DOI 10.36622/VSTU.2020.48.4.004
UDC 614.841.34

S. V. Fedosov[1], A. A. Lazarev[2], M. V. Toropova[3], V. G. Malichenko[4]

EQUATIONS FOR THE OPERATING TEMPERATURE OF THERMOSENSITIVE ELEMENTS OF FIRE DETECTORS EMBEDDED IN A CONCRETE BLOCK

Moscow State University of Civil Engineering (National Research University) (MGSU) [1]
Russia, Moscow
Volga State University of Technology[1]
Russia, Yoshkar-Ola
Ivanovo Fire and Rescue Academy of the State Fire Service of the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters[2]
Russia, Ivanovo
Ivanovo State Politechnical University[3, 4]
Russian Federation, Ivanovo

[1]*Academician of RAASN, Honored worker of Science of the Russian Federation, Laureate of the Russian Government Prize in Science and Technology, Honorary Builder of Russia, Laureate of the State Prize of the Republic of Mari El in the Field of Architecture and Construction, D. Sc. in Engineering, Prof. of the Dept. of Technology of Binders and Concrete, e-mail*: *FedosovSV@mgsu.ru*
[2]*PhD in Education, Assoc. Prof. of the Dept. of Supervision and Examination of Fires, e-mail: kgn@edufire37.ru*
[3]*PhD in Engineering, Assoc. Prof. of the Dept. of Natural Sciences and Technosphere Safety, e-mail:mators@mail.ru*
[4]*PhD student of the Dept. of Natural Sciences and Technosphere Safety, e-mail: mvg84@bk.ru*

Statement of the problem. Solving the problem of giving the properties of a building structure to detect fires outside buildings is one of the ways to prevent the transition of fire from one building to another. Embedding of fire automation equipment in construction products should be carried out after making the appropriate calculations. The absence of an expression for determining the temperature of the heat-sensitive element of a fire detector inside a concrete block requires detailed calculations. At the same time, it is necessary to study the influence of the distance to the object of a possible fire, the size of the heat-sensitive element, and the heat flow on the time of fire detection by a construction product included in the smart home system.

Results. As part of the temperature measurement of heat-sensitive elements of fire detectors inside the concrete block, empirical data were obtained. This information allows us to describe the radiant heat exchange at an early stage of a fire. This is typical of open burning outdoors.

Conclusions. Approximate equations are obtained for determining the temperature and response time of a fire detector inside a concrete block at the initial stage of a fire, depending on the distance to the fire object (radiation source), heat flow, and the size of the thermosensitive element. These values can be determined with sufficient accuracy.

Keywords: smart house, sensors, networking, fire detector, fire safety.

Introduction. Over 10 thousand fires break out in Russia annually causing a massive destruction. This is largely due to the transfer of smoke during a fire to adjoining buildings [5]. Over

600 people die in such fires in Russia every year. However, there are practically no technical tools available for detecting such fires, as the existing fire detectors are designed to protect facilities. For them to be placed on the outside of the building, appropriate adaptation is required. One of the options would be to place a fire detector inside a concrete block. The places of installation of these concrete blocks with fire detectors in them [6, 9] must be determined by means of calculation. This is due to the lack of regulatory requirements for this kind of building products, as they are located outdoors. A special role is played by the time when the temperature-sensitive element of the fire detector heats up to a temperature of 54 °C. Heating above the specified value leads to the fire detector generating a "fire" alarm. Such alarms can be monitored by the "smart home" system [11—15, 17—22]. These contribute to the relevance of the study, which is in the contradiction between the need for formulas for identifying where new tools for detecting fire and should or should not be located. The objective of the study is to identify the formulas showing the dependence of the distance to the object of a possible fire, the size of the thermosensitive element, the heat flux at the time of fire detection by a building product included in the "smart home" system.

In this case, the "smart home" system manages fire safety not only inside the building, but also outside it. In separate facilities of enterprises and institutions, it is easy to implement measures to ensure that in the event of a fire, all staff members know the procedure and there are trained individuals who are able to lead a volunteer fire brigade if necessary. In residential areas, particularly in cases of frequent change of tenants, this is a lot more challenging. Hence it is important that the owners and management companies establish a fire safety strategy and ensure that there is always a team of responsible individuals on duty to take full control of the situation in the event of a fire.

This function can be performed by appropriately trained personnel involved in day-to-day safety responsibilities. It is also important that a complete re-cord of the operation of the fire detection, fire alarm and fire extinguishing systems is maintained, so that a complete inspection of any location is performed to prevent the adoption of any measures that would lead to the inoperability of any part of these systems. It is crucial that in cases where the concept of an engineering design for buildings has been approved and adopted, the measures contained in this design are always complied with. At the same time, financial needs cannot compromise fire safety.

The temperature of the thermosensitive element corresponding to the issuance of the "fire" alarm must be reached in a time interval of up to 600 sec, since, a fire commonly develops at a rapid rate during this period of time. It is important to know this value both while designing and installing a building product.

1. Equation of radiant heat transfer between bodies. This equation according to the formula (1) [3, 4] could become the foundation for such a calculation:

$$g_p = 5.7\varepsilon_{np}\left[\left(\frac{T_{\phi}}{100}\right)^4 - \left(\frac{T_{c\theta}}{100}\right)^4\right]\varphi_{1\phi}, \quad (1)$$

where 5,7 is the blackbody emissivity, Watt·m^{-2}·K^{-4}; ε_{np} is the reduced emissivity of the system identified by means of calculation using the formula (2) [4];

$$\varepsilon_{np} = \left(\frac{1}{\varepsilon_{\phi}} + \frac{1}{\varepsilon_{\theta}} - 1\right), \quad (2)$$

where ε_{ϕ} is the degree of blackness of the torch (when burning a tree it is 0.7); ε_{θ} is the degree of blackness of the irradiated substance as identified in reference literature [4]; T_{ϕ} is the temperature of the flame torch, К, for wood and wood products, the average value is taken to be 1300 K based on [4] $T_{c\theta}$ is the combustible temperature, К; $\varphi_{1\phi}$ is the irradiance coefficient between the radiating and irradiated surfaces.

At the same time, this equation (1) does not consider the location of a thin lens or glass between bodies carrying out radiant heat transfer. Thus while using this equation (1) to identify the temperature of the temperature-sensitive elements of fire detectors built into concrete blocks, a significant error may occur.

2. Measurement of temperature values of temperature-sensitive elements of fire detectors built into concrete blocks. Measurements are performed by means of a pyrometer through a technological hole in a concrete block. The measurement results at a distance of 20 cm, 30 cm, 40 cm from a thin lens with an optical power of 20 Diopters to a 2000 Watt IR source are shown in Fig. 1.

Fig. 1 that the dependence Φ = f (B) has a polynomial (parabolic) character. As a result of the approximation, the following equations were obtained:

$$\Phi_{1.1}(B) = 3.07B - 0.15B^2 + 41.8, \quad (3)$$

where B is the time of exposure to IR radiation on a black thermosensitive element (hereinafter in formulas (4)—(10)), min

$$\Phi_{1.2}(B) = 3.5B - 0.18B^2 + 39.4, \quad (4)$$

$$\Phi_{1.3}(B) = 1.43B - 0.07B^2 + 35.9. \quad (5)$$

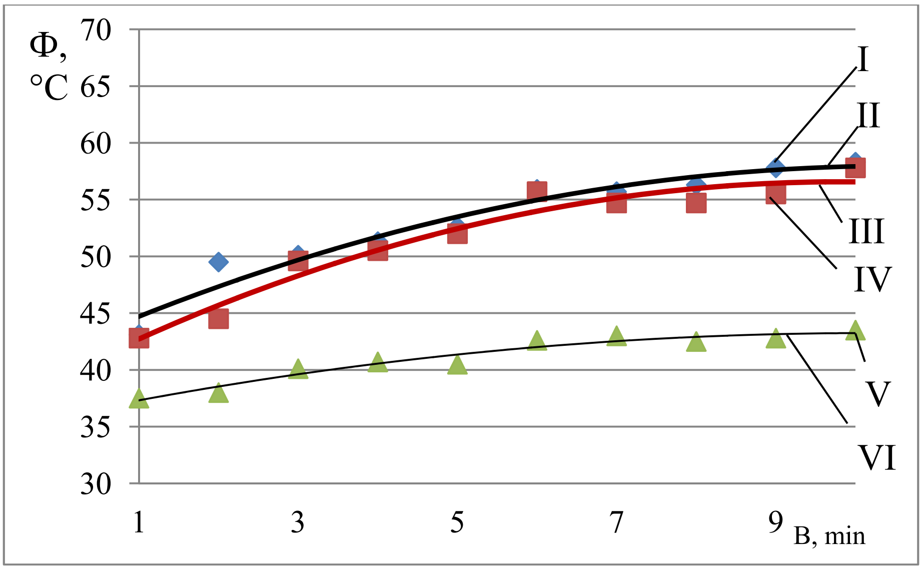

Fig. 1. Results of bench tests of heat-sensitive elements of fire detectors in concrete blocks at defined distances Dependence of the temperature (Φ) of a thermosensitive element with a diameter of 58 mm on the heating time (B): I — at a distance of 20 cm from the lens to the source of infrared radiation; IV — at a distance of 30 cm from the lens to the source of infrared radiation; V — at a distance of 40 cm from the lens to the source of infrared radiation; Trends: II — for dependence I; III — for dependence IV; VI — for dependence V

Another important aspect to be studied was the determination of the dependence of the heating time of the thermosensitive element on the power of the IR radiation source. Fig. 2 shows the results of measurements at a distance of 20 cm from a thin lens with an optical power of 20 Diopters to infrared radiation sources of 1000 Watt, 1500 Watt, 2000 Watt.

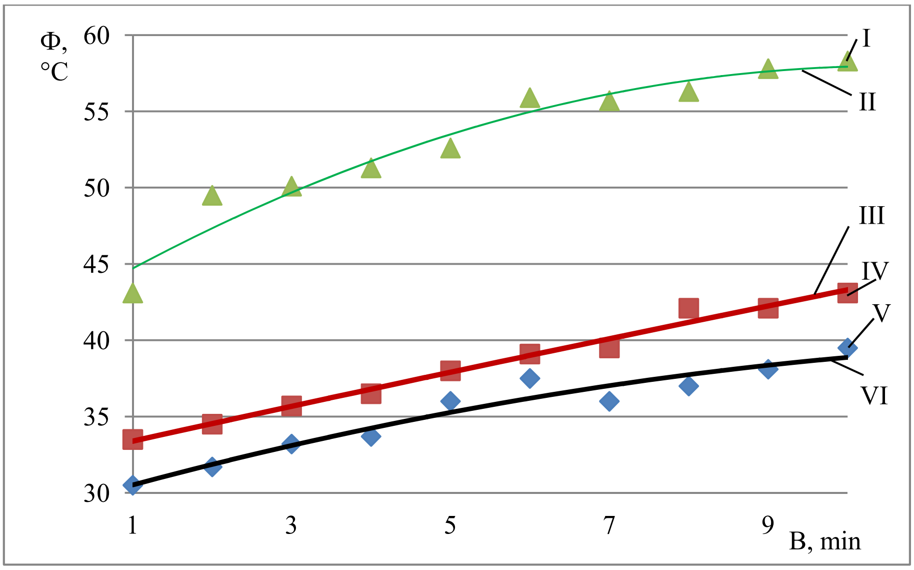

Fig. 2. Results of bench tests of thermosensitive elements of fire detectors built into concrete blocks at a certain power of infrared radiation Dependence of the temperature (Φ) of the 58 mm thermosensitive element on the heating time (B): I — at a radiation power of 2000 W; IV — at a radiation power of 1500 W; V — at a radiation power of 1000 W; Trends: II — for dependence I; III — for dependence IV; VI — for dependence V

The dependence $\Phi = f(B)$ in Fig. 2 is also polynomial (parabolic). For dependence 1 in Fig. 2 for $\Phi_{2.1}(B)$, formula (3) is valid. As a result of the approximation, the following equations were obtained:

$$\Phi_{2.2}(B) = 1.15B - 0.01B^2 + 32.24\,, \tag{6}$$

$$\Phi_{2.3}(B) = 1.5B - 0.05B^2 + 29.07\,. \tag{7}$$

The next stage of the bench tests was to establish the dependence of the heating time of the thermosensitive element of different sizes. Fig. 3 shows the results of this measurement at a distance of 20 cm from a thin lens with an optical power of 20 Diopters to a 2000 Watt infrared source.

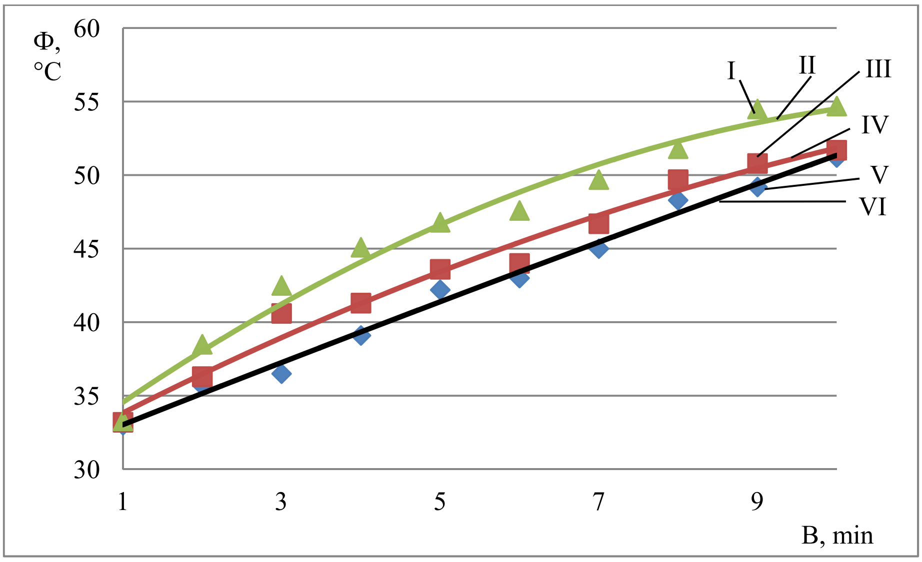

Fig. 3. Results of bench tests of certain sizes of heat-sensitive elements of fire detectors built into concrete blocks Dependence of the temperature (Φ) of the thermosensitive element on the heating time (B): I — with a temperature sensitive element diameter of 50 mm; III - with a temperature-sensitive element diameter of 30 mm; VI — with a temperature sensitive element diameter of 10 mm; Trends: II — for dependence I; IV — for dependence III; V — for dependence VI

The dependence $\Phi = f(B)$ in Fig. 3 is similarly polynomial (parabolic). As a result of the approximation, the following equations were obtained:

$$\Phi_{3.1}(B) = 3.98B - 0.16B^2 + 30.74\,, \tag{8}$$

$$\Phi_{3.2}(B) = 2.88B - 0.08B^2 + 31.03\,, \tag{9}$$

$$\Phi_{3.3}(B) = 2.16B - 0.01B^2 + 30.89\,. \tag{10}$$

3. Identifying the universal equations. The resulting equations (3)—(10) have the following form: $\Phi(B) = aB^2 - bB + c$.

Further, using the *Statistica* software package, the equations were obtained:

$$\Phi(B,P) = 3.88B - 0.13B^2 - 469P^2 + 244P - 4.05BP + 11.18, \quad (11)$$

where B is the time of exposure to infrared radiation on a black thermosensitive element, min, P is the distance from the source of IR radiation to the lens, m.

This formula (11) is applicable for calculating the average temperature parameters of the temperature-sensitive element of a fire detector built into a concrete block [6], at a time interval of 1 min ≤ B ≤ 10 min, at a distance of 20 cm ≤ P ≤ 40 cm to the radiation source.

$$\Phi(B,M) = 18.94M^2 - 0.08B^2 + 1.58B - 41.64M + 0.39BM + 50.63, \quad (12)$$

where B is the time of exposure to infrared radiation on a black thermosensitive element, min, M is the IR source power, Watt.

Formula (12) is applicable for calculating the average parameters of a heat-sensitive element of a fire detector built into a concrete block [6] over a period of time 1 min ≤ B ≤ 10 min, at the power of the infrared radiation source 1000 Watt ≤ M ≤ 2000 Watt.

$$\Phi(B,И) = 0.15И^2 - 0.08B^2 + 2.87B - 0.011И + 0.05BИ + 29.48, \quad (13)$$

where B is the time of exposure to infrared radiation on a black thermosensitive element, min, $И$ is the diameter of the thermosensitive element, cm.

Formula (13) is applicable to calculate the average temperature parameters of the temperature-sensitive element of a fire detector built into a concrete block [6], at a time interval of 1 min ≤ B ≤ 10 min, with a temperature-sensitive element diameter 1 cm ≤ $И$ ≤ 5 cm.

In formulas (11)—(13) time is used not in SI units. Here the time is given in minutes for the convenience of calculations.

Conclusions. The values of temperatures of black temperature-sensitive elements of thermal fire detectors built into concrete blocks were measured. Polynomial equations are obtained making it possible to describe the dependence of the considered thermosensitive elements under specific conditions on the distance, power of IR radiation, and geometric dimensions. The approximation error is no more than 6 %.

The resulting approximate equations identify the parameters necessary for designing concrete blocks with built-in fire detectors for installation. A comparison with domestic and foreign studies [1—4, 10] shows the results of similar empirical data. Installation of a thermal fire detector with a black heat-sensitive element 5 cm in diameter in a concrete block is the most viable option. At the same time, as a result of exposure to solar radiation on this building product, the “fire” alarm does not occur.

References

1. Vershkov D. I., Goldobin Yu. M. [Dynamics of heat transfer to heating surfaces in a hot water boiler furnace]. *Energo- i resursosberezhenie. Energoobespechenie. Netraditsionnye i vozobnovlyaemye istochniki energii. Atomnaya energetika. Materialy Mezhdunarodnoi nauchno-prakticheskoi konferentsii studentov, aspirantov i molodykh uchenykh* [Proc. “Energy and resource conservation. Energy supply. Non-traditional and renewable energy sources. Nuclear energy”], 2018. Pp. 134—137.

2.Kopylov N. P., Khasanov I. R. Effektivnost' primeneniya teplozashchitnykh ekranov dlya zashchity ot teplovykh potokov pri pozharakh [Efficiency of application of heat protection screens for protection from heat flows during fires]. *Bezopasnost' Truda v Promyshlennosti*, 2016, no. 11, pp. 38—43.

3. Koshmarov Yu. A. *Teplotekhnika* [Heat Engineering]. Moscow, Akademkniga Publ., 2006. 501 p.

4. Koshmarov Yu. A., Bashkirtsev M. P. *Termodinamika i teploperedacha v pozharnom dele* [Thermodynamics and heat transfer in firefighting]. Moscow, 1987. 444 p.

5. Lazarev A. A., Malichenko V. G., Toropova M. V. [On improving the fire safety of objects of protection of the Ivanovo region in the fire-dangerous period]. Aktual'nye voprosy sovershenstvovaniya inzhenernykh sistem obespecheniya pozharnoi bezopasnosti ob"ektov. Sbornik materialov VI Vserossiiskoi nauchno-prakticheskoi konferentsii [Proc. “Current issues of improving engineering systems for ensuring fire safety of objects”], 2019. Pp. 190—195.

6. S. V. Fedosov, A. A. Lazarev, M. V. Toropova, Malichenko V. G. *Sovmeshchennyi s pozharnym izveshchatelem betonnyi blok* [Combined with a fire detector concrete block]. Patent RF, 2020, № 2020101506.

7. Sazonova S. A., Nikolenko S. D. Chislennoe reshenie zadach v sfere pozharnoi bezopasnosti [Numerical solution of problems in the field of fire safety]. *Modelirovanie sistem i protsessov*, 2016, vol. 9, no. 4,pp. 68—71.

8 .Sazonova S. A., Nikolenko S. D. Raschet koeffitsienta teplopoter' na nachal'noi stadii pozhara v srede Mathcad [Calculation of the heat loss coefficient at the initial stage of a fire in the Mathcad environment]. *Nauchnyi vestnik Voronezhskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta*, 2016, no. 2(8), pp. 86—93.

9. Fedosov S. V., Golovanov V. I., Lazarev A. A., Toropova M. V. Problemy sovershenstvovaniya monitoringa pri stroitel'stve maloetazhnykh zhilykh zdanii [Problems of improving monitoring in the construction of low-rise residential buildings]. *Privolzhskii nauchnyi zhurnal*, 2020, no. 2(54), pp. 50—56.

10. Denoel J.-F. Fire Safety and Concrete Structures. FEBELCEM, 2007. 87p.

11. Hsu W. L., Jhuang J. Y., Huang C. S., Liang C. K., Shiau Y. C. Application of Internet of Things in a kitchen fire prevention system. Applied Sciences (Switzerland), 2019, no. 9 (17). Pp. 3520–3544.

12. Jabbar W. A., Kian T. K., Ramli R. M., Zubir S. N., Zamrizaman N. S. M., Balfaqih M., Shepelev V., Alharbi S. Design and Fabrication of Smart Home with Internet of Things Enabled Automation System. IEEE Access, 2019, no. 7, pp. 144059—144074.

13. Kazarian A., Teslyuk V. Units and structure of automated “smart” house control system using machine learning algorithms. 14th International Conference The Experience of Designing and Application of CAD Systems in Microelectronics (CADSM), 2017. Pp. 364—366.

14. Khakimova A., Kusatayeva A., Shamshimova A., Sharipova D., Bemporad A., Familiant Y., Shintemirov A., Ten V., Rubagotti M. Optimal energy management of a small-size building via hybrid model predictive control. Energy and Buildings, 2017. Pp. 1–8.

15. Kodali R. K., Jain V., Bose S., Boppana L. IoT based smart security and home automation system. InProceeding - IEEE International Conference on Computing, Communication and Automation, ICCCA, 2016. Pp. 1286–1289.

16. Pozdieiev S.V., Nizhnyk V. V., Ballo Y. V., Nuianzin A. M., Uhanskyy R. V., Kropyvnytskiy V. S. Justification of safe fire-prevention distance between fermenters for biogas production. Safety and off-site Technology, 2018, vol. 51, no. 3, pp. 60—67.

17. Rehman R.M.N.-U. Model of Smart System Based On Smart Grid, Smart Meter and Wireless Based Smart Appliances. IOSR Journal of Electrical and Electronics Engineering, 2012, no. 1 (5), pp. 06—10.

18. Shaukat N., Ali S. M., Mehmood C. A., Khan B., Jawad M., Farid U., Ullah Z., Anwar S. M., Majid M. A survey on consumers empowerment, communication technologies, and renewable generation penetration within Smart Grid. Renewable and Sustainable Energy Reviews, 2018, no. 81, pp. 1453—1475.

19. Silva M. F. de O. Arduino guide device for people with visual impairment. Nucleus, 2018, no. 15 (2), pp. 159–162.

20. Singh V. K., Hirwani C. K., Panda S. K., Mahapatra T. R., Mehar K. Numerical and experimental nonlinear dynamic response reduction of smart composite curved structure using collocation and non-collocation configuration. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 2019, no. 233 (5), pp. 1601—1619.

21. Tulenkov A., Parkhomenko A., Sokolyanskii A., Stepanenko A., Zalyubovskiy Y. The features of wireless technologies application for smart house systems. Proceedings of the 2018 IEEE 4th International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems, IDAACS-SWS, 2018. Pp. 1—5.

22. Yunusov A., Riskaliev D., Abdukarimov N., Eshkabilov S. Signal processing and conditioning tools and methods for road profile assessment. Lecture Notes in Mechanical Engineering, 2020, pp. 742—751.