Simulation and calculation of temperature fields PIR detector

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Abstract: Work solves function of the PIR detector located in an environment where there are thermal sources with a surface temperature that is close to human body temperature. There simulating and calculating thermal behavior of the sensor in COMSOL Multiphysics and the Maple in environment with terms of different types of heating rooms in order to show that the detector can operate on as a passive type detector, but as an active type detector, where the heating works as a transmitter of heat radiation and own detector as its receiver. In this case, the detector is able to detect objects that are for the standard type masked or hidden.

Key-Words: - PIR detector, simulation, temperature fields, temperature radiation, heating sensor

1 Introduction

This paper deals with the function of the passive PIR detector that can function as an active detector under certain conditions, which enhance its possibilities in terms for detecting intruders, who could successfully mask under normal circumstances and they would become invisible for the detector.

2 Principle of the PIR detector

The principle of the PIR detector is shown in Fig. 1. The detector consists of pyroelement 1 which is receiving radiation from an intruder. This radiation passes through the filter 2, which suppresses radiation of wavelength less than 8 micron and greater than 12 micron and is therefore permeable for the 8 to 12 microns with a maximum of 10 microns wavelength, which corresponds to the temperature of the intruder, i.e. about 37 ° C. Infrared optics detector 3 performs the concentration of thermal radiation on pyroelement while creating segments 4, wherein the detector "see" and "not see". If intruder moves tangentially 5 over these areas, this leads to intermittent radiation after passing through the filter to generate pyroelement charge whose magnitude is measured after signal processing 6 and then the signal is sent as an alarm message on I&HAS security.

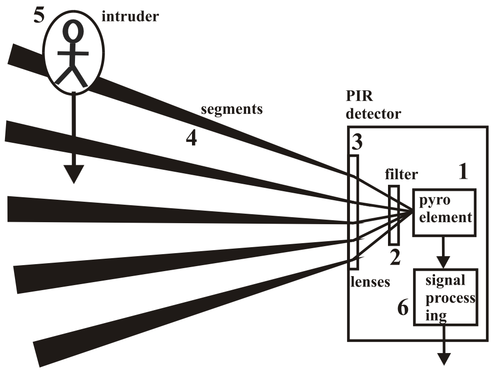


Fig. 1 Principle of PIR detector

3 Principle of active function of the PIR detector

The main function of the PIR detector is relatively easy to disrupt such a way that object (intruder) does not transmit thermal radiation. This can be relatively easily realized as an intruder uses curtain that hides the intruder in the direction of the PIR detector. In Fig. 2 are shown infrared images of various materials for the intruder masking. On left side is a man dressed in neoprene, in middle in winter clothes and on the right man disguised in an insulated liner.

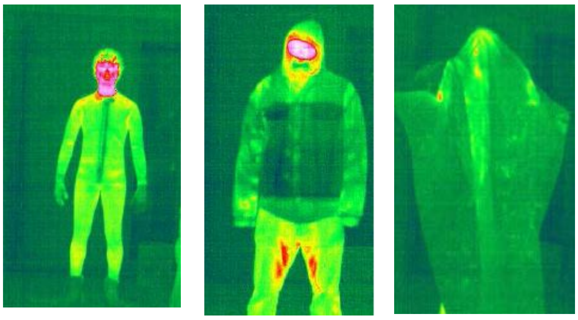


Fig. 2 Masked intruder dressed in neoprene, winter clothing and isothermal foil

Fig. 3 shows the principle of active PIR detector. A source of thermal radiation is in the background. It transmits radiation in the range of 10 µm wavelength. If the masked intruder moves in front of this background, there is a change of the heat flux from the background so that it obscures the individual segments, which quality PIR detector measures as a change of the incident radiation and activates the alarm condition.

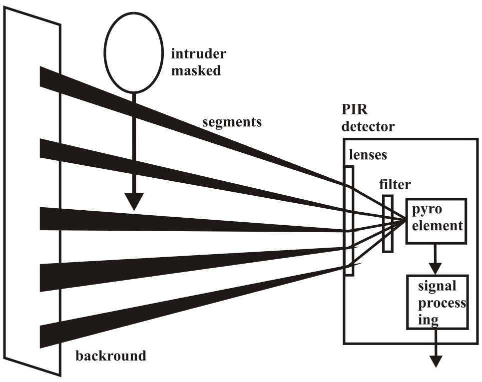


Fig. 3 Principle of active PIR detector

4 Mathematical model of heating sensor by radiation

Thermal radiation incident on the sensor is partially reflected and partially absorbed by the sensor, thereby to ensure that the temperature measured at the beginning of the measurement does not fully effective temperature.

We used the Stefan-Boltzmann law for the quantitative description of the temperature distribution in the pyroelement inside the detector, which is heated by radiation. According to Stefan-Boltzmann law, the density of heat flux between the source and the heated surface is expressed as (1) [3]:

$$q(\tau) = \sigma.C(T_2^4 - T_1^4) \qquad (1)$$

where:

σ - Stefan-Boltzmann constant,

$\sigma = 5.67.10^{-8}$ W m^{-2} K^{-4}

C – constant which characterizes emission surface and geometric properties, [1]

T2 – source temperature, [K]

T1 – temperature of heated surface, in this case the surface temperature, [K] .

Mathematical model of the sensor (pyroelement) heating can be described by equations (2) – (5):

$$\frac{\partial T}{\partial \tau} = a.\frac{\partial^2 T}{\partial x^2}\,,\ (0 \le x \le b, 0 < \tau) \qquad (2)$$

$$\left(\frac{\partial T}{\partial x}\right)_{x=0} = 0 \qquad (3)$$

$$\lambda\left(\frac{\partial T}{\partial x}\right)_{x=b} = q \qquad (4)$$

$$T = T_p \ \text{for}\ \tau = 0 \qquad (5)$$

where:

b - half thickness of the sensor, [m]

x - direction coordinate, [m].

Analytical solution of non-stationary temperature field for sensor plate shape symmetrically heated by radiation has been obtained by Laplace transform as:

$$\frac{T - T_p}{T_c - T_p} = K_i\left[Fo + \frac{1}{2}\left(\frac{x}{b}\right)^2 - \frac{1}{6} - 2\sum_{n=1}^{\infty}\frac{\cos\left(\frac{x}{b}p_n\right)}{p_n^2\cos(p_n)}e^{(-Fop_n^2)}\right] \qquad (6)$$

where *Ki* is Kirpičev criterion (7)

$$K_i = \frac{qb}{\lambda(T_c - T_p)} \quad (7)$$

Tc is medium temperature of radiators.

Fourier criterion *Fo* represents the dimensionless heating time which can be calculated according to equation:

$$Fo = \frac{a\tau}{b^2} \quad (8)$$

where:

τ - time of heating, [s]

a - thermal diffusivity of sensor, [$m^2.s^{-1}$]

The thermal diffusivity is given by equation:

$$a = \frac{\lambda}{\rho c_p} \quad (9)$$

where:

λ - the thermal conductivity of sensor, [$W.m^{-1}.K^{-1}$]

ρ - the density of the sensor material, [$kg.m^{-3}$]

c_p - the specific heat capacity of the sensor material,

[$J.kg^{-1}.K^{-1}$].

Members *p* of the analytical solution of (6) are determined from equation (10):

$$p_n = n \cdot \pi \quad (10)$$

According to the solution (6) it is evident that with increasing time of heating, the influence of endless series elements decreases, i.e., we can also expect Fourier criterion *Fo* for which influence endless series may be neglected and for $Fo > Fo_k$ the temperature at any point in the wall is almost linear function of time and temperature profile across the pyroelement (in *x*-axis direction).

5 Simulations in Comsol Multiphysics

The aim of simulations was to compare the incident heat radiation to the surface of pyroelement, if the intruder was in the room, or not. It was considered for both heated and unheated room, with vertical or floor heater.

Fig. 4 shows room with an unheated vertical heating. Fig. 4a depicts the layout position of the heater, pyroelement and intruder. Fig. 4b shows the distribution of incident heat flux to the surface pyroelement and in Fig. 4c is seen course of the heat flux in vertical section of the pyroelement.

Fig. 5 shows the same situation as in Fig. 4 for the heated room.

Fig. 6 shows the results of simulations for an unheated room with underfloor heating, where in Fig. 6a is drawing position of underfloor heating, pyroelement and intruder inside the room. Fig. 6b depicts the distribution of incident heat flux to the surface of pyroelement and in Fig. 6c is shown course of the heat flux in a vertical section of the pyroelement.

Fig. 7 shows the same situation as Fig. 6 for room heated by underfloor heating.

The table 1 shows a summary of the simulation results which are shown in Figs. 4 – 7. The column 2 of the Table1 gives the values of the heat flux in the middle of pyroelement that corresponds to a minimum simulated value.

In the presence of intruder before heater, the heat flux incident on a surface of pyroelement decreased about a significant value which the PIR detector is able to measure.

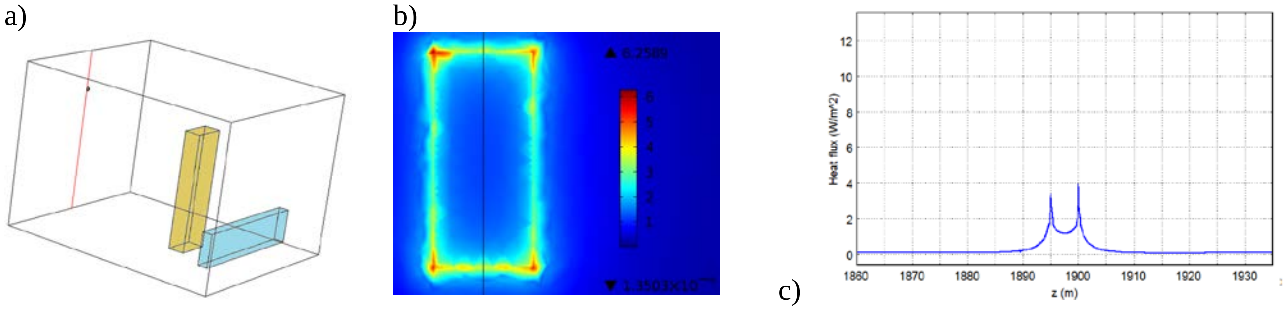
Tab. 1 Minimum values of the heat flux on the surface of pyroelement determined by computer simulations

Vertical heating	
Unheated room without intruder	3.7 W/m^2
Unheated room with intruder	1.3 W/m^2
Heated room without intruder	21 W/m^2
Heated room with intruder	6 W/m^2
Floor heating	
Unheated room without intruder	4.2 W/m^2
Unheated room with intruder	3.75 W/m^2
Heated room without intruder	27 W/m^2
Heated room with intruder	20 W/m^2

Vertical heater - unheated room: air temperature 7 ° C, the heating temperature 5 ° C

Room with intruder

a) b) c)



Room without intruder

a) b) c)

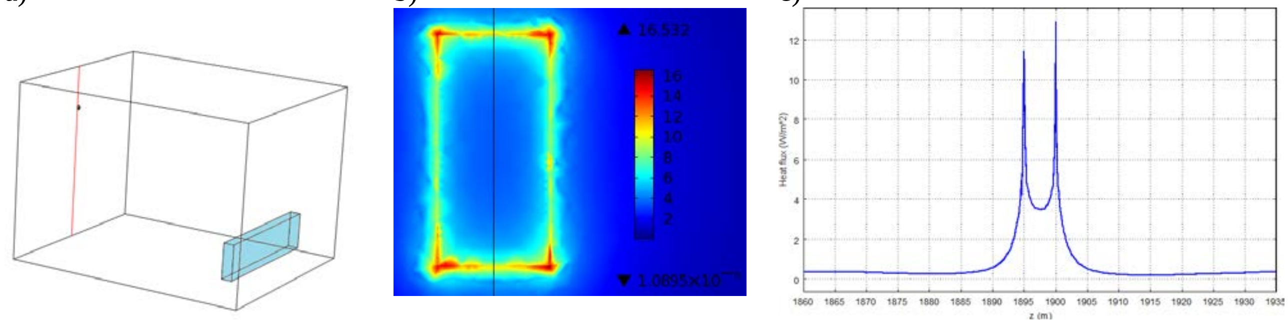
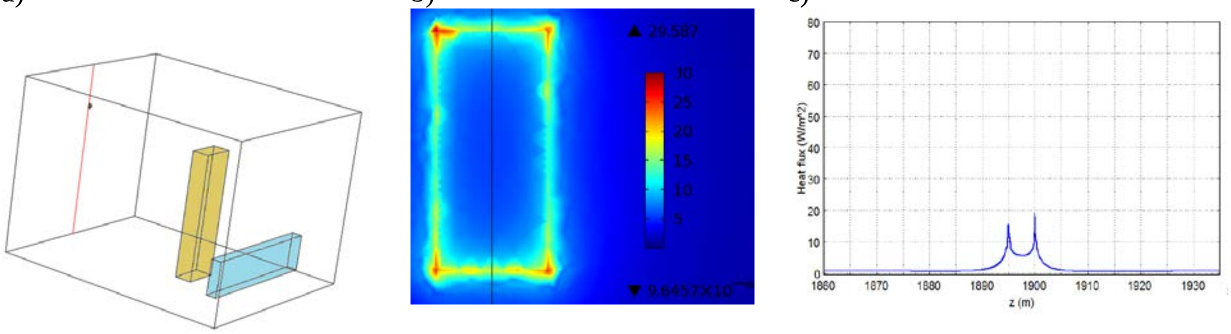


Fig. 4 Simulation of heat flux on the surface of pyroelement for unheated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

Vertical heater - heated room: air temperature 24 ° C, heating temperature 37 ° C

Room with intruder

a) b) c)



Room without intruder

a) b) c)

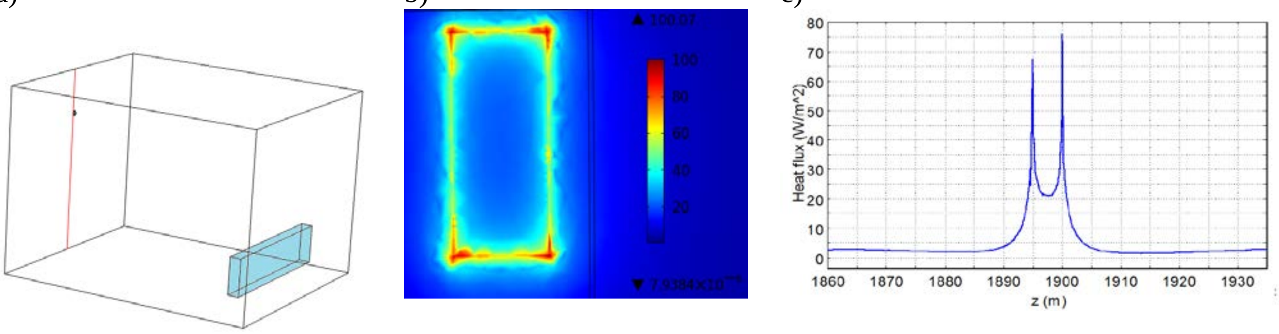
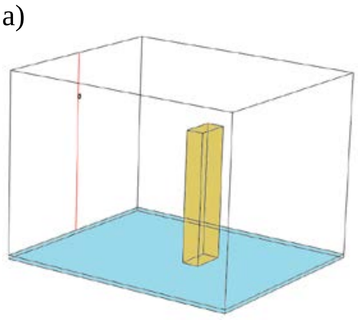


Fig. 5 Simulation of heat flux on the surface of pyroelement for heated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

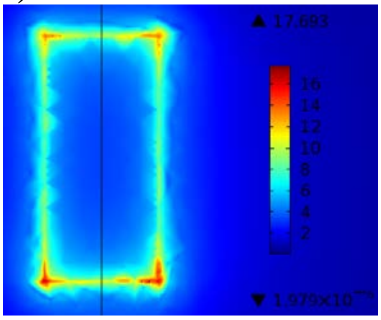
Floor heating - unheated room: air temperature 7 ° C, the heating temperature 5 ° C

Room with intruder

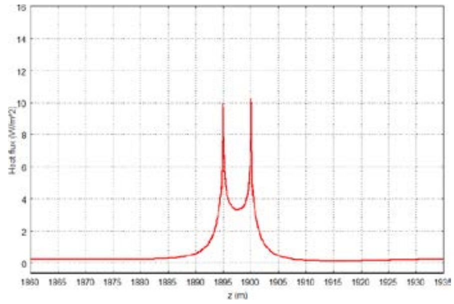
a)



b)

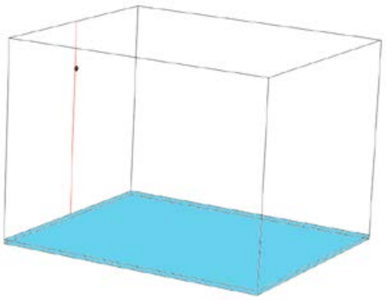


c)



Room without intruder

a)



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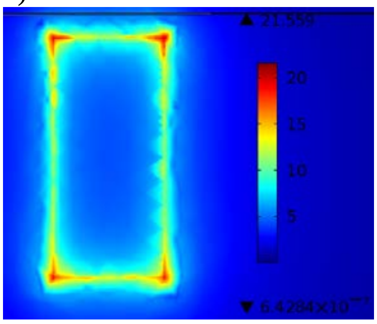

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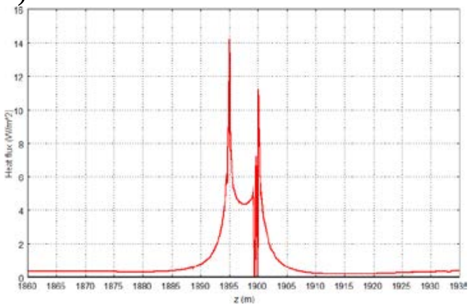
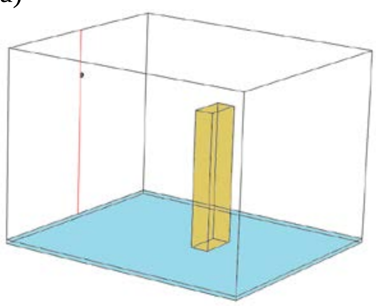


Fig. 6 Simulation of heat flux on the surface of pyroelement for unheated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

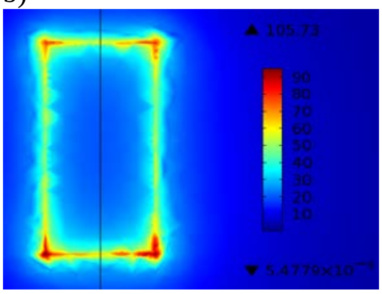
Floor heating - heated room: air temperature 24 ° C, heating temperature 37 ° C

Room with intruder

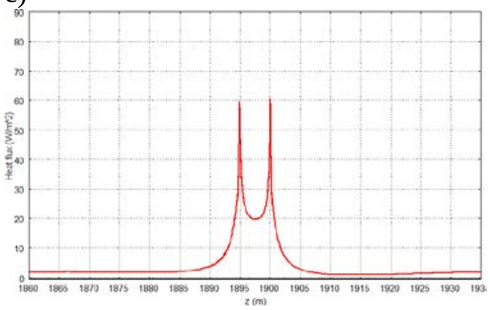
a)



b)

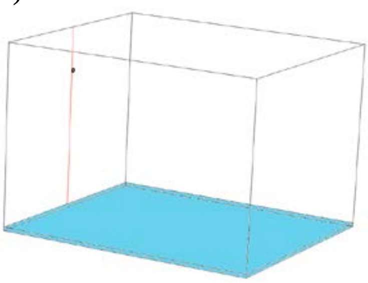


c)



Room without intruder

a)



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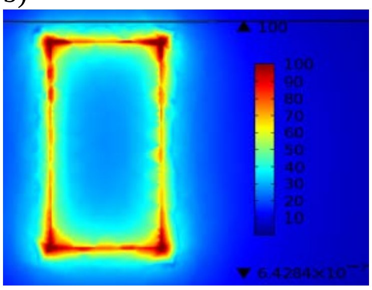

c)

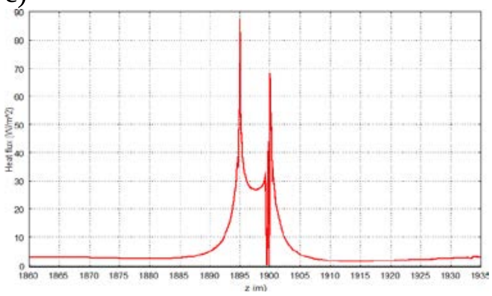

Fig. 7 Simulation of heat flux on the surface of pyroelement for heated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

6 The calculation of temperature fields in pyroelement

The next section will be a calculation of temperature fields of pyroelement when heating due to the presence of intruders. As mentioned in the previous section, due to the presence of an intruder in the room will increase the heat flux incident on a surface pyroelement and thus to its heating. In these Figures 8 to 11 shows the progress of heating for 30 seconds in a room with both vertical and underfloor heating. In Table 2 shows the temperature differences pyroelement surface relative to its intended initial temperature. Calculations were made by Maple analytical solution described by equation (6) in Chapter 4.

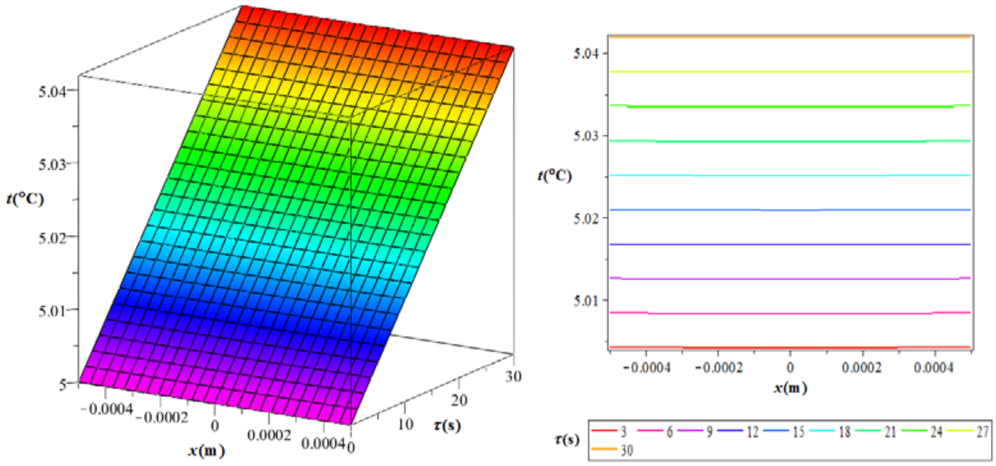

Fig. 8 Pyroelement course of heating in an unheated room with intruder (room with vertical heating). 3D temperature distribution pyroelement (left), 2D temperature field at selected times of heating.

Parameters: the initial temperature pyroelement 5 °C, the temperature of the source (intruder) 37 °C, density of heat flux incident on a surface pyroelement 1.3 $W.m^{-2}$ pyroelement thickness 1 mm, thermal conductivity pyroelementu $2.5.10^{-6}$ $m^2.s^{-1}$.

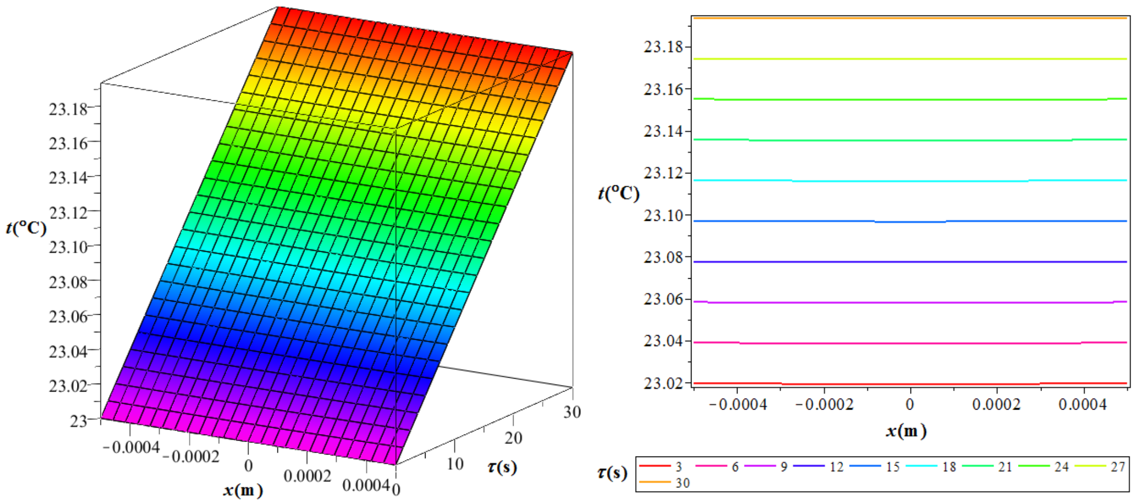

Fig. 9 Pyroelement course of the heating element in heated room with intruder (room with with vertical heating).

Parameters: the initial temperature pyroelement 23 °C, the temperature of the source (intruder) 37 °C, density of heat flux incident on a surface pyroelement 6 W.m^{-2} pyroelement thickness 1 mm, thermal conductivity pyroelementu 2.5.10^{-6} m^2.s^{-1}.

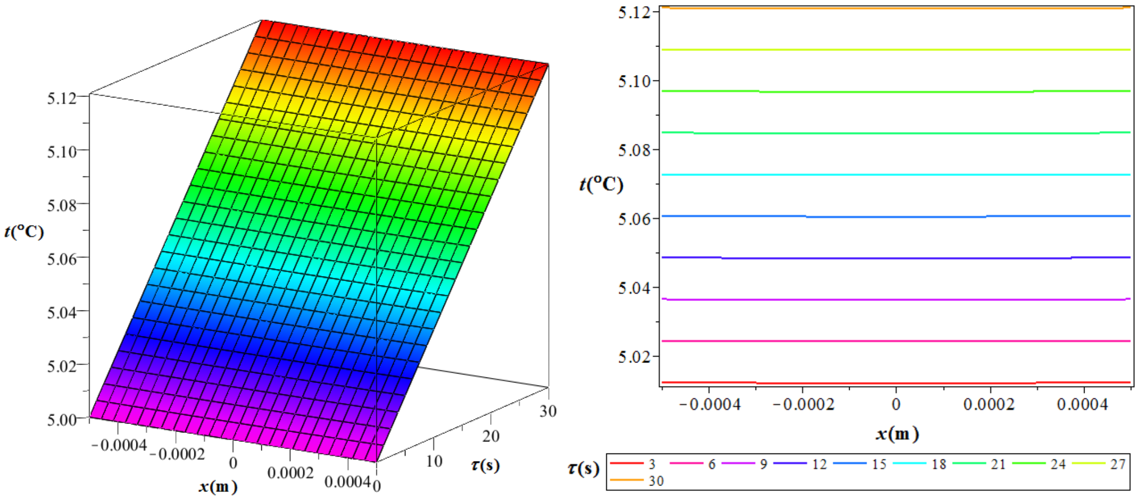

Fig. 10 Pyroelement course of the heating element in an unheated room with intruder (room with underfloor heating).

Parameters: the initial temperature pyroelement 5 °C, the temperature of the source (intruder) 37 °C, density of heat flux incident on a surface pyroelement 3.75 W.m^{-2} pyroelement thickness 1 mm, thermal conductivity pyroelement 2.5.10^{-6} m^2.s^{-1}.

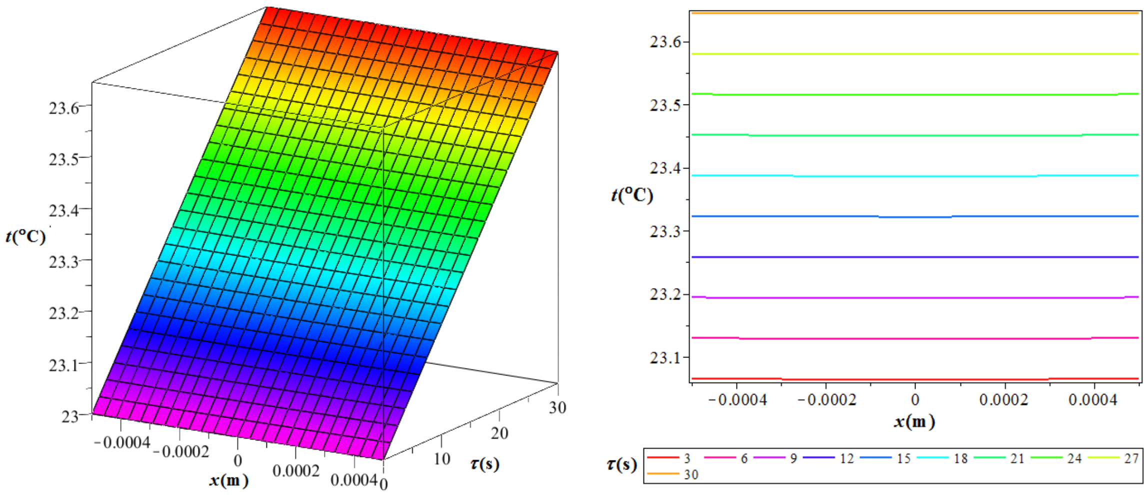

Fig. 11 Pyroelement course of the heating element in heated room with intruder (room with underfloor heating).

Parameters: the initial temperature pyroelement 23 °C, the temperature of the source (intruder) 37 °C, density of heat flux incident on a surface pyroelement 20 W.m^{-2} pyroelement thickness 1 mm, thermal conductivity pyroelement 2.5.10^{-6} m^2.s^{-1}.

Tab. 2 The temperature increase of surface pyroelement due to the presence intruder in the room.místnosti.

Time presence of an intruder:	**3 s**	**15 s**	**30 s**
Unheated room with intruder (room with vertical heating)	0.004 °C	0.021 °C	0.043 °C
Heated room with intruder (room with vertical heating)	0.020 °C	0.098 °C	0.195 °C
Unheated room with intruder (room with underfloor heating)	0.010 °C	0.061 °C	0.121 °C
Heated room with intruder (room with underfloor heating)	0.060 °C	0.330 °C	0.650 °C

7 Conclusion

From previous results it is evident that the fastest rise in temperature occurred in the heated room with floor heating due to the largest quantity of incident heat radiation surface pyroelementu. By contrast, the smallest increase in temperature was observed in unheated rooms with vertical heating. Overall, using the source of thermal radiation, in this case, heating can detect an intruder and PIR detector becomes active detector which is able to detect intruders even disguised.

Acknowledgments
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