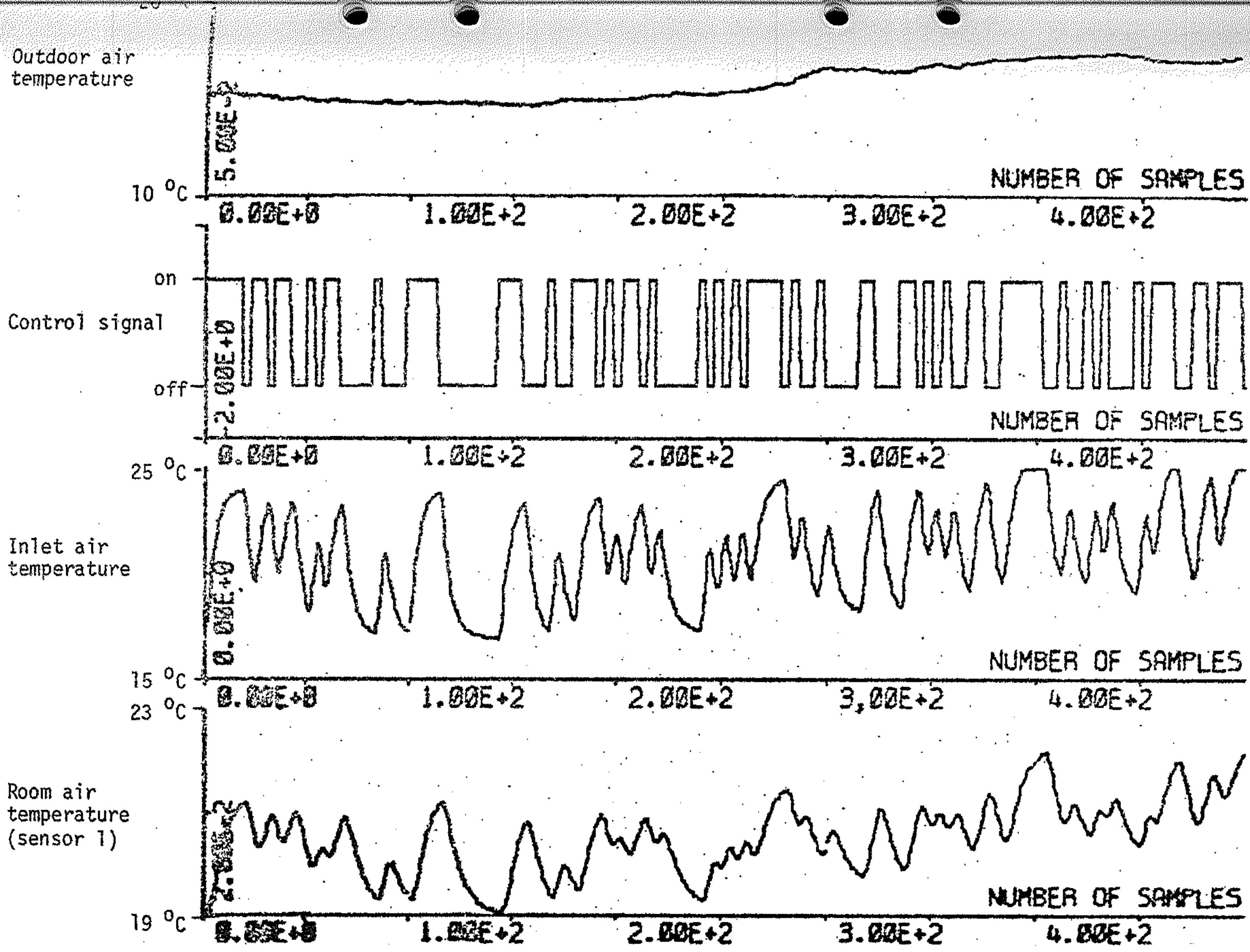

Figure 3.1 Identification experiment

3.3 Identification result

Models of first and second order with different delays have been identified for the input output system effect to room air temperature. The best models are given in table 3.1. All are of first order. All models with temperature sensors close to the walls have a time delay of 3 minutes. The model with the sensor in the middle of the room has a delay of 4 minutes. This can be explained by that the inlet air sticks to the walls and the ceiling.

Table 3.1

Model	Temperature sensor	Model parameters			
		a_1	b_1	k	v_{rms}
(3.1)	1 room middle	-0.921	0.104	4	0.071
(3.2)	2 south wall	-0.919	0.115	3	0.076
(3.3)	3 south west corner	-0.916	0.099	3	0.064
(3.4)	4 west wall	-0.920	0.105	3	0.070

4 Simulated onoff control

Simulations with digital onoff control have been made with the models given in section 3. The effect of different sensor timeconstants, onoff differences and locations are studied in simulations. The mean error, peak to peak and period time of the room air temperature are used to compare the different simulations.

The mean deviation of an onoff controlled output from a first order system with timedelay is computed for different timeconstants and loads.

4.1 Different temperature sensor timeconstants

The timeconstant of the temperature sensor used in the experiments has been determined to 30 seconds. Most room air temperature sensors have larger timeconstants. How does this effect the behaviour of onoff control such as mean error, peak to peak and period time of the output?

This can be simulated for several cases with a model of the process. These process models are given in section 3.3. The model between the room air temperature $y_2(t)$ with the new timeconstant T_2 and the room air temperature $y_1(t)$ with the old timeconstant T_1 can be given as

$$y_2(t) = a_1\, y_2(t-1) + b_o\, y_1(t) + b_1\, y_1(t-1) \qquad (4.1)$$

where

$$a_1 = e^{-1/T_2}$$

$$b_o = T_1/T_2$$

$$b_1 = 1-T_1/T_2 - e^{-1/T_2}$$

This digital filter (4.1) corresponds to the continuous filter

$$G(s) = \frac{(sT_1+1)}{(sT_2+1)} \qquad (4.2)$$

The digital onoff regulator is as follows

$$u(t) = \begin{cases} 1 \text{ on if } y_2(t) - y_{set} < 0 \\ -1 \text{ off if } y_2(t) - y_{set} \geq 0 \end{cases} \qquad (4.3)$$

The input u(t) is only determined in every sampling point.

The models (3.2), (4.1) and the regulator (4.3) have been simulated for T_1=0.5 min. and T_2=0.5, 2., 8. and 32. min. The load has been 0.5, 0.7 and 0.9. The result from the simulations are given in table 4.1.

Table 4.1

Simulated mean error e_m, peak to peak value pp and periodtime pt of the room air temperature as a function of temperature sensor timeconstant and load

Sensor timeconstant in minutes	Load	e_m in ^oC	pp in ^oC	pt in minutes
0.5	0.5	0.00	0.70	11
0.5	0.7	-0.16	0.75	14
0.5	0.9	-0.23	0.75	21
2.0	0.5	0.00	1.03	18
2.0	0.7	-0.14	1.04	20
2.0	0.9	-0.24	0.92	27
8.0	0.5	0.00	1.51	28
8.0	0.7	-0.12	1.41	29
8.0	0.9	-0.19	1.09	37
32.0	0.5	0.00	1.82	35
32.0	0.7	-0.09	1.76	40
32.0	0.9	-0.12	1.38	55

4.2 Different temperature sensor onoff difference

The model (3.2) is used together with a regulator given below

$$u(t) = \begin{cases} 1 \text{ on if } y_1(t)-y_{set} + d\,u(t-1) < 0 \\ -1 \text{ off if } y_1(t)-y_{set} + d\,u(t-1) \geq 0 \end{cases} \qquad (4.4)$$

The onoff difference varies with the type of temperature sensor from 0.2 °C to 1.0 °C. How does this effect the mean error, peak to peak and period time of the output y(t)? The parameter d has been equal to 0.0, 0.125, 0.25 and 0.5 °C. The results are shown in table 4.2.

Table 4.2

Simulated mean error e_m, peak to peak pp and periodtime pt of the room air temperature as a function of the temperature sensor onoff difference 2d and load

Sensor onoff difference 2d in °C	Load	e_m in °C	pp in °C	pt in minutes
0.0	0.5	0.00	0.70	11
0.0	0.7	-0.16	0.75	14
0.0	0.9	-0.23	0.75	21
0.25	0.5	0.00	0.92	15
0.25	0.7	-0.09	0.92	17
0.25	0.9	-0.12	0.94	31
0.5	0.5	0.00	1.13	20
0.5	0.7	-0.08	1.10	21
0.5	0.9	-0.05	1.12	50
1.0	0.5	0.01	1.51	27
1.0	0.7	-0.03	1.47	31
1.0	0.9	-	-	-

4.3 Different temperature sensor location

How does the temperature sensor location effect the mean error, peak to peak and period time of the output?

The models (3.1), (3.2) and (3.4) have been simulated with digital onoff control. The result is shown in table 4.3.

Table 4.3

Simulated mean error e_m, peak to peak pp and periodtime pt of the room air temperature as a function of temperature sensor location and load

Sensor location	Load	e_m in ^oC	pp in ^oC	pt in minutes
room middle	0.5	0.00	0.84	15
"	0.7	-0.14	0.81	17
"	0.9	-0.25	0.83	26
south wall	0.5	0.00	0.70	11
"	0.7	-0.16	0.75	14
"	0.9	-0.23	0.75	21
west wall	0.5	0.00	0.64	11
"	0.7	-0.14	0.73	14
"	0.9	-0.21	0.69	21

4.4 Mean error in onoff control

The mean value of the output $y(t)$ can easily be computed for a first order system with a time constant T and a time delay of one time unit. The continuous transfer function is assumed to be as follows

$$G(s) = \frac{e^{-s}}{(sT+1)}$$

The output $y(t)$ can be given as

$$y(t) = \int_0^{t-1} e^{-(t-1-s)/T} \quad u(s)\, ds$$

where

$$u(t) = \begin{cases} 1 & \text{on if } y(t) - y_{set} < 0 \\ 0 & \text{off if } y(t) - y_{set} \geq 0 \end{cases}$$

The on-period is assumed to be t_1+1. t.u. and the off-period to be t_2+1. t.u. The maximum and minimum values of the output are assumed to be y_{max} and y_{min}. The output can now be computed for onoff period.

$$y(t) = 1. - (1. - y_{min})e^{-t/T} \qquad 0 < t \leq t_1+1.$$
$$y(t) = y_{max}\, e^{-(t-t_1-1.)/T} \qquad t_1+1. \leq t \leq t_1+t_2+2.$$

The four unknown parameters t_1, t_2, y_{min} and y_{max} can be determined using the following equations

$$y(t_1+1.) = y_{max}$$

$$y(t_1+t_2+2.) = y_{min}$$

$$y(t_1) = y_{set}$$

$$y(t_1+t_2+1.) = y_{set}$$

The mean value of the output during an onoff period can be computed as follows

$$y_m = \int_0^{t_1+t_2+2.} y(t)\, dt/(t_1+t_2+2.)$$

The difference y_m-y_{set} is computed for different setpoint values and for different timeconstants. The problem is symmetric with respect to y_{set}=0.5. The result is shown in figure 4.1. The curves indicates that a system with a timeconstant close to the time delay will have large error at low and high setpoints or loads.

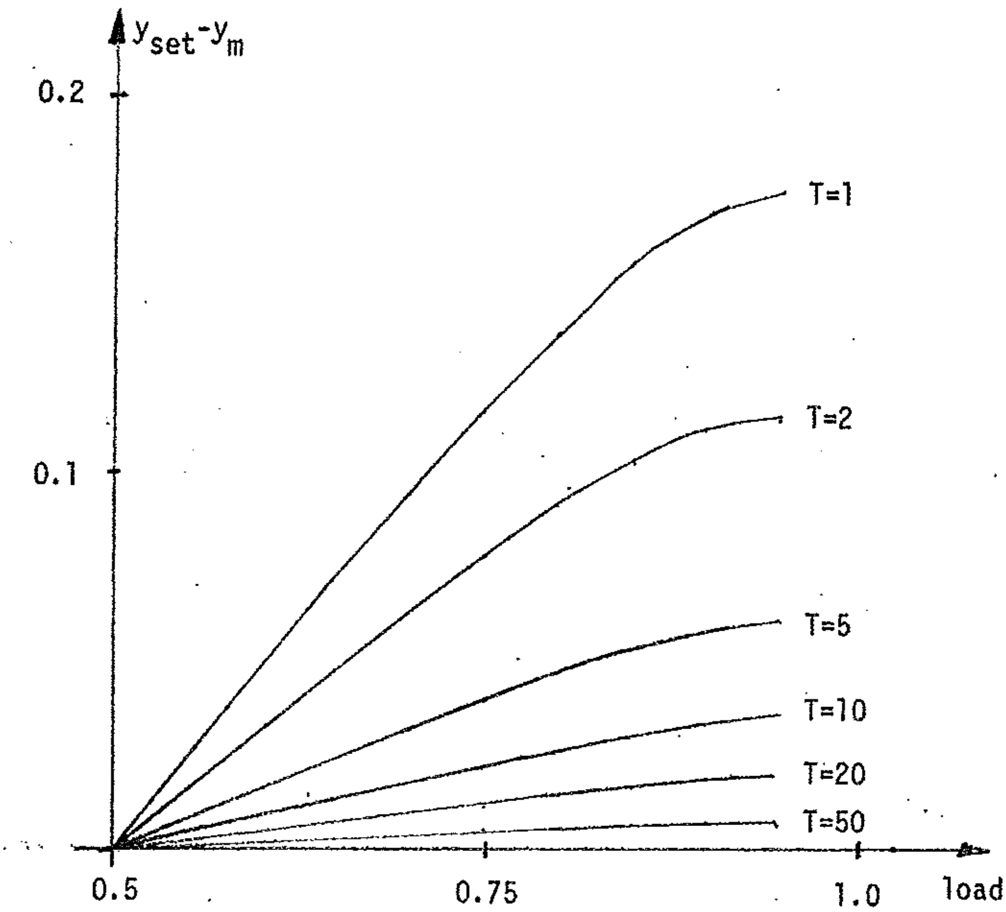

Figure 4.1 The mean error in onoff control of a first order system with a time-delay of one time unit, a time-constant T time units and a gain of one unit as a function of the load and the timeconstant T.

5 Fullscale onoff experiments

Fullscale experiments with onoff control have been made as the different types of simulations in section 4.

5.1 Different temperature sensor time-constant

The temperature sensor 2 was used. The measured temperature signal was filtered as in section 4.1 in order to change the temperature sensor timeconstant. Four timeconstants have been used 0.5, 2., 8. and 32. minutes. The results of the experiments are shown in figure 5.1. The setpoint was 18 ^{o}C.

5.2 Different temperature sensor onoff difference

The temperature sensor 2 was used. The control signal was determined as in section 4.2. The onoff difference has been 0.25, 0.5 and 1.0 ^{o}C. The results of the experiments are shown in figure 5.2. The setpoint was 19. ^{o}C.

5.3 Different temperature sensor location

The temperature sensors 1 in the middle of the room, 2 on the south wall and 4 on the west wall were used 200 minutes each in the mentioned order. The temperature sensors timeconstant were 0.5 minutes and the onoff difference were 0.0 ^{o}C. The result of the experiments are shown in figure 5.3. The setpoint was 20. ^{o}C.

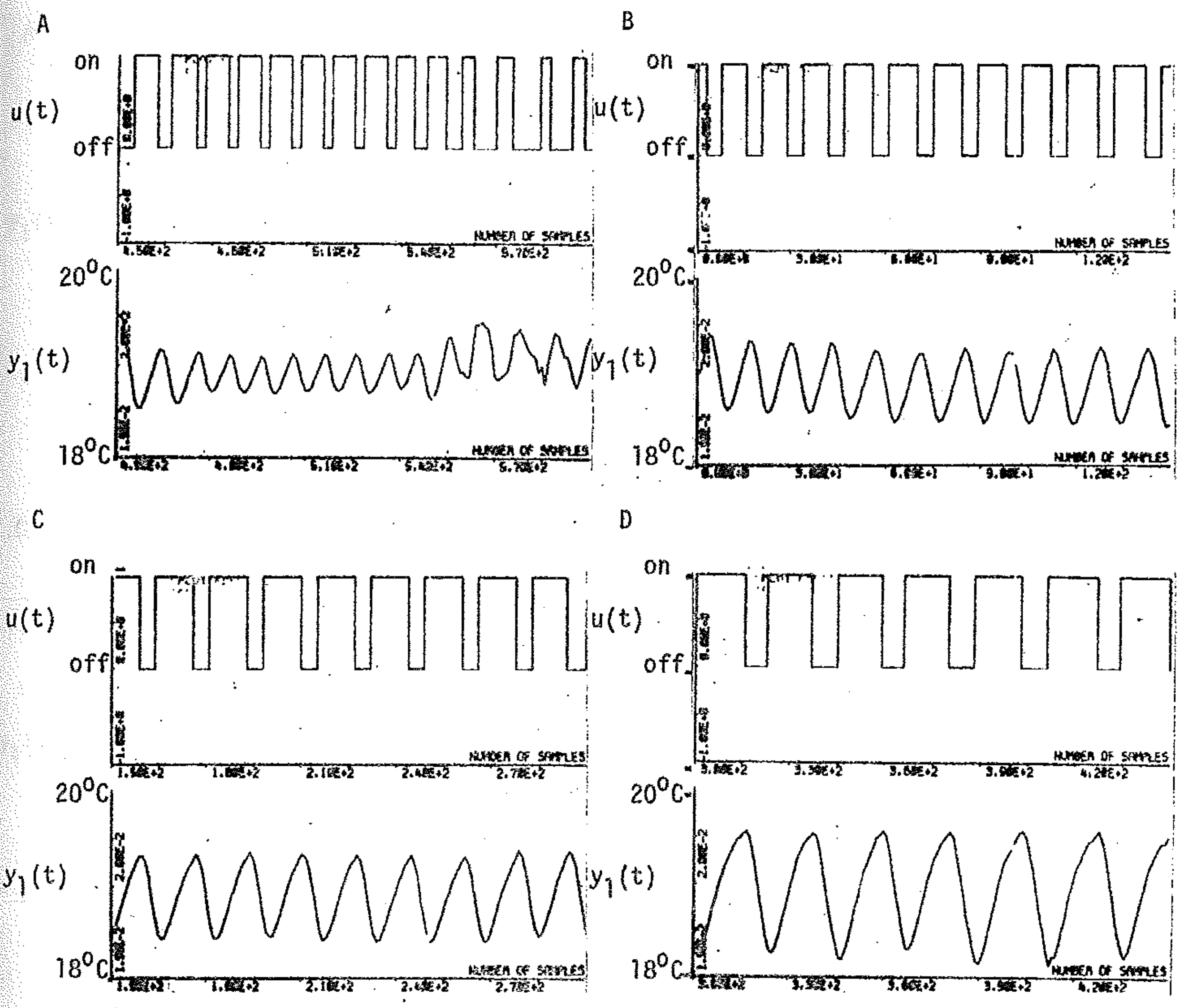

Figure 5.2 Fullscale onoff control experiments with different onoff differences 2 d. u(t) is the control signal. $y_1(t)$ is the measured room air temperature in ^{o}C at the south wall. The four experiment parts of 150 minutes length are: A d=0.0, B d=0.125, C d=0.25 and D d=0.5. The setpoint has been 19 ^{o}C. The sampling interval has been 1 minute.

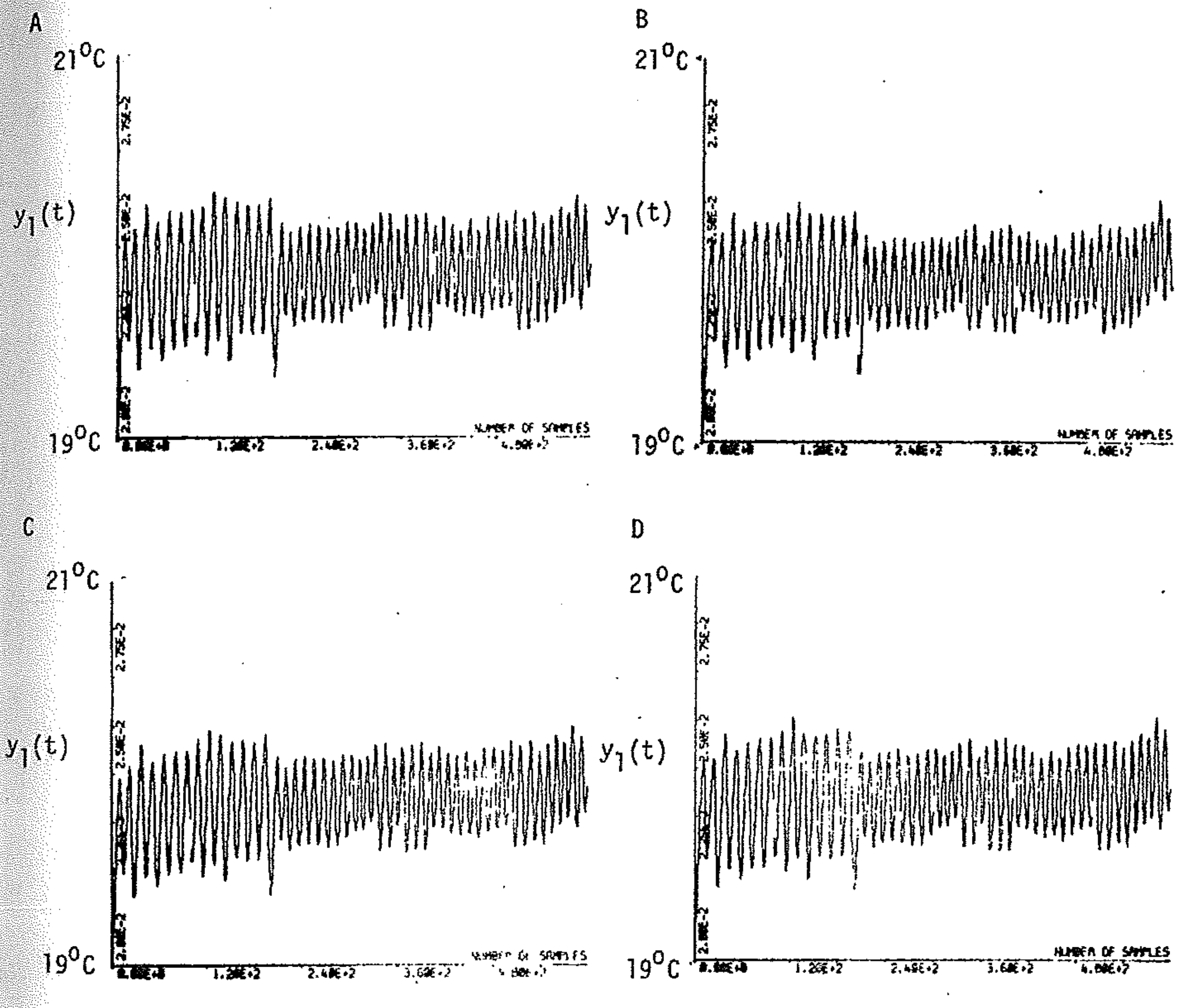

Figure 5.3 Fullscale onoff control experiments with different temperature sensor locations. $y_1(t)$ is measured roomair temperature in ^{o}C. The four roomair temperature curves are:
A room middle, B south wall, C south-west corner and D west wall. The onoff control has used the temperature sensors as follows: samples 1-200 room middle, samples 201-400 south wall and samples 401-600 west wall. The setpoint has been 20 ^{o}C. The sampling interval has been 1 minute, The whole time scale is 600 minutes or samples.

6 Comparison and conclusions

The results from the simulation in section 4.1 to 4.3 and from the fullscale experiments in section 5.1 to 5.3 have been put together in the corresponding tables 6.1 to 6.3.

Table 6.1 shows how the onoff control depends on the temperature sensor timeconstant in the simulations of model (3.2) and the corresponding fullscale experiments. The period time is the same at small timeconstants but at large timeconstants the periodtime in the fullscale experiments becomes smaller than in the simulations.

The simulated and fullscale peak to peak deviation of the room-air temperature are almost equal except for the smallest time-constant. The difference between simulated and fullscale experiments is usually less than 25%.

The effect of the onoff temperature difference is shown in table 6.2. Both the peak to peak deviation and the periodtime are smaller in the fullscale experiments. The difference is usually less than 25%.

The results of different temperature sensor locations are given in table 6.3. The fullscale peak to peak deviation and period-time are smaller than the simulated. The best fullscale temperature onoff control is also the best simulated. The worst full-scale control is also the worst simulated.

The results above show that a model can be used to study different aspects of onoff control by simulations. The deviation between fullscale and simulated values have almost been less than 25%.

The fullscale experiments and the simulations both show that the periodtime and the peak to peak value of the room air temperature are increased by increased temperature sensor timeconstants and onoff differences.

Another conclusion is that an onoff control using a temperature sensor in the middle of the room will be worse than an onoff control using a sensor close to some of the walls.

A fourth conclusion is that onoff control can be used to control the room air temperature, if deviations of $\pm 0.3\ ^{o}C$ can be accepted. The heating effect has in this case only been 2 kW. If a larger heating effect P in kW is used, then the deviation pp in ^{o}C will be proportional to the effect P as follows

$$pp = 0.3\ P$$

using the values from the 2 kW heating effect. If a large effect P has to be used then pure onoff control might not be very suitable. Instead should a major part of the heating effect be fixed and a minor part should be controlled onoff.

Table 6.1

Comparison between periodtime pt, peak to peak pp and mean deviation e_m of room air temperature from fullscale and simulated onoff control experiments using different temperature sensor timeconstants T_2

T_2 in min	Comparison value	Fullscale experiment	Simulated experiment
	pt	10	11
0.5	pp	0.59	0.70
	e_m	0.08	0.00
	pt	15	18
2.0	pp	1.07	1.03
	e_m	0.03	0.00
	pt	21	28
8.0	pp	1.49	1.51
	e_m	0.00	0.00
	pt	25	35
32.0	pp	1.82	1.82
	e_m	-0.08	0.00

Table 6.2

Comparison between periodtime pt, peak to peak pp and mean deviation e_m of room air temperature from fullscale and simulated onoff control experiments using different temperature sensor onoff differences 2d

Onoff difference in °C	Comparison value	Fullscale experiment	Simulated experiment
	pt	10	14
0.0	pp	0.41	0.75
	e_m	-0.10	-0.16
	pt	15	17
0.125	pp	0.79	0.92
	e_m	-0.13	-0.09
	pt	17	21
0.25	pp	0.92	1.10
	e_m	-0.10	-0.08
	pt	23	31
0.50	pp	1.38	1.47
	e_m	-0.10	-0.03

Table 6.3

Comparison between periodtime pt, peak to peak pp and mean deviation e_m of room air temperature from fullscale and simulated onoff control experiments using different temperature sensor location

Location	Comparison value	Fullscale experiment	Simulated experiment
	pt	14	17
room middle	pp	0.71	0.81
	e_m	-0.18	-0.14
	pt	12	14
south wall	pp	0.56	0.75
	e_m	-0.13	-0.16
	pt	11	14
west wall	pp	0.47	0.73
	e_m	-0.11	-0.14