# IDENTIFICATION OF DYNAMICAL PROPERTIES OF CENTRAL HEATING PIPES BURIED IN A FLOOR*


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The paper deals with the central heating supply pipes laid under the floor. The experiment was conducted in order to estimate the dynamical proprieties of the floor surface temperature above these pipes. As the result, the floor surface temperature profiles were measured and analysed.


## 1. INTRODUCTION

### 1.1 PIPING LAYOUTS

The typical piping layouts are:

1. manifold layout – each radiator possesses its own individual run (fig. 1),
2. layout with branch runs – there are tee joints under the floor (fig. 2),
3. mixed layout (combination layout) – there is a manifold with a series of runs, but the closely located radiators may be fed by one run with tee joints (fig. 3),
4. loop layout – the pipes are laid around the building in a loop, which feeds the radiator; there are one-pipe and two-pipe systems (fig. 4).

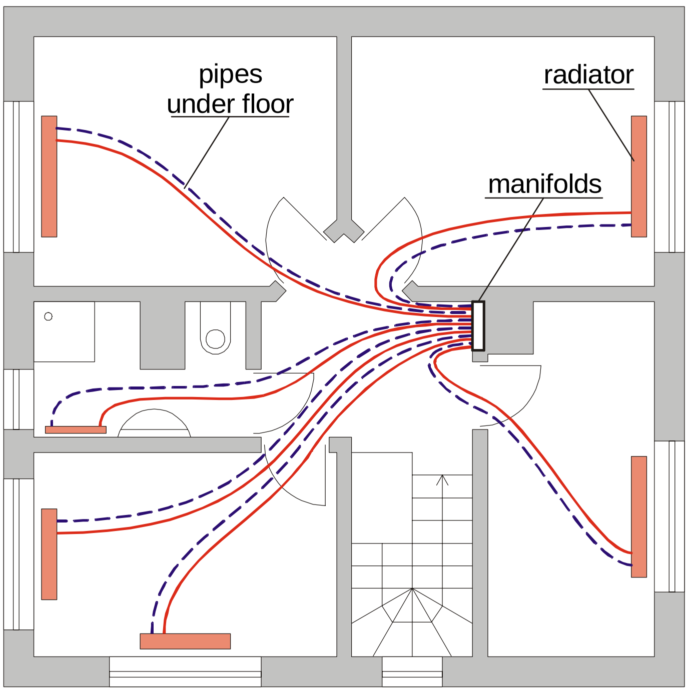


**Figure 1. Manifold layout (system with individual runs for each radiator).**

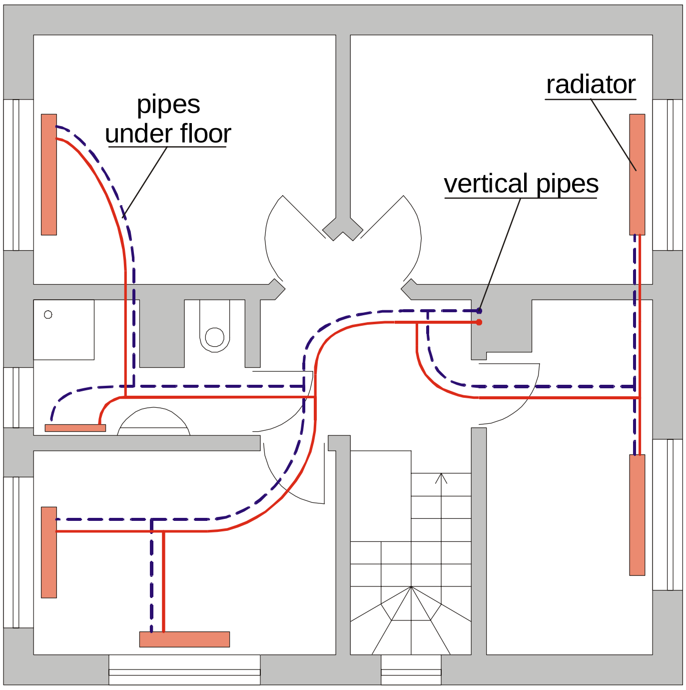


**Figure 2.** **Layout with branch runs and tee joints under the floor.**

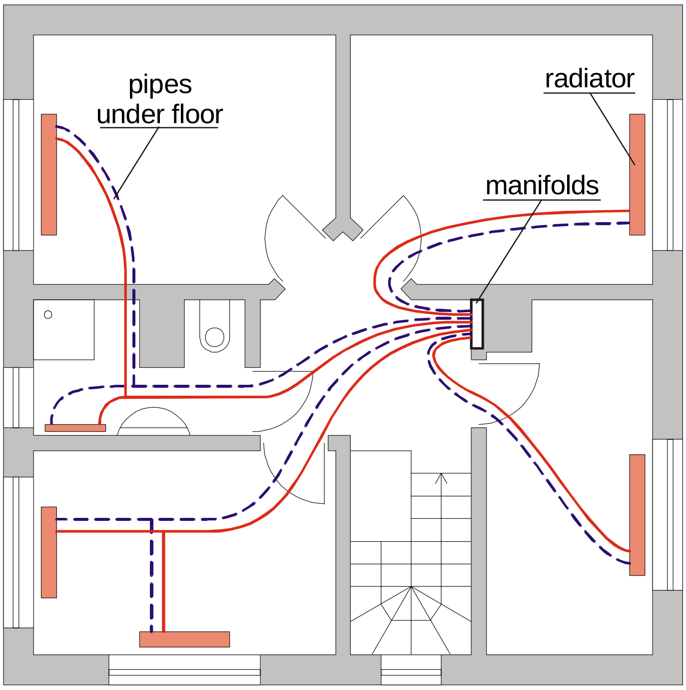


**Figure 3.** **Mixed layout (combination layout) with manifolds and tee joints.**

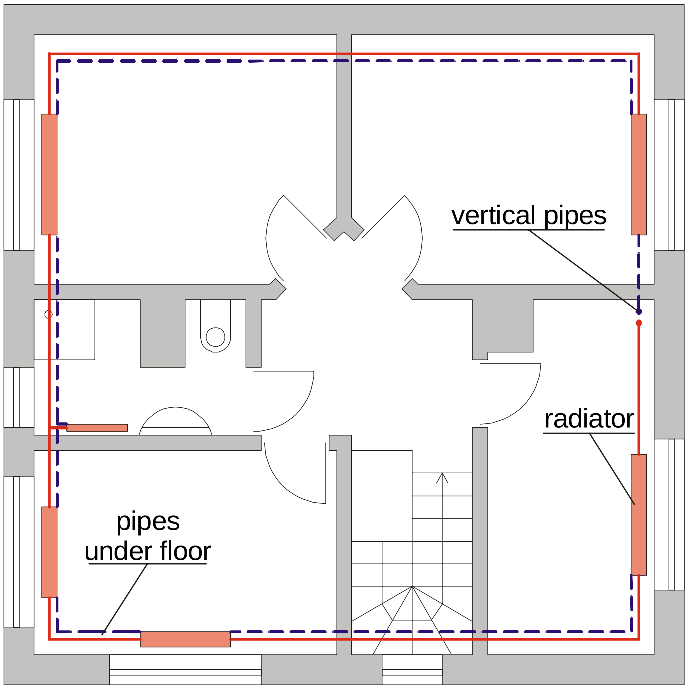


**Figure 4. Loop layout.**

The pipes may have an insulation layer around them, may be laid in a protective goffered pipe or may be put directly in concrete. Unless the pipes are well insulated, they may distribute large amounts of heat. Thus the heat is supplied to the rooms not only by the radiator, but also through the warm floor surface. The block diagram of such combined floor/radiator heating system is shown in figure 5.

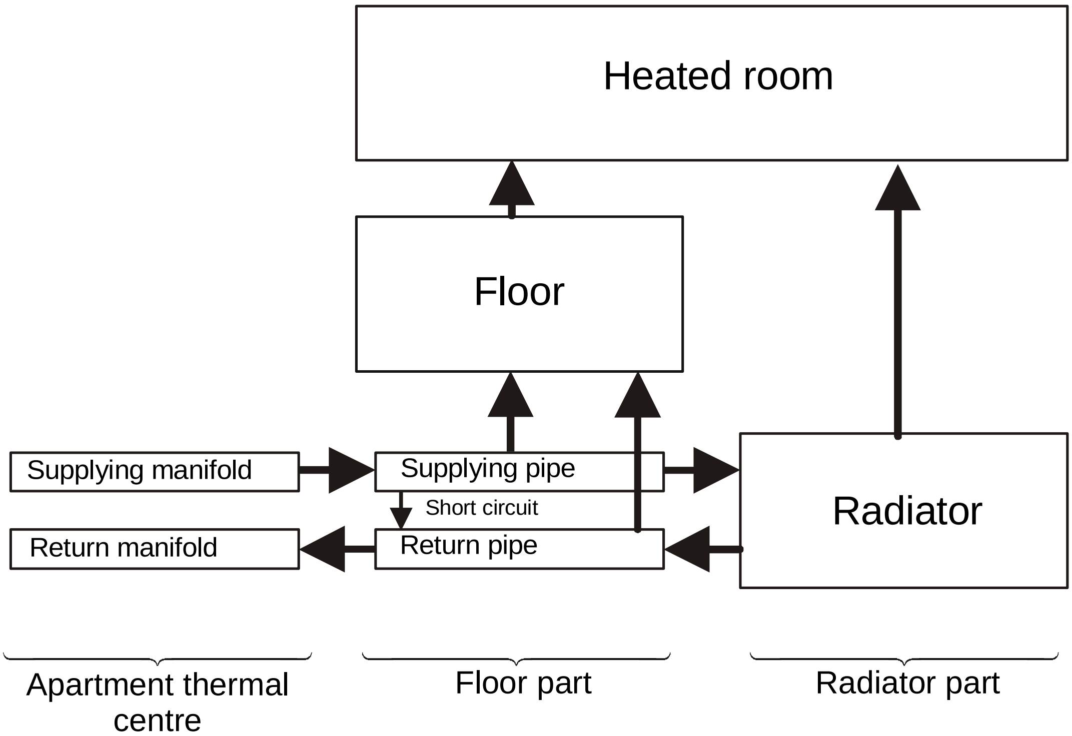


**Figure 5. Block diagram of combined floor/radiator heating system in case of a radiator supplied by a pair of pipes laid under the floor. Heat streams are marked as arrows. [1]**

The use of a protective goffered pipe limits the heat losses in some degree, but still large amount of heat may be supplied to the dwelling through the floor surface.

### 1.2 HEAT TRANSFER PHENOMENA OF THE SYSTEM

The dangerous phenomena which can arise when the pipes are laid under the floor are:

1. exceeding permissible floor surface temperature (29–33°C),
2. lower temperature of the supply water coming to the radiator than assumed in the design,
3. heat losses/gains to the adjacent dwellings,
4. “short circuit” between the supplying and return pipes with omission of the heated room.

As it is shown in figure 6, only a part of heat losses from the pipes is transferred to the *target room*, the room where the radiator fed by these pipes is installed. The large part of heat losses is transferred to other rooms in the same dwelling and also outside the dwelling. If this fact is not taken into account in the design process, it can lead to overheating of some rooms (especially the rooms with large number of pipes, like corridors and staircases) and not proper heating of other rooms.

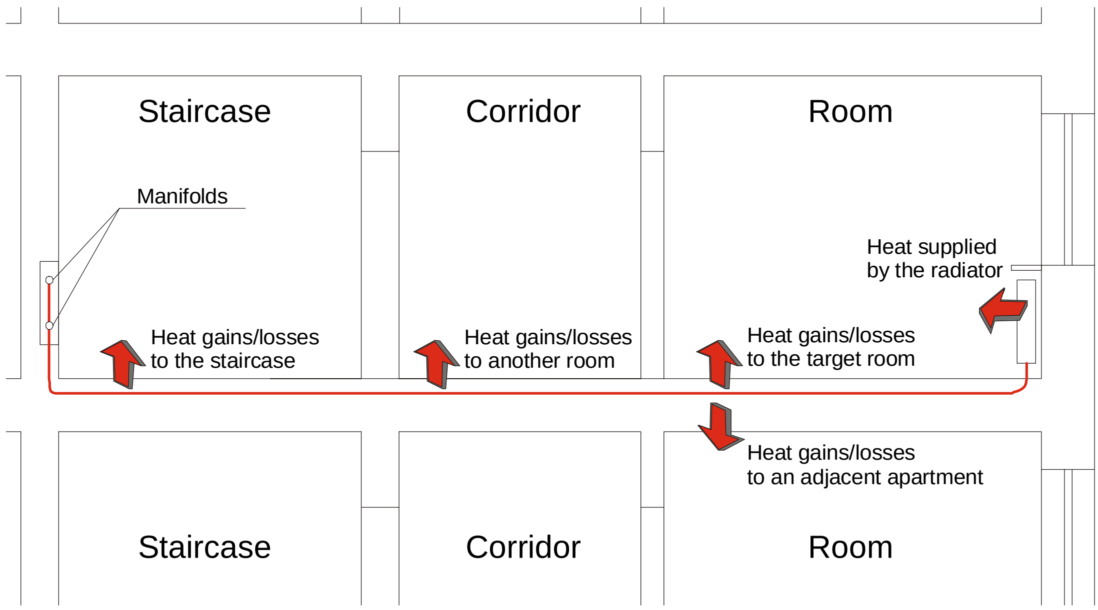


**Figure 6. Heat gains/losses in case of water pipes laid under the floor. Cross-section of a building [1].**

## 2. DESCRIPTION OF THE SYSTEM UNDER STUDY

The test installation was built in Environmental Engineering Faculty Building at Warsaw University of Technology. The floor structure is shown in figure 7 and table 1. The pipes were made of polyethylene and had the conductivity of 0.46 W/(m·K). The outer diameter of the pipes was 12.0 mm and the inner diameter – 8.4 mm. The distance between the pipes was 10 cm. The supply and return pipes were 6 m long each. The pipes were buried in concrete without any insulation layer around them (the insulating layer of foamed polystyrene was placed under the pipes). The thickness of the concrete layer was 10 cm.

The floor temperature was measured at the distance of 90 cm from the manifold. The measurement points were located in the distance of 10 cm between each other. As it is shown in figure 7, the point P4 was directly above the supply pipe and P3 – above the return pipe. The air temperature was measured on the level of one meter above the floor.

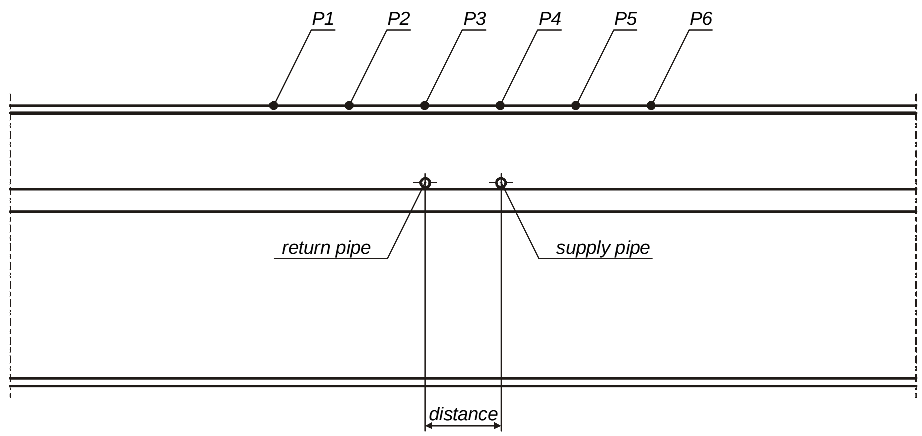


**Figure 7. Cross-section of  the floor.**

**Table 1. Floor structure.**

| No. | Layer | Thickness, m | Heat conductivity, W/(m·K) | Heat resistance, $m^2K/W$ |
|---|---|---|---|---|
| 1 | Tiles | 0.010 | 1.05 | 0.010 |
| 2 | Concrete | 0.100 | 1.00 | 0.100 |
| 3 | Foamed polystyrene | 0.030 | 0.040 | 0.750 |
| 4 | Beam-and-slab floor | 0.220 | – | 0.180 |
| 5 | Plaster work | 0.010 | 0.820 | 0.012 |

## 3. ANALYSIS OF THE EMPIRICAL DATA

### 3.1 FLOOR TEMPERATURE ABOVE THE PIPE (POINT P4)

The difference between the temperature of supply water reaching the manifold and air temperature in the room was considered as the input signal to the system, whereas floor temperature above the supply pipe (P4) as the output signal.

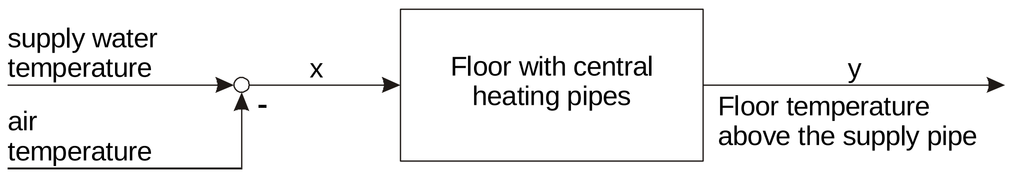


**Figure 8. Block diagram of the system.**

At the specific time the electric boiler was turned on with the setpoint of 43.5 ºC. After that, it took about 30 minutes for the water temperature to achieve the setpoint level. Therefore, the change cannot be considered as a step one. The aim of the experiment was to establish dynamical properties of the floor with the pipes independently from the boiler, that is why the numerical approximations were used to fit the experimental curves.

### 3.1.1 FIRST ORDER INERTIAL ELEMENT

The description of the dynamical properties of the system will be started with the application of the first order inertial element. The general differential equation for this element is:

$$T\frac{dy}{dt} + y = kx + y_o \qquad (1)$$

where:

$t$ – time,

$y(t)$ – output signal,

$x(t)$ – input signal,

$T$ – time constant,

$k$ – proportional gain,

$y_o$ – offset adjustment parameter.

The equation (1) can be transformed as follows:

$$T\frac{dy}{dt} + y = kx + y_o \qquad (2)$$

$$T\frac{dy}{dt} = kx + y_o - y \qquad (3)$$

$$\frac{dy}{dt} = \frac{kx + y_o - y}{T} \qquad (4)$$

$$dy = \frac{kx + y_o - y}{T}dt \qquad (5)$$

In order to enable numerical calculation the following approximation was done:

$$\Delta y = \frac{kx + y_o - y}{T}\Delta t \qquad (6)$$

Assuming following equations:

$$x = t_{\text{sup}} - t_{air} \qquad (7)$$

$$y_o = t_{air} \qquad (8)$$

finally the output signal at the specific time can be calculated approximately using the following formula:

$$y_i = y_{i-1} + \frac{k\left(t_{\text{sup},i} - t_{air,i}\right) + t_{air,i} - y_{i-1}}{T}\Delta t \qquad (9)$$

where:

$t_{\text{sup},i}$ – supply water temperature at the time $i$,

$t_{air,i}$ – air temperature at the time $i$.

The parameters $k$ and $T$ were found by curve fitting as follows:

$$k = 0.252 \text{ K/K},$$

$$T = 166.8 \text{ min.} \approx 3 \text{ h.}$$

The correlation coefficient of the curve fitting equals 0.9968. The curve fitting is presented graphically in fig. 9. Points marked as "P4" are results of floor temperature measurement above the supply pipe, whereas the line marked as "P4 (P-T1)" comes from calculation.

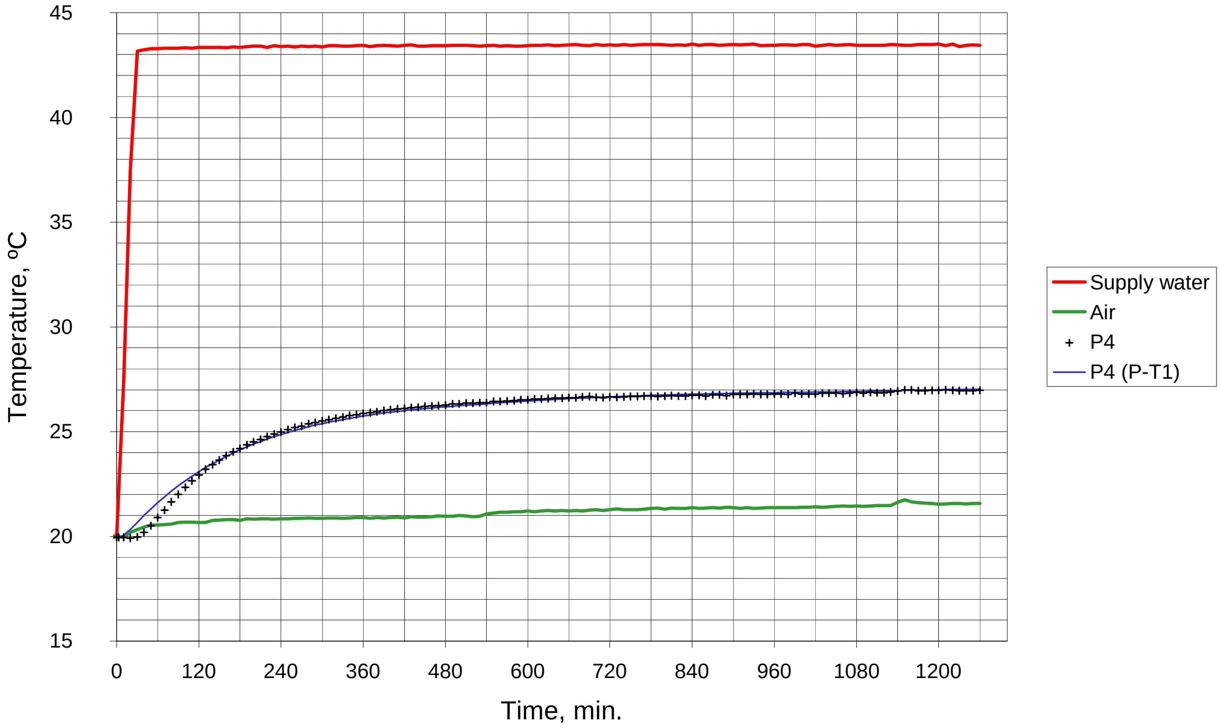


**Figure 9. Curve fitting for the floor temperature above the supply pipe by means of the first order inertial element**

### 3.1.2 FIRST ORDER INERTIAL ELEMENT WITH DEADTIME

Although the first order inertial element seems to be satisfactory to describe dynamical properties in this case, better results may be achieved by means of the first order inertial element with deadtime. The deadtime results from the water transport in pipes, and the time needed for the pipe material temperature change to reach the floor surface.

In this case the following formula was used:

$$y_i = y_{i-1} + \frac{k\left(t_{\sup,i-T_o} - t_{air,i-T_o}\right) + t_{air,i-T_o} - y_{i-1}}{T} \Delta t \qquad (10)$$

where:

$T_o$ – deadtime,

$t_{\sup,i-T_o}$ – supply water temperature $T_o$ minutes before,

$t_{air,i-T_o}$ – air temperature $T_o$ minutes before.

The parameters of the curve were found as follows:

$$k = 0.250 \text{ K/K},$$

$$T = 152.9 \text{ min.} \approx 2.5 \text{ h},$$

$$T_o = 30.0 \text{ min.} = 0.5 \text{ h}.$$

The correlation coefficient of the curve fitting in this case is higher and equals 0.9988. The comparison of the curve fitting with and without deadtime is shown in fig. 10.

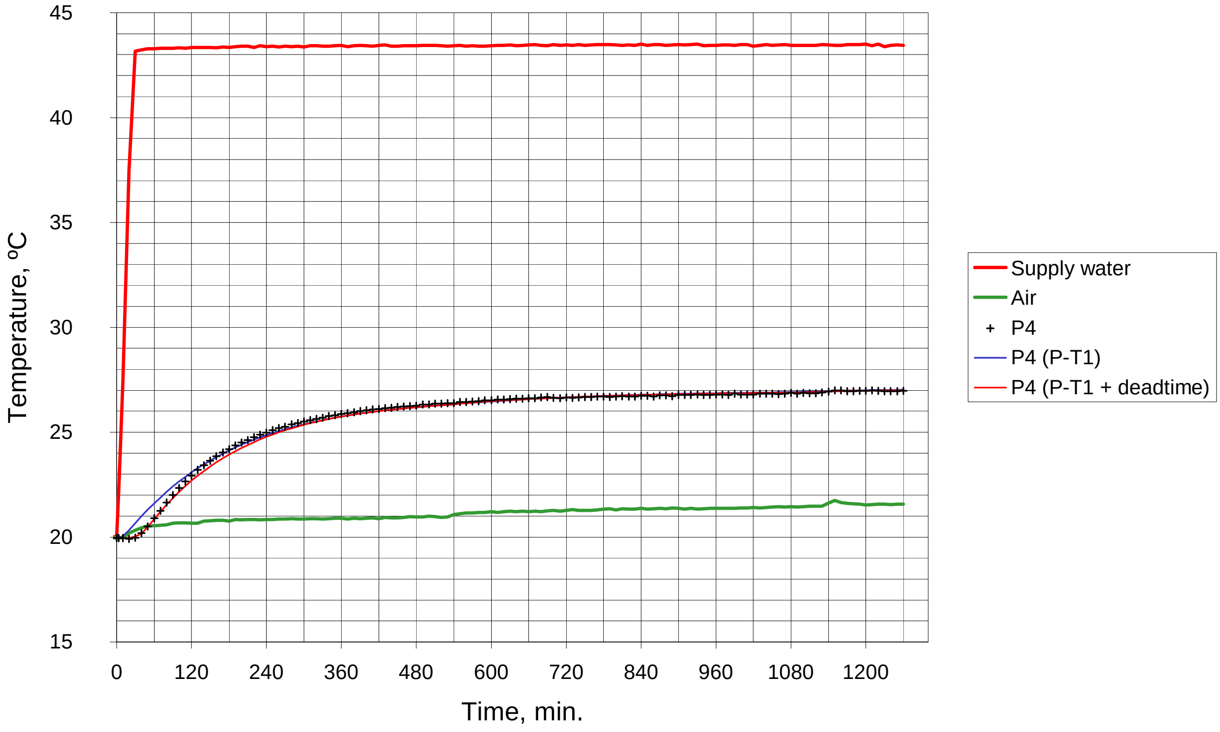


**Figure 10. Comparison of the curve fitting for the floor temperature above the supply pipe by means of the first order inertial element with and without deadtime.**

### 3.2 FLOOR TEMPERATURE AT OTHER POINTS

The time constant, deadtime and proportional gain were found for other points in a similar way. The results are shown in table 2. The location of the measurement points is shown in figure 7.

Generally, the inertia of the system is very high. Not only the values of the time constant are high (2.5–5.5 h), but also the significant deadtime (0.5–1.5 h) occurs, when no response of the system is observed.

The values of the time constant and the deadtime are higher for the points more distant from the pipes.

**Table 2. Parameters of the first order inertial element with deadtime for different points on the floor.**

| Point | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|
| $k$, K/K | 0.0758 | 0.1427 | 0.2129 | 0.2502 | 0.1488 | 0.0571 |
| $T_o$, min. | 100 | 60 | 40 | 30 | 60 | 90 |
| $T$, min. | 327 | 223 | 148 | 153 | 185 | 229 |
| Correl. coef. | 0.9993 | 0.9996 | 0.9999 | 0.9988 | 0.9997 | 0.9971 |

### 3.3 THE TEMPERATURE PROFILES ON THE SURFACE OF THE FLOOR

The hourly temperature profiles on the surface of the floor are presented in figure 11. It takes considerably less time to achieve the steady-state conditions for the area directly above the pipes than for the more distant area (basing on table 2 and figure 11). In the presented case it took about 12 hours for the area above the pipes to achieve the steady-state conditions, whereas it took about 20 hours for the points situated 20 cm away from the pipes.

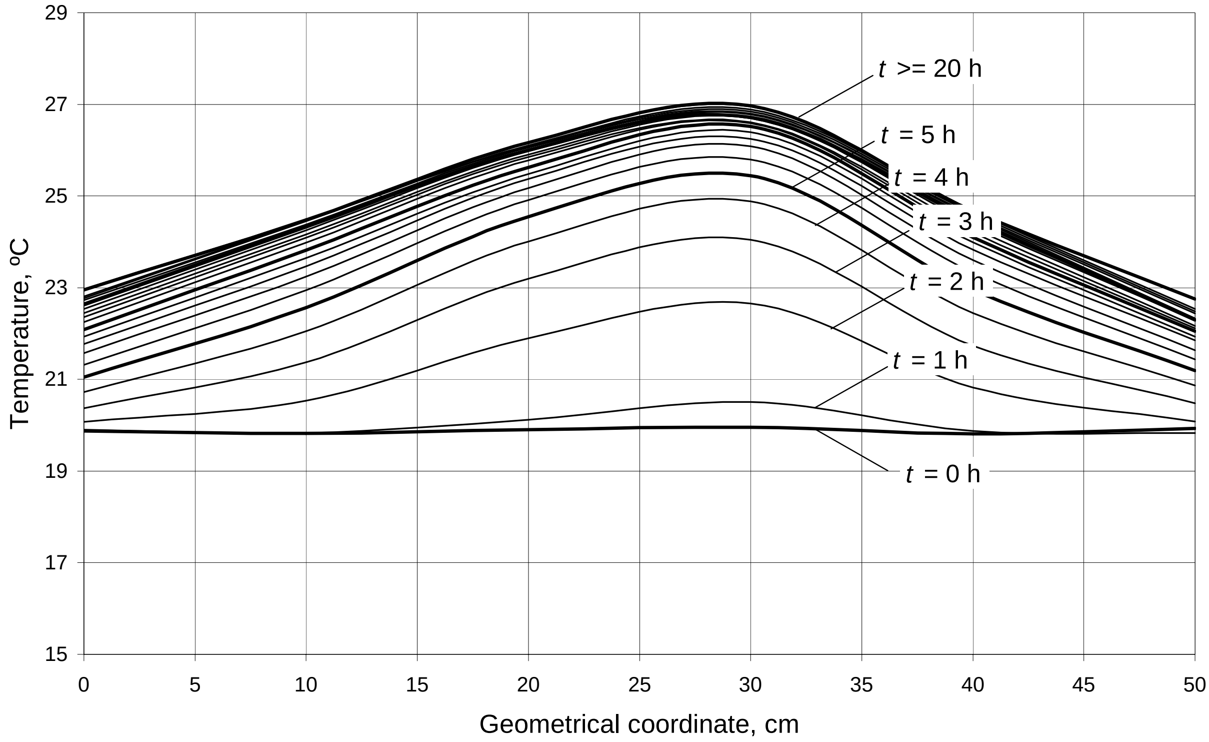


**Figure 11. The temperature profiles on the surface of the floor on the cross-section perpendicular to the pipes.**

### 4. CONCLUSIONS

The inertia of the floor with central heating pipes buried in is very high. The time constant for the examined case was estimated between 2.5 h and 5.5 h. The deadtime of 0.5 to 1.5 h was also identified, when no response of the system was observed. The values of the time constant and the deadtime are higher for the points more distant from the water pipes.

Unless the pipes are well insulated, they may disperse the large amount of heat. Some of this heat will come to the *target room* – where the radiator supplied by these pipes is located – but the large part of the heat will be transferred to the other rooms in the same dwelling or to the rooms in another dwelling.

The radiators are normally equipped with the thermostatic (or sometimes manual) valves. But even after shutting the valve, the heat will be supplied to the room for a long time. As the result of that controllability of the heating system becomes more difficult and the energy cost will be higher. One can say that the heat will be supplied not to the right place (e.g. overheating of corridors) and also not necessarily in the right time (after closing the valve).

Therefore, it is highly advisable that the pipes buried in a floor are well insulated rather than laid only in a protective pipe or directly in concrete.

### 5. REFERENCES


1. Strzeszewski M.: *Low-Temperature Combined Floor/Radiator Heating Systems*, Proceedings of International Conference Sustainable Building 2002, Oslo, Norway, September 23-25, 2002. (http://www.is.pw.edu.pl/~michal_strzeszewski/articles/oslo2002_low.pdf)