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Experiments with onoff control of room air temperature

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EXPERIMENTS WITH ONOFF CONTROL OF ROOM AIR TEMPERATURE

L.H. Jensen

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Abstract

Onoff control uses normally only the sign of the output. If the output and its derivative are used together the onoff control can be improved for a first order system with time delay. The improved control is tested in a fullscale process with good result.

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1 INTRODUCTION

An often used control in climate control is onoff control. The control signal has only got two states: on and off and is usually chosen after the sign of the output. This gives in many cases a sufficient control but it can be improved.

One way to improve the behaviour is to use both the output and its derivative to chose the control signal. A simple example with a first order system with a time delay is analysed in section 2.

Fullscale experiments have been made with different onoff controls. The controllaws and the experiments are shown in section 3.

Finally some remarks are made in section 4 on basis of the experiments.

2 ANALYSIS

If one considers a linear first order system with a timeconstant T, a gain of 1. and with timedelay of one timeunit, one can compute how a continuous onoff regulator would behave. The timeunit can always be chosen as the timedelay of the studied system. The gain can also be scaled so that the gain is equal to one. The on value of the input is set to 1. and the off to 0.0.

If not only the output is used as in normal onoff control but also the derivative of the output one can show that the oscillations can be made less than the normal onoff control.

To get the smallest oscillations the off period should be one timedelay or one timeunit, if the mean output is in the interval (0.5,1). The on periodlength is varied. In the interval (0.0,0.5) the on period should be one timeunit and the off periodlength is varied.

Assume that the onoff control has a periodic solution consisting one on period and onoff period (see figure 2.1).

For the on period the output is given by:

$$y_1(t) = (y_1-1.)e^{-t/T} + 1, \qquad 0 \leq t \leq s + 1. \qquad (2.1)$$

And for the off period the output is given by:

$$y_2(t) = y_2 e^{-(t-s-1.)/T} \qquad s+1. \leq t \leq s+2 \qquad (2.2)$$

The mean output is assumed to be in the interval (0.5,1.). Two relations which must be fullfilled are:

$$y_1(s+1.) = y_2 \qquad (2.3)$$

$$y_2(s+2.) = y_1 \qquad (2.4)$$

For a given timeconstant T and a given mean output one can compute a corresponding mean input and thereby also the parameter s from:

$$u_{mean} = (s+1.)/(s+2.) \qquad (2.5)$$

A certain u_{mean} gives a certain s and then y_1 and y_2 can be solved from equation (2.3) and (2.4). Now it only remains to compute the regulator parameters.

The regulator is of the form:

$$f(t) = a - y(t) - b\dot{y}(t)$$

a and b are regulator parameters.

The off condition is $f(t) \geq 0.0$.

The on condition is $f(t) < 0.0$.

If b is less than 1./T then is f(t) strictly increasing in the open interval (0.,s+1.) and is strictly decreasing in the open interval (s+1,s+2).

Furthermore f(t) is discontinuous in the points 0., s+1. and s+2.

The switch point at s from on to off gives the following equation

$$f(s) = 0 \text{ or}$$
$$a - y_1(s) - b\,\dot{y}_1(s) = 0 \qquad (2.6)$$

The switch condition is only that f(t) should change sign but when f(t) is contionuous around the switch point s then f(s) must be zero.

At the other switch point at s+1. from off to on the function f(t) is discontinuous and this gives two ineqaulities

$$f(s + 1. - \varepsilon) \geq 0$$

$$f(s + 1. + \varepsilon) \leq 0$$

The first inequality is always fullfilled because f(t) is strictly increasing in the interval (0,s+1) and the f(s) = 0. The second inequality can be turned into a equation if the smallest b to fullfill the inequality should be used. So we get:

$$a - y_2(s+1.) - b\, \dot{y}_2(s+1.) = 0 \qquad (2.7)$$

Now the regulator parameters can be computed from the equations (2.6) and (2.7) when the functions $y_1(t)$ and $y_2(t)$ are known.

In table 2.1 the regulator parameters a and b and the difference y_2-y_1 has been computed for different values of T and u_{mean}. The same is done for pure onoff control to be able to make a comparison.

From table 2.1 one sees that the regulator parameter varies due to the working point (u_{mean}) and the timeconstant of the system.

The parameter a can be looked upon as a setpoint for the regulator, which ought to be close to mean of the output.

For small timeconstants and high u_{mean} values the parameter a differs much from u_{mean} but at higher timeconstants it gets close to u_{mean}.

The parameter b varies slightly with the timeconstant T but more with the working point u_{mean} (see figures 2.2 and 2.3).

A simple approximative method to chose a and b is to set a equal to the desired output and b to a value less than 0.5 timedelay/samplinginterval.

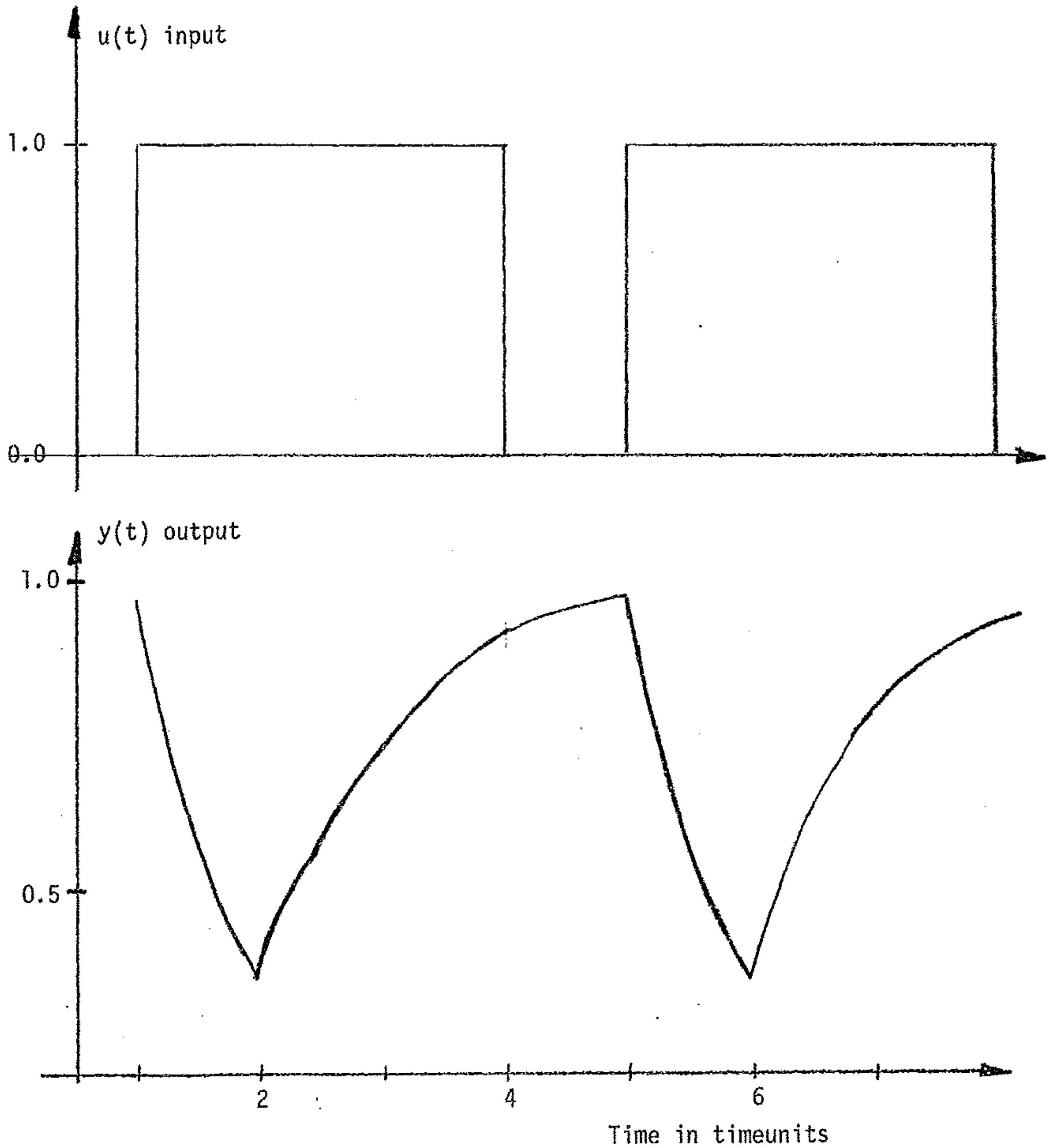

Figure 2.1 Periodic solution for improved onoff control of a system with T = 1 timeunit and u_{mean} = 0.75

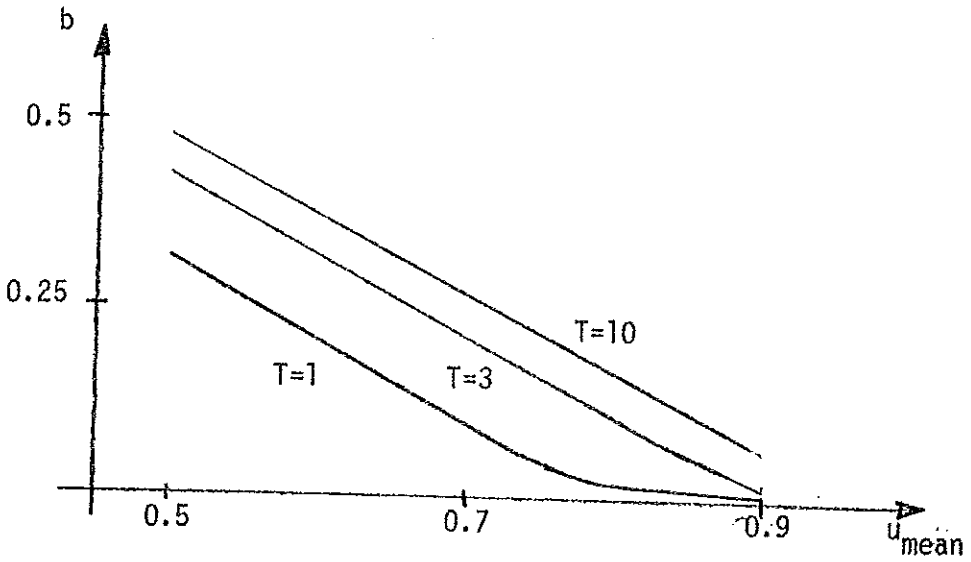

Figure 2.2 The D feedback as a function of u_{mean} for different timeconstants T.

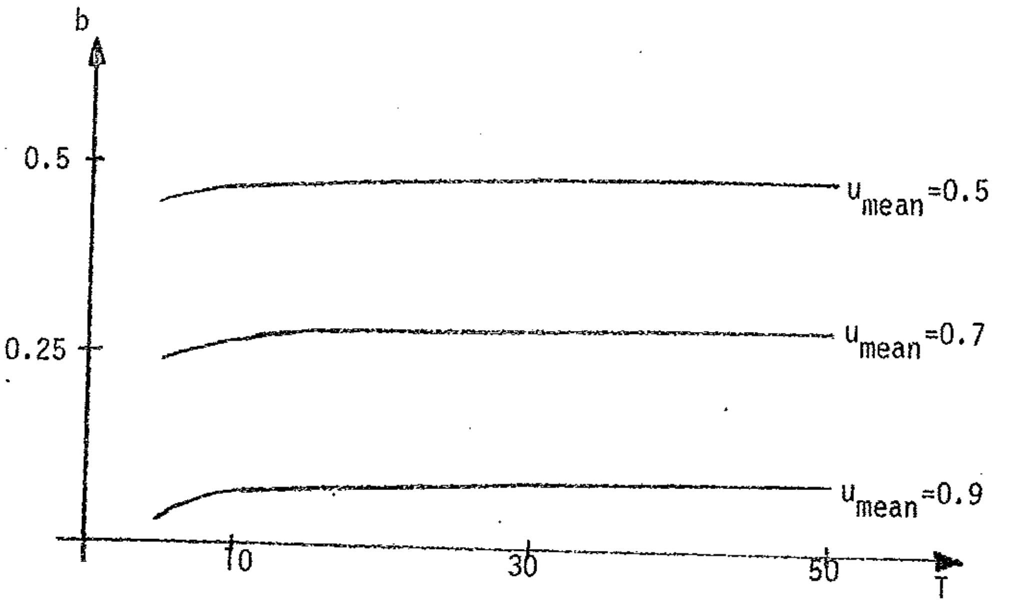

Figure 2.3 The D feedback as a function of the timeconstant T for different u_{mean}.

Table 2.1

Peak to peak values for P onoff and PD onoff control as a function of the working point u_{mean} and the timeconstant T. The regulator variables a and b in PD onoff control are also given.

T	u_{mean}	ppPD	ppP	b	a
1.	0.5	0.46	0.63	0.316	0.500
1.	0.7	0.59	0.63	0.099	0.844
1.	0.9	0.63	0.63	0.000	0.999
3.	0.5	0.17	0.28	0.425	0.500
3.	0.7	0.23	0.28	0.214	0.748
3.	0.9	0.28	0.28	0.017	0.980
10.	0.5	0.050	0.095	0.476	0.500
10.	0.7	0.070	0.095	0.272	0.714
10.	0.9	0.089	0.095	0.064	0.933
30.	0.5	0.017	0.033	0.492	0.500
30.	0.7	0.023	0.033	0.290	0.705
30.	0.9	0.030	0.033	0.087	0.912

3 EXPERIMENTS

Four different onoff controls have been tested in a fullscale room. The room air was controlled by the onoff regulator, which controlled two electrical radiators (1 kW each). The room is a normal office room. Further details are given in Adamson (1969).

A PDP-15 process computer was used in the experiments. The measurements and controls were carried out by a coupler/controller (HP 2570A) 400 meters from the process computer. Details about the coupler/controller system are given in Jensen (1973a).

All experiments were subjected to two controlled disturbances. Between the 20th and 25th minute outdoor air was fanned into the room with a capacity of ten roomair changes per hour.

Between the 80th and 140th minute an extra radiator (500 W) was switched on. The experiment length was 200 minutes.

The process has got a timedelay of 2 to 3 minutes and a main timeconstant of about 10 minutes. The model is given in Jensen (1973b).

The best weight for the derivatives lies between 0.0 to 0.5 for a normalized system. The regulator was not continuous but a discrete PD regulator with high gain and with saturation. The sampling interval was 20 seconds. This scales up the weight for the derivatives from 0.5 to 4.5 (9 times = timedelay/sampling interval). In the experiments the following values were used 0.0, 5.0, 10.0 and 15.0.

The process output y(t) the room airtemperature was measured in ^{o}C and the input u(t) the heatingeffect in kW.

No filtering was made in the regulator.

The regulator

$$u(t) = \begin{cases} 2. & \text{if } z(t) > 2.0 \\ z(t) & \\ 0. & \text{if } z(t) < 0 \end{cases}$$

$$z(t) = -100.\left[y(t) + b(y(t) - y(t-1))\right] +.1.$$

The input u(t) was almost always on the bounds.

This regulator is not exactly the one described in section 2. The regulator parameter a is set equal to the desired value. The regulator parameter b depends on the load but here b is fixed.

Experiment 1 b = 0.0

The derivative of the output was not used here. The peak-to peak value for the room air temperature was about 1 ^{o}C. When the extra radiator was turned on the oscillations decreased (see figure 3.1). The sampling was 1 minute.

Experiment 2 b = 5.0

The derivative of the output is weighted five times more than the output itself. The result is much better. The oscillations becomes 2 to 3 times smaller. When the extra radiator is turned on the mean output is different from the desired value (see figure 3.2).

Experiment 3 b = 10.0

The oscillations gets still smaller. When the extra radiator is turned on the mean deviation becomes large (see figure 3.3).

Experiment 4 b = 15.0

As experiment 3 and the mean deviation becomes still worse (see figure 3.4).

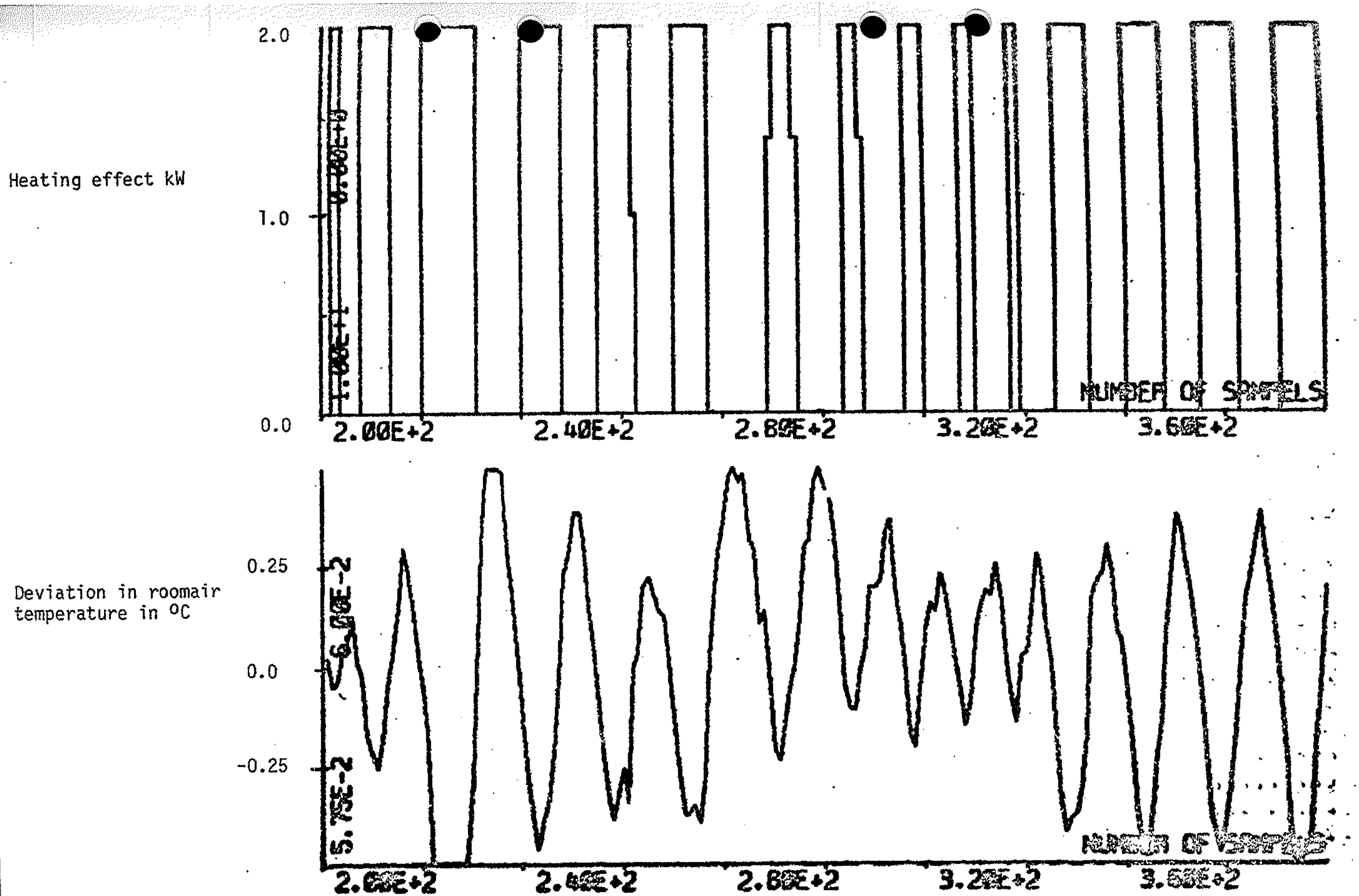

Figure 3.1 Experiment 1 PD onoff control with b = 0.0

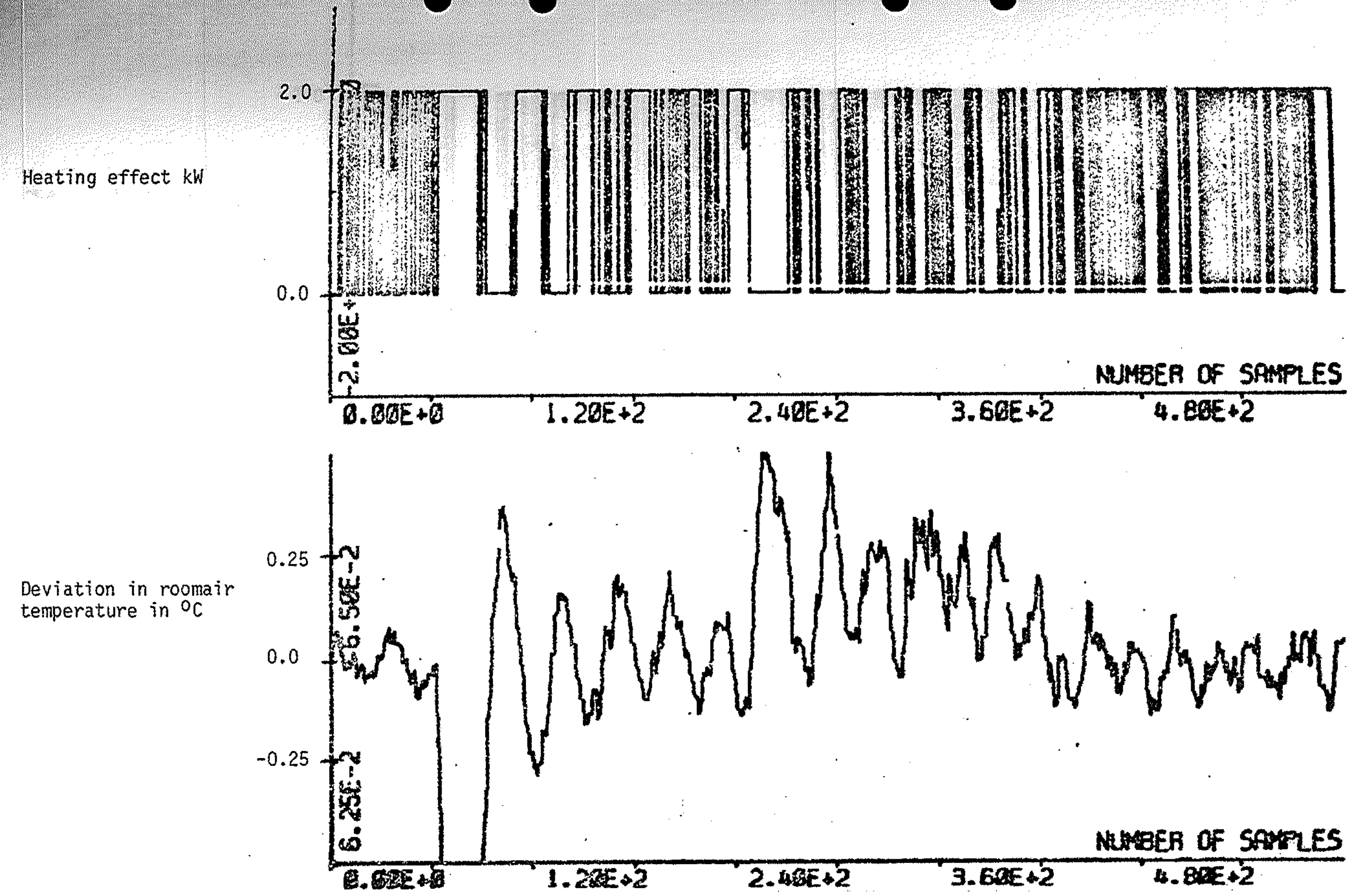

Figure 3.2 Experiment 2 PD onoff control with b = 5.0

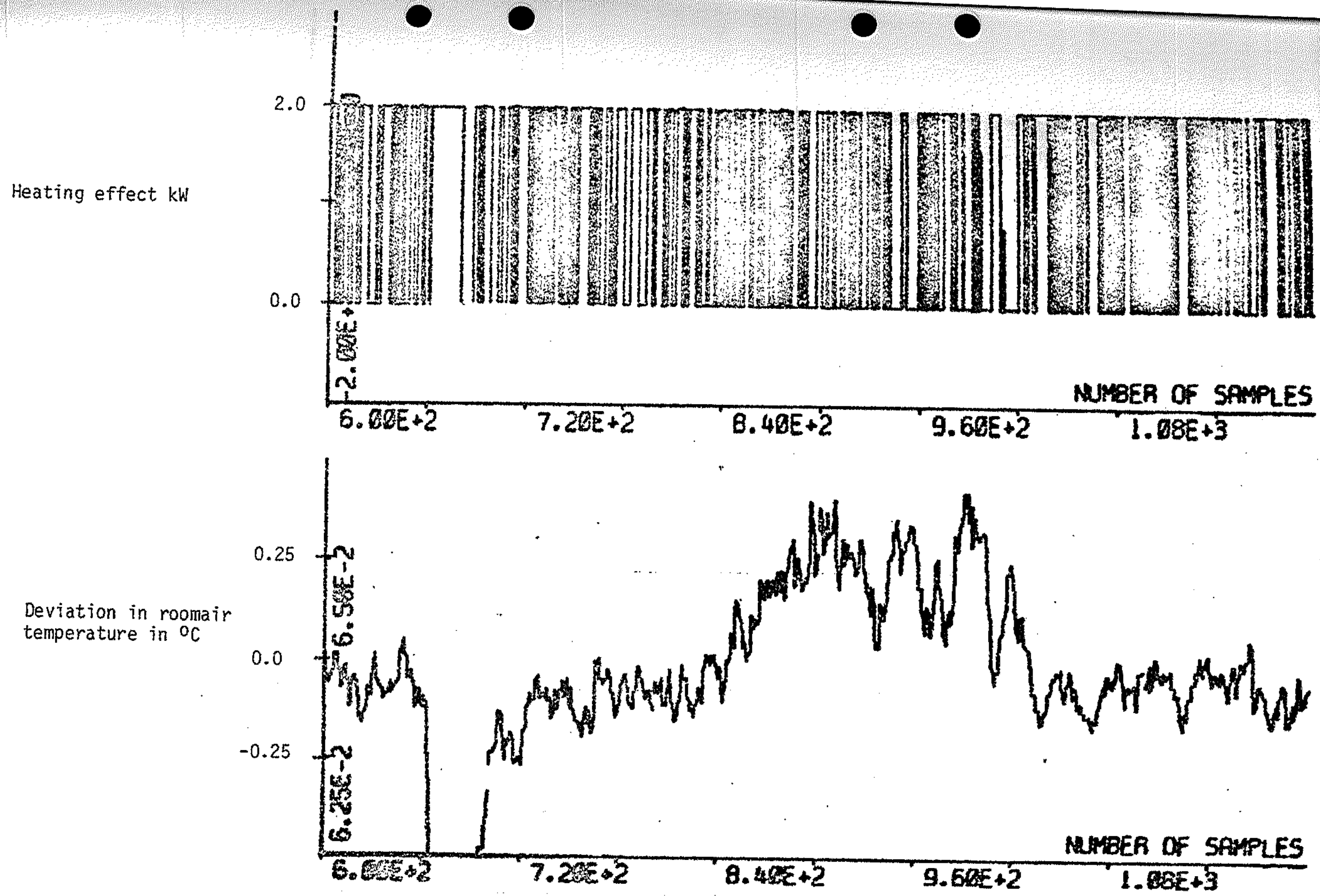

Figure 3.3 Experiment 3 PD onoff control with b = 10.0

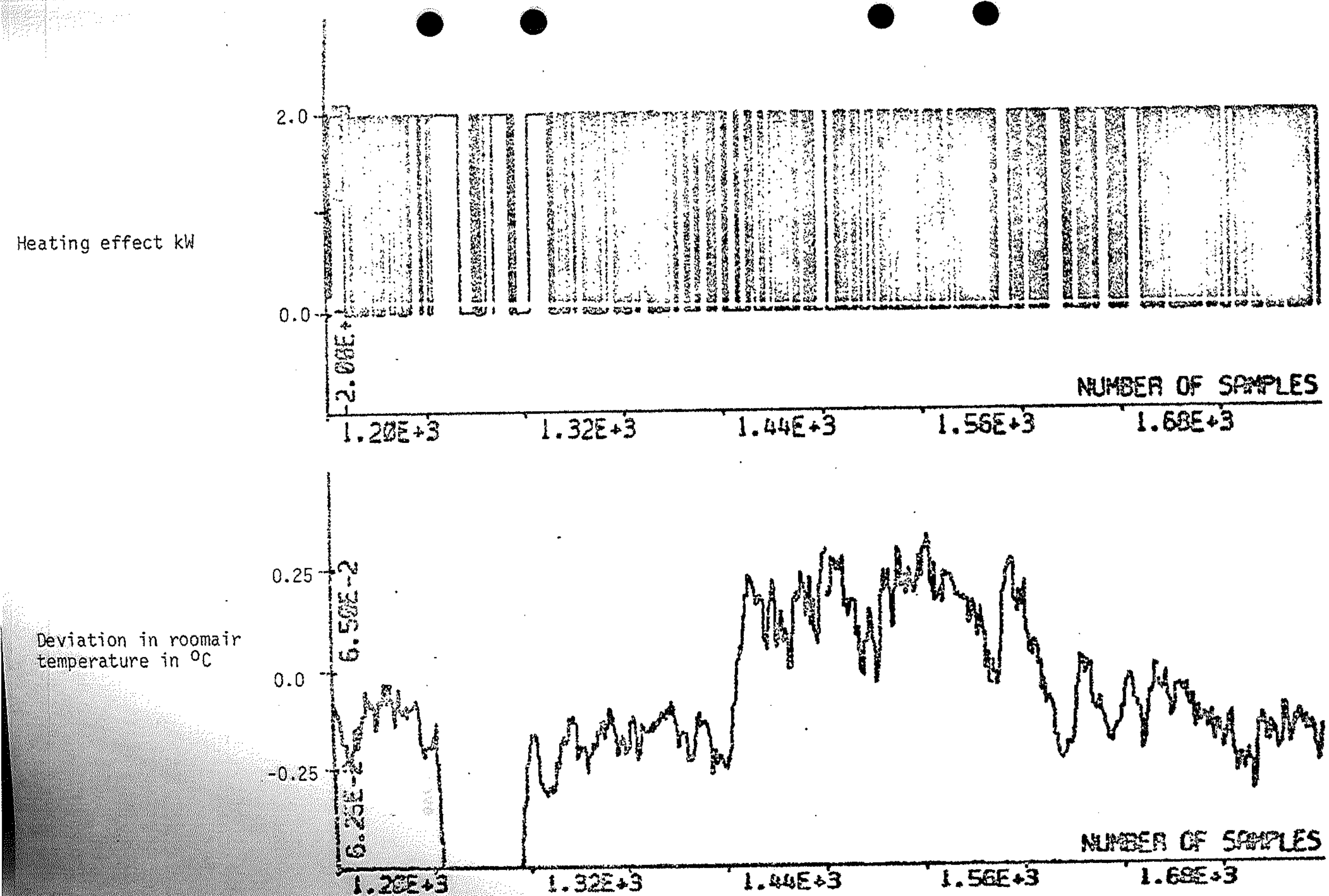

Figure 3.4 Experiment 4 PD onoff control with b = 15.0

4 REMARKS

The mean deviation of the output when the extra radiator is turned on can be explained. If a high weight is used for the derivative of output in comparison with the output itself, it might dominate completely. This leads to that same number of ons and offs are generated. The process is assumed to be in steady state.

If one assumes that the output of the process minus the set point can be regarded as a random variable y(t) with a $N(m,\sigma)$ distribution and independant in time. The combination of the output and its derivative can then be described as a random variable distributed $N(m, \sqrt{1+2b+2b^2}\,\sigma)$. It is obvious that if m is smaller that $\sqrt{1+2b+2b^2}\,\sigma$ then this random variable will almost be positive one half of the time and negative the other half. The result of this is that the control generates equal amounts of ons and offs. This calculation also shows that the performance of the PD onoff regulator can be inferior when the sampling interval is decreased. The derivative gain b is given as 0.5 · timedelay/sampling interval.

It is now possible to compute the mean deviation m if b and σ are given and when the ratio between ons and offs should be 1 to 3. This is the case when the extra radiator is turned on which contributes with 500 W of the desired 1000 W. The standard deviation for the room air temperature can be estimated to 0.05 °C. The mean deviations from the four experiments have also been estimated and are given in table 4.1.

Table 4.1

Computed and measured mean deviation in ^{0}C

Experiment	$m_{computed}$	$m_{measured}$
1	0.03	~0.0
2	0.26	~0.18
3	0.55	~0.30
4	0.74	~0.37

The figures in table 4.1 show that the computed and measured mean deviation increases with the weight of the derivative of the output.

The straightforward method of implementing the derivative can not be recommended. Instead some kind of filtering should be used.

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