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CALCULATED ASSESSMENT OF THE DEPENDENCE OF THE INTENSITY OF WIND INFLUENCE ON THE POSSIBILITY OF FIRE SPREADING TO NEARBY BUILDINGS

A model of heat exchange processes between the source of thermal radiation and the studied samples was developed by using methods of steady-state and non-steady-state thermal conductivity according to the methods of gas dynamics. The dependence of the change in temperature and the critical surface density of the heat flow on the speed of the air flow on the samples and the distance from the source of heat action was determined. The conducted research and generated data tables can be used in the future for the development of an improved simplified method of forecasting the thermal impact of fire on adjacent construction objects, taking into account wind influence.

With the help of the FDS software complex, a model of heat exchange during a fire was created step by step. The dependence of the temperature change on the air flow rate on the samples and the distance from the source of thermal action was determined. The resulting dependence can be further determined by a correction factor that will take certain criteria into account. This coefficient will be expedient to use when substantiating fire-fighting distances between buildings and structures due to the mathematical model of heat exchange between objects during a fire using gas dynamics methods, as well as when substantiating the algorithm for creating a mathematical model of FDS heat and mass transfer during the burning of a class A fire.

Based on the revealed regularities, a table of safe distances was constructed depending on the heat-generating capacity of the fire load, wind speed, and duration of exposure to determine the correction factor for wind exposure. The methodological basis for the calculation justification of the minimum safe fire distances has been expanded by creating structural schemes-methods that together make up a hierarchical structure and are the theoretical basis for creating the corresponding regulatory basis. It was established that the wind speed during the assessment of the spread of fire to neighboring buildings can be taken into account by introducing a correction factor into the formula for calculating the safe fire distance between buildings.

Key words: *adjacent building objects, mathematical model, fire model, temperature, critical surface heat flux density.*

Formulation of the problem. The condition for the ignition of any material under the influence of heat emitted from the fire source is to exceed a certain critical value of the heat flux density for such a substance and material. To date, there is an insufficient statistical base of critical values of surface heat flux density for various substances and materials, which takes into account wind speed. Heat flow [1] is a physical quantity that determines the amount of heat passing through an isothermal surface per unit time, directed in the direction opposite to the temperature gradient, or is a time derivative of the amount of heat passing through such a surface. The characteristic of the heat flow is its density, which according to [2] is defined as the amount of heat passing through the enclosing structure per unit of time, related to the area of the calculated surface measuring 1 m². Also, according to [2] heat flow density or specific heat flow, which characterizes the intensity of heat exchange, the amount of heat through a unit of surface per unit of time is determined.

The critical surface density of the radiant flux according to [2] is defined as the minimum value of the heat flux density at which a stable flame burning of the materials on which the radiant flux falls occurs. It should also be noted that the heat exchange process is affected by the wind and its speed. At the same time, the nature of such an impact is described differently by different scientists, which can affect the start of a fire in adjacent buildings and premises.

Analysis of recent achievements and publications. The analysis of statistical data of fire registration cards [3] allows us to conclude that every fourth fire in Ukraine can spread to adjacent buildings and structures, technological equipment and objects of the natural ecosystem through the spread of thermal energy with subsequent ignition. To prevent the spread of fire to adjacent building objects, calculation methods for determining safe distances are used [3-8], however, methods for predicting the thermal effect of fire on adjacent building objects, which would take into account environmental conditions, namely the parameters of wind influence, which can significantly influence the specified predictions which are given in [4, 6].

Taking into account the above, there is a need for further scientific research to improve the calculation method of predicting the thermal effect of fire on adjacent construction objects, taking into account the wind effect.

Setting the problem and solving it. The purpose of the work was to determine the magnitude of the influence of wind speed during the assessment of the spread of fire to neighboring buildings and to create a table of safe distances depending on the heat-generating capacity of the fire load, wind speed and duration of exposure to determine the correction coefficient of wind influence based on the identified patterns. To achieve this goal, the following task was set and solved:

To achieve the goal, the following tasks were set and solved:

1. To develop models of heat exchange processes between the source of thermal radiation and the studied samples under conditions of wind influence and variable distance to the sample using gas dynamics methods.

2. Based on the identified patterns, a table of safe distances was constructed depending on the heat-generating capacity of the fire load, wind speed, and duration of exposure to determine the correction factor for wind exposure.

3. Set the coefficient of influence of wind speed when assessing the spread of fire to neighboring buildings.

Methods. Thanks to the methods of mathematical modeling, it is possible to investigate heat transfer processes with given conditions of environmental parameters, namely wind influence. Using the FDS software complex, a mathematical model of the heat exchange process during a fire was created step by step, and the effect of wind on the values of temperature and critical surface density of heat flow under conditions of wind influence was investigated.

Modeling of processes of changes in temperature and critical surface heat flow density using gas dynamics methods was carried out on the basis of the methodology [9].

The model of placement of the studied sample, shown in fig. 1.

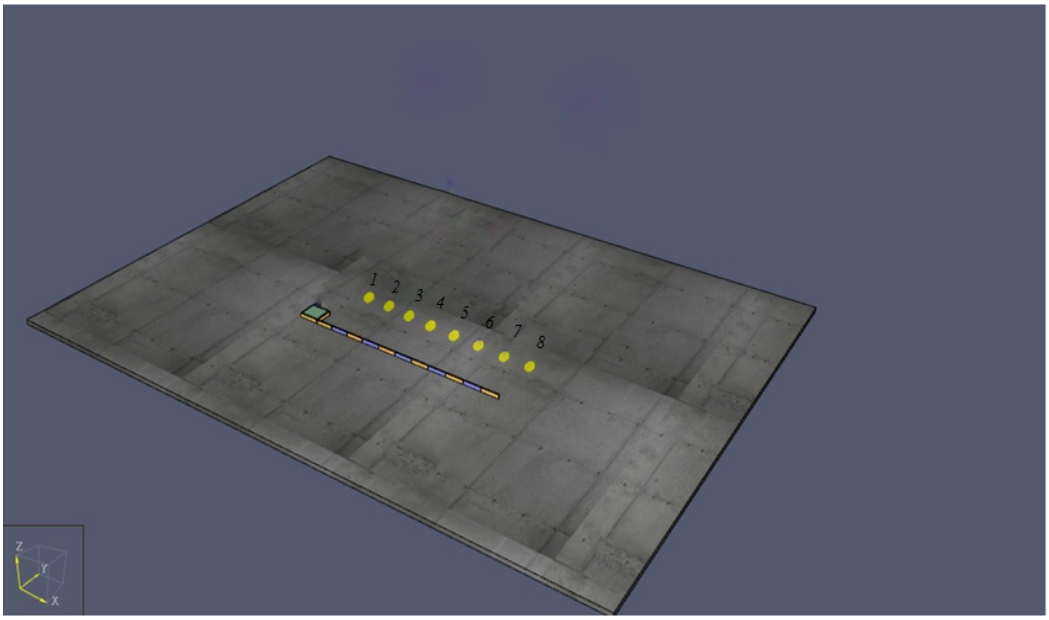


Figure 1. Model of placement of the sample under study, 1, 2, 3, 4, 5, 6, 7, 8 – temperature measurement sensors at different distances

Numerical modeling of the dynamics of the spread of heat flow from a fire was performed using the FDS tool, which is a modern software complex that allows you to create, edit and analyze complex fire development models. The Smokeview program was used for three-dimensional and two-dimensional visualization of the results of simulation of fire dynamics.

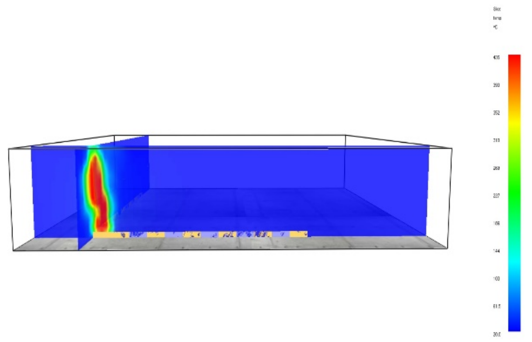
Thermal radiation is calculated using the finite element method in a three-dimensional grid (modeling area). This software helps to reproduce the real conditions of a model fire, including for open space.

Results and Discussion. During the research, the raw data was analyzed, a model was created that corresponded to the real conditions of field tests, in particular, the model included a concrete platform (base), for the material construction of which a monolithic concrete of the "heavy concrete" type was chosen, with a density of 2260 kg/m3, a specific heat capacity of 2 .04 kJ/(kg·K) and thermal conductivity of 1.35 W/(m·K). Steel with a density of 7600 kg/m^3, specific heat capacity of 0.06 kJ/(kg·K) and thermal conductivity of 35 W/(m·K) was used as the material for the capacity of the model hearth. Diesel fuel was used as fuel, with a specific heat release of 1907, a lower heat of combustion of 45400.0, a linear flame speed of 0.4, and a specific mass burning rate of 0.042.

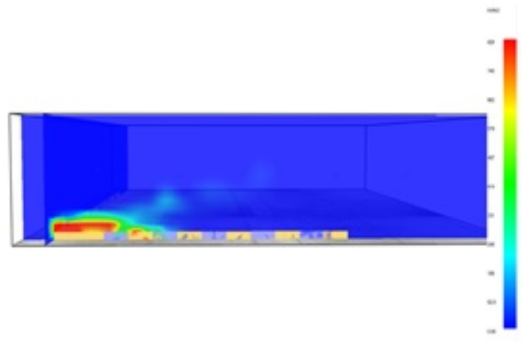
Sensors of gas meters were placed at a height of 2 m at a distance of 0.5 m and from 1 m to 12 m with a distance step of 1 m from each other. To achieve optimal calculation accuracy, it is customary to use cells with a step of 0.1 m and with the same cubic size to all three spatial dimensions (x, y, z). The duration of the simulation was 300 s, which is due to the value of the maximum thermal radiation from the model hearth, which occurs in the period from 60 s to 240 s.

Based on the results of the research, the following results were obtained.

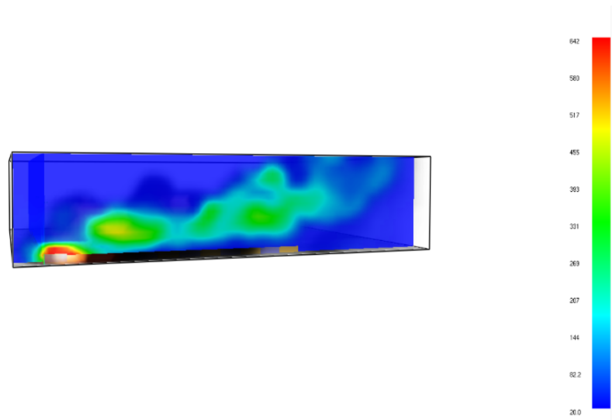
The general visualization of temperature with the display of temperature fields in planes is shown in Figure 2.



a)



b)



c)

Figure 2. Temperature visualization model with display of temperature fields in planes: a) without wind; b) wind with a speed of 5 m/s; c) wind with a speed of 10 m/s

According to the simulation results, a table of the ignition temperature was formed depending on the distance to the radiation source and the influence of wind of different speeds, table 1.

Table 1

Distance l, m	Ignition temperature T, °C		
	Wind speed *v*, m/s		
	0 m/s	5 m/s	10 m/s
0,5	425	398	395
1	315	426	423
2	125	306	474
3	103	152	381
4	95	90	205
5	73	71	124
6	68	69	101
7	57	48	93
8	54	41	74
9	47	38	65
10	32	29	51
11	31	27	39
12	30	26	27

The data in Table 1 are plotted and depicted in Fig. 3.

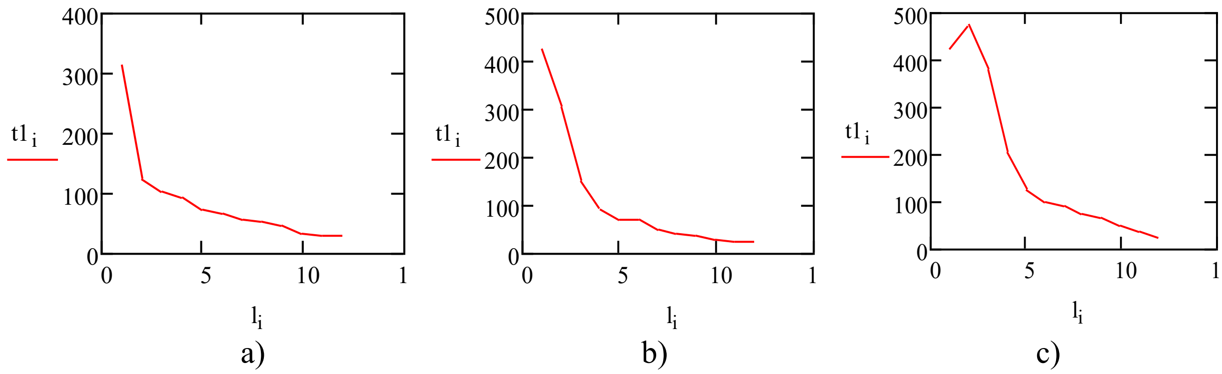


Figure 3. Dependence of temperature change on the effect of wind speed and distance from the radiation source a) without wind effect; b) under the influence of wind at a speed of 5 m/s; c) under the influence of wind at a speed of 10 m/s

Analyzing the results of modeling and the data of graphic images, we can make assumptions about the influence of wind on the processes of heat exchange between the fire torch and adjacent building objects. For example, if a temperature equal to 200°C is taken as the critical temperature of influence, then the distance that ensures the safety condition of thermal action in the considered case will be equal to:

- in windless weather - 2 m;
- in weather with a wind speed of 5 m/s 0 - 3 m;
- in weather with a wind speed of 10 m/s - 4 m.

The obtained data show that in case when the object exposed to thermal radiation is located on the windward side of the source of thermal radiation (fire), the presence of wind can significantly affect the assessment of safe distances between the object emitting heat and the object who perceives it.

Such a dependence can be determined by the strength of the wind flow, which in further scientific research can be determined by a correction factor that must take into account the following criteria:

- the amount of fire load;
- time of thermal action;
- influence of wind speed.

The obtained simulation results and data of graphic images confirm the obtained data of experimental studies regarding the presence of the influence of wind on the processes of thermal irradiation of a nearby object from a fire torch in the case when the object is located on the windward side of the source of thermal radiation (fire).

Such influence can be described by the corresponding coefficient of wind influence.

To describe the coefficient of wind influence, a full factorial calculation experiment was carried out.

The following criteria, which significantly affect thermal processes during a fire, were chosen: duration of thermal exposure, fire load, and wind speed. The range of the specified parameters is shown in the table 2 [9].

Table 2. Intervals of parameters in the experiment selected as factors

wind speed, m/s		Fire load, Q, MJ/m²		Duration of heat exposure, T, min	
The smallest value, v	The greatest value, v+	The smallest value, Q	The greatest value, Q+	The smallest value, T	The greatest value, T+
2,5	10	20	1800	10	150

The specified intervals show the smallest and largest value of the parameters in the experiment that are selected as factors.

With the help of a computer model, the temperature value from the thermal effect of the fire on the neighboring buildings in wind conditions was calculated, as shown in the table 3 [9].

Table 3. Estimated values of the temperature of the thermal effect on the neighboring buildings under the influence of the wind

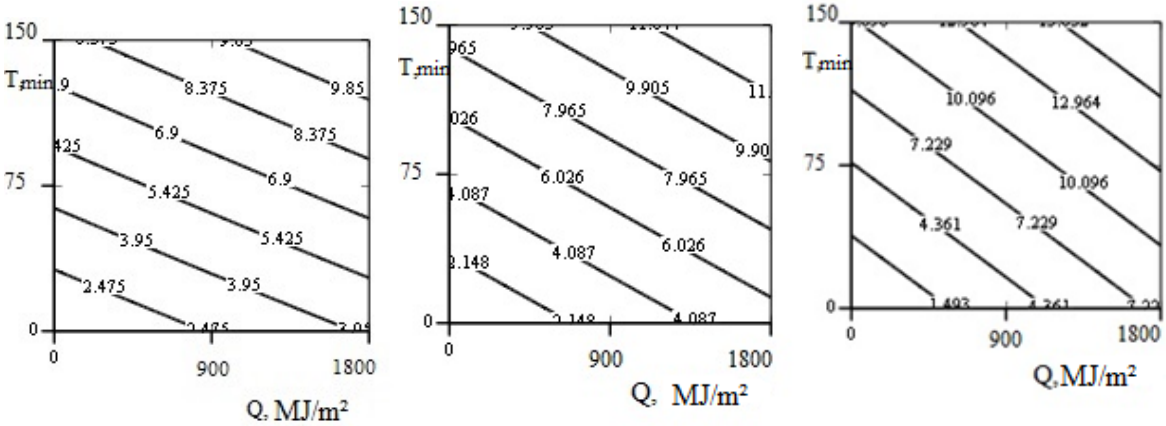
Distance from the center of heat radiation, m	Estimated value of the temperature of the thermal effect of the fire on the neighboring buildings in conditions of wind influence							
	1	2	3	4	5	6	7	8
18	206	118	148	24	42	24	38	22
15	232	171	206	27	64	29	51	26
10	251	203	230	51	76	40	72	29
8	296	218	252	74	83	63	80	41
6	303	241	281	101	98	87	96	69
4	367	328	342	205	196	191	206	90
2	518	426	501	381	268	208	292	152

By interpolating the obtained data according to the ignition temperature, which in this case is taken as 255 °C for pine wood, safe distances between buildings during a fire are obtained, taking into account the magnitude of the fire load, wind speed and duration of thermal radiation, table 4 [9].

Table 4. Main parameters of reinforced concrete

Experiment number	1	2	3	4	5	6	7	8
Distance from the center of heat radiation	18,7	9,9	15,2	4,1	3,8	2,5	4,1	1

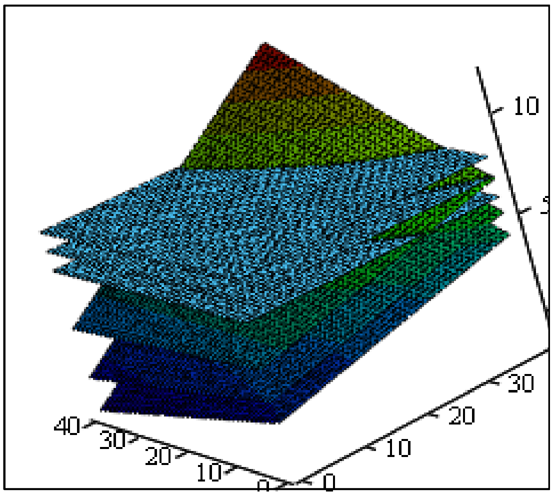
Based on the results of the calculations, diagrams were constructed, with the help of which, by choosing the appropriate wind speed, duration of irradiation, and the value of the fire load, it is possible to find the distance at which the condition of non-spreading of the fire with the specified parameters of the fire load and its duration to neighboring objects is ensured (Fig. 4).



a) b) c)

Figure 4. Diagram of determination of safe distance taking into account wind speed. Distances to the source of radiation and duration of heat exposure: a) for wind speed of 2.5 m/s; b) for a wind speed of 5 m/s; c) for a speed of 10 m/s

On the basis of the obtained data, a surface of the dependence of the distance on the most influential factors was constructed 5.



M1, M2, M3, R1, R2, R3

Figure 5. The surface of the dependence of the distance on the most influential factors

On the basis of the revealed regularities, the impact of fire on neighboring buildings was established, taking into account the wind, which can be described in the form of a coefficient that takes into account the influence of the wind, the value of which is α=1,2.

Conclusions

With the help of the FDS software complex, a model of heat exchange during a fire was created step by step. The dependence of the temperature change on the air flow rate on the samples and the distance from the source of thermal action was determined. The resulting dependence can be further determined by a correction factor that will take certain criteria into account. This coefficient will be expedient to use when substantiating fire-fighting distances between buildings and structures due to the mathematical model of heat exchange between objects during a fire using gas dynamics methods, as well as when substantiating the algorithm for creating a mathematical model of FDS heat and mass transfer during the burning of a class A fire.

Based on the results of this work, the following was established:

1. Based on the identified patterns, a table of safe distances was constructed depending on the heat-generating capacity of the fire load, wind speed, and duration of exposure to determine the correction factor for wind exposure.

2. The methodological basis for the calculation justification of the minimum safe fire distances has been expanded by creating structural schemes-methods that together make up a hierarchical structure and are the theoretical basis for creating the corresponding normative basis.

3. It has been established that the wind speed during the assessment of the spread of fire to neighboring buildings can be taken into account by introducing a correction factor into the formula for calculating the safe fire distance between buildings α=1,2.

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РОЗРАХУНКОВА ОЦІНКА ЗАЛЕЖНОСТІ ІНТЕНСИВНОСТІ ВІТРОВОГО ВПЛИВУ НА МОЖЛИВІСТЬ ПОШИРЮВАННЯ ПОЖЕЖІ НА СУСІДНІ БУДІВЛІ

Розроблено модель процесів теплообміну між джерелом теплового випромінювання та досліджуваними зразками шляхом використання методів стаціонарної і нестаціонарної теплопровідності за методами газодинаміки. Визначено залежність зміни температури та критичної поверхневої щільності теплового потоку від швидкості потоку повітря на зразки та віддалення від джерела теплової дії. Проведені дослідження та сформовані таблиці даних в подальшому зможуть бути використані для розробки удосконаленого спрощеного методу прогнозування теплового впливу пожежі на суміжні будівельні об'єкти з урахуванням вітрового впливу.

За допомогою програмного комплексу FDS поетапно створено модель теплообміну під час пожежі. Визначено залежності зміни температури від швидкості потоку повітря на зразки та віддалення від джерела теплової дії. Отримана залежність в подальшому може бути визначена поправочним коефіцієнтом, який буде враховувати певні критерії. Даний коефіцієнт буде доцільно використовувати при обґрунтуванні протипожежних відстаней між будинками та спорудами за рахунок математичної моделі теплообміну між об'єктами під час пожежі за методами газодинаміки, а також під час обґрунтування алгоритму створення математичної моделі FDS тепломасопереносу під час горіння пожежі класу А.

На основі виявлених закономірностей побудовано таблицю безпечних відстаней залежно від теплоутворювальної здатності пожежної навантаги, швидкості вітру та тривалості опромінювання для визначення поправочного коефіцієнта вітрового впливу. Розширено методологічну базу для розрахункового обґрунтування мінімальних безпечних протипожежних відстаней створенням структурних схем-методів, що разом складають ієрархічну структуру та є теоретичною основою для створення відповідної нормативної бази. 3. Встановлено, що швидкість вітру під час оцінювання поширювання пожежі на сусідні будівлі може бути врахована шляхом введення в формулу для розрахунку безпечної протипожежної відстані між будівлями поправочного коефіцієнту.

Ключові слова: *суміжні будівельні об'єкти, математична модель, модельне вогнище пожежі, температура, критична поверхнева густина теплового потоку.*