This paper considers the issue of assessing the possible impact of fire in external air conditioning units on the evolution of façade fires using the example of a typical façade of the building. Current methods for assessing the effectiveness of limiting the spread of façade fires do not take into account the possibility of external fire load. Existing methods of studying the effects of combustible components in façade systems are intended only to investigate the reaction to the fire of façade systems. At the same time, it should be understood that modern façade systems include additional components that not only have a significant fire load but can be the cause of a fire. Taking that into consideration, a study was conducted on the impact of a possible fire of external air conditioning units on the development of its evolution by vertical structures in buildings. During the FDS modeling, the possibility of facing materials from a low combustibility group, which are typical for modern façade systems, is taken into account. Analysis of the fire load of the components included in the design of air conditioning units has made it possible to recreate the model of the combustion reaction of the main components and determine the value of its maximum intensity. The data on the thermal distributions on the surface of the façade made it possible to make assumptions about the necessary structural parameters that should be observed when determining the places of installation of baskets for air conditioners. The established dependences are a prerequisite for revising the criteria for assessing the potential fire danger of façade systems, which may include additional engineering systems. The derived dependences will make it possible to revise approaches to existing field procedures for assessing the fire danger of façade systems. The practical result of the implementation of these data may be amendments to building codes to increase the level of fire protection of façade systems and buildings in general

Keywords: restriction of fire spread, fires of external air conditioning units, façade fires, temperature distributions on the façade of the building

UDC 614.843
DOI: 10.15587/1729-4061.2022.259533

DETERMINING THE EFFECT OF FIRE FROM EXTERNAL AIR CONDITIONING UNITS ON BUILDINGS' FAÇADES

Yaroslav Ballo
PhD*
Roman Yakovchuk
Doctor of Technical Sciences, Associate Professor
Department of Civil Protection
and Computer Modeling of Ecogeophysical Processes
Lviv State University of Life Safety
Kleparivska str., 35, Lviv, Ukraine, 79007
Vadym Nizhnyk
Doctor of Technical Sciences, Senior Researcher*
Anna Borysova
Corresponding author
PhD
Sector of Editorial and Scientific-Publishing Activity**
E-mail: borysova_anna@ukr.net
*Fire Protection Research Center**
**Institute of Public Administration
and Research in Civil Protection
Vyshhorodska str., 21, Kyiv, Ukraine, 04074

Received date 21.04.2022
Accepted date 14.06.2022
Published date 29.06.2022

How to Cite: *Ballo Y., Yakovchuk R., Nizhnyk V., Borysova A. (2022). Determining the effect of fire from external air conditioning units on buildings' façades. Eastern-European Journal of Enterprise Technologies, 3 (10 (117)), 72–79. doi: https://doi.org/10.15587/1729-4061.2022.259533*

1. Introduction

Ignition of external air conditioner units is one of the most dangerous causes of façade fires. Among the dangerous factors that can influence the spread of fire façade systems, there are incorrect geometric parameters for installing external air conditioning units. In addition, these units may be installed at close range to the façade or to the outer light openings filled with structures that include combustible materials, the absence of fire distances between the outer units of air conditioners, etc.

It should be noted that in most cases such fires caused significant damage to the structure of houses, significant material damage, and, in some cases, led to the death of people. Analysis of the total number of fires in some European countries over the past 15 years [1–3] shows an annual increase of 3–5 % of affected people and a 10–15 % increase in material damage as a result of the ignition of air conditioning equipment. Fig. 1 provides an example of a fire of an external air conditioning unit, which caused the ignition of adjacent air conditioning unit on the façade of the building, which occurred in 2021 in the city of Cherkasy.

Fig. 1. Photograph of the consequences of the fire in the vertical arrangement of air conditioners

The external air conditioning unit is a fireproof product since its structure includes components that together constitute a significant fire load. The lack of regulatory requirements for the installation of air conditioning units creates prerequisites for the inconsistent accumulation of fire-prone combustible components on façade systems, which, in the case of fire, could create additional risks of rapid spread of the fire. Fig. 2 provides an example of improper installation of external air conditioning units on the façade of the building.

Fig. 2. An example of improper installation of external air conditioner units on the façade of the building

An analysis of fires overseas, including a report by the U.S. National Fire Protection Association [4], revealed that between 2011 and 2021, air conditioners were responsible for an average of 2,800 home fires a year. That accounted for about 1 % of the total number of fires in residential and public buildings. At the same time, it should be noted that most of those fires occurred during the three summer months, namely June, July, and August when air conditioners operate under the greatest load [5]. Analysis of the consequences showed that on average, losses ranged in USD 60–80 million per year, with 20 to 140 civilians dying each year [6, 7].

To date, during the assessment of the design of the façade systems of the building, it is believed that the potential source of the fire is in the middle of the premises. At the same time, the analysis of fires shows that the potential threat of a façade fire can be not only in the middle of the room but also directly on the façade of the building.

In addition, the analysis of fires showed that in a significant part of the buildings in which façade fires occurred due to the ignition of air conditioners, facing materials from a combustibility group G1 were used (according to Ukrainian standards [8]), which, according to the European analog [9], corresponds to the A2-s1, d1 – B-s3, d2 classification.

Thus, determining the impact of fire from external air conditioning units located on the facades of buildings is a relevant task, the result of addressing which will define the criteria for assessing the fire danger of facades. At the same time, this will reveal potential ways to improve construction codes to improve the level of fire safety of buildings and structures in general.

2. Literature review and problem statement

Earlier analysis revealed that the requirements of the current regulatory documents in Europe do not contain specific design requirements for the installation of baskets for external air conditioner units (hereinafter referred to as the basket of air conditioners) on the facades of houses.

Existing European advanced procedures for testing façade systems [9–11] do not take into consideration the fire load from engineering systems that can be arranged on the façade of the building and, accordingly, do not take into account their fire potential. The requirements [12] do not contain parameters to limit the distance of air conditioner baskets to the façade plane, and do not contain structural requirements for the installation of baskets of external air conditioning units. In addition, in [12] there are no fire requirements for distances to windows and other light openings, as well as distances to adjacent air conditioner units, both horizontally and vertically. It should be noted separately that improper vertical arrangement of air conditioners is more dangerous in terms of the likelihood of vertical evolution of fire on the façade of the building than horizontal.

A separate issue of potential fire risks from external air conditioning units is the use of flammable refrigerants in their structure. Paper [13] covers the combustibility of hydrocarbon refrigerants and analyzes safety standards and the necessary precautions when using hydrocarbons in air conditioning systems. However, work [13] does not contain an analysis of the total fire load inside the air conditioning unit or the procedure for determining it. Study [14] considers various fire-hazard scenarios for the operation of air conditioning modules. However, the analysis does not contain results on the possible fire impact on the façade systems of buildings and measures for the possibility of limiting it.

General requirements for fire safety for the designs of external air conditioning units during their operation are defined in [15]. The regulations state that the outer space and walls of houses around air conditioners should be cleared of tree branches, climbing plants, and other objects and structures made of combustible materials within a radius of at least 1.5 meters. However, these requirements relate to performance indicators that cannot be taken into consideration at the design stage. In norms [16], it is forbidden to use, as supporting structures, combustible elements of frame structures instead of installation fasteners of factory production. Other metal structures are not used when installing air conditioning in the window opening, as well as making changes to the design of air conditioners not provided for by the manufacturer. At the same time, these requirements are limited exclusively to the design of the basket itself for the air conditioning unit without taking into consideration the type of the façade system itself.

Work [17] reveals the features of fire hazard during the leakage of refrigerants but there is no analysis of their possible synergy with other fire-hazard components of the air conditioner. Study [18] on modeling the fire of air conditioning units tackles fires in the middle of the room and cannot be used to analyze façade fires. In [19], the research focuses on modeling a large-scale model of refrigerant explosion but the results of that analysis are applicable for closed volumes in the room, and cannot be used for open façade systems.

All this allows us to assert that it is expedient to conduct a study on fire safety of structural parameters during the installation of external air conditioning units on the facades of buildings. In addition, there is a task is to study the thermodynamic process of spreading the upward heat flow during a fire on the facades of a building in open space. A separate issue is the study of the impact of a possible fire of an external air conditioning unit on façade elements from combustibility group G1, in particular decorative aluminum composite panels used for decorative external storage of the air conditioner unit. This issue is a prerequisite for reviewing existing criteria and analyzing potential risks during the assessment of fire danger of façade systems.

3. The aim and objectives of the study

The aim of this work is to identify the impact of fire from external air conditioning units on the spread of fire by vertical construction structures in buildings. This will make it possible to determine the safe parameters for installing external air conditioning units on the facades of houses and prevent the evolution of a possible fire in the case of ignition.

To achieve the set aim, the following tasks have been solved:

– to design a typical model of a fragment of the façade of the house, baskets of air conditioners, and the air conditioner itself using the FDS software package;

– to establish dynamic indicators of heating the surface of façade structures of buildings, as well as the dependence of the fire as a result of ignition of the air conditioning unit;

– to determine the safe structural parameters for arranging the basket of air conditioners to ensure the restriction of the spread of fire by vertical construction structures.

4. The study materials and methods

The object of our research is the processes of critical heating of the surface of facades of buildings as a result of the fire of the external air conditioning unit, as well as further forecasting the spread of fire by such structures.

The hypothesis of the study assumes that the identified patterns of the evolution of the façade fire of the building in the event of a fire of the external air conditioning unit will determine the safe parameters for the installation of external air conditioning units, thereby preventing the development of a possible façade fire in the case of ignition.

During the simulation, the results of the analysis of the requirements of regulations in the field of construction to the class of reaction to the fire of the material of external cladding were taken into consideration, in accordance with [20]. When determining the criteria for the impact of temperature regimes on the façade, the approaches reported in works [21–23] were taken into consideration, taking into account the requirements of European regulatory documents.

To simulate and study the spread of rising heat flow during a fire if the air conditioning unit on the façade of the house, FDS software was used to create a fragment of the façade of the house. The basic material chosen for the house structure was clinker full-bodied brick as the most common material for filling external enclosing structures, including monolithic frame houses made of reinforced concrete. Brick density, 1900 kg/m^3; specific heat capacity, 0.8 kJ/(kg·K); thermal conductivity, 0.65 W/(m·K). The light openings (windows) of the house are filled with glass with a density of 2500 kg/m^3, with a specific heat capacity of 0.67 kJ/(kg·K) and thermal conductivity of 0.061 W/(m·K). The facing material of the façade is not taken into consideration in the model of the fragment of the building in order to obtain thermal distributions on the façade solely from the influence of the external fire factor. The step of the calculation grid of the FDS model is 25 cm^2, which is due to the geometric dimensions of the model of the building fragment and the multiplicity of the size of the grid cell relative to the geometrical parameters of the external air conditioner unit.

The outdoor air conditioning unit is arranged in a special basket, which is attached to the façade of the building and is closed from the outside with decorative aluminum composite panels, which, according to [8] of the fire classification, belong to the building materials of group G1 (low combustibility). Fig. 3 provides an example of a façade system equipped with baskets for external air conditioner units. This type of facades with aluminum composite panel, used for decorative external storage of the air conditioner unit, is taken as a base during the construction of the FDS model.

The combustibility of G1 is characteristic of substances and materials that cannot burn without a source of ignition, but under appropriate conditions, they are able to emit gases that form smoke. Low-combustible materials of group G1 have a flue gas temperature of not more than 135 °C, the degree of damage along the length of the sample is not more than 65 %, the degree of damage by the weight of the sample is not more than 20 %.

Separately, it should be noted that the presence of a solid decorative panel is the most dangerous structure for external air conditioner units, due to the restraint of thermal influence in the horizontal plane and its direction to the upper floor. When building a model, a typical mounting node for the structure of the external air conditioner unit is used, as shown in Fig. 4.

Fig. 3. An example of a façade system equipped with baskets for external air conditioner units with a decorative aluminum composite panel

Aluminum composite panels for facades are a multilayer material, which consists of two sheets of aluminum and polyethylene filler. The adopted physical characteristics of the panels are as follows:

– thermal expansion coefficient, 0.024 mm/m t° (°C);

– elasticity module E, 70,000 H/mm^2;

– relative elongation >5 %;

– impact resistance, 50 kg/cm;

– thermal resistance, –50 °C to +80 °C;
– heat transfer capacity, 5.45 W/m^2;
– hygroscopicity, 0.01 % (the material is not hygroscopic).

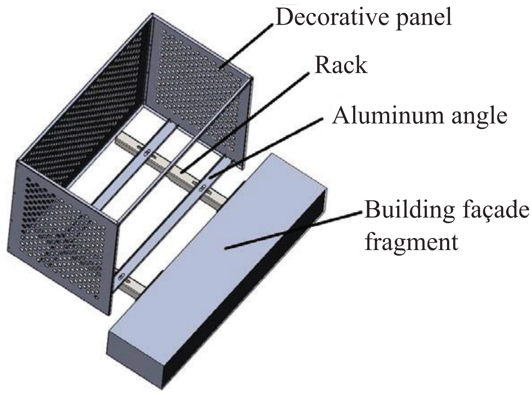


Fig. 4. An example of the design of an external air conditioner basket with a decorative aluminum composite panel

During the construction of a 3D model of the external air conditioner unit, the list of standard components that are part of its structure was studied and the following initial physical data were accepted:
– refrigerant type, R32;
– refrigerant weight, 1.15 kg;
– dimensions, height-width-depth: 960×700×396 mm;
– total weight, 43.5 kg, which includes:
– metal – 32 kg;
– rubber – 2.3 kg (fire load, 33.5 MJ/kg);
– polyvinyl chloride – 6.2 kg (fire load, 33.5 MJ/kg);
– paper-layered plastic – 1.1 kg (18 MJ/kg);
– fiberglass – 0.75 kg (5 MJ/kg);
– freon, type R32a–R290 – 1.15 kg (65.6 MJ/kg).

In addition, when building a model, an important part of the fire reproduction is to determine the combustion reaction, which is an integral part of the initial causes of the fire. Studies [24] have shown that among the main causes of fire in the outer units of air conditioners are freon leakage, which is 42.6 %. Among other reasons, violations of the rules of operation and maintenance were recorded, which are 43.4 %, and mechanical damage to wire insulation, which is about 10 %.

The accepted scenario of the simulated fire is the ignition of the external air conditioning unit as a result of freon leakage, which caused a combustion reaction with a maximum temperature of 1170 °C. The outer air conditioning unit is located between two windows at a distance of 15 cm from the façade plane. There is no decrease in the intensity of combustion (fading). Specific heat release amounted to 230 kW/m^2. The linear rate of flame spread is not considered as a subject of our study, and is taken at 0.05 m/s for the visual reproduction of combustion based on the analysis of real fire events.

For the possibility of visual assessment of thermal distributions, the outer surface of the façade can visualize changes in the temperature of the heating of the surface during the entire duration of the simulation.

To more accurately determine the values of the spread of rising heat flow during a fire along the body of the external air conditioner unit from the center and in each direction in increments of 20 cm, thermal meters are arranged in the gas environment. These meters record a change in the temperature values of the structure of the aluminum composite panel over time.

During modeling, wind exposure is not simulated as creating a decrease in the density and uniformity of the heat flow and reducing the height of the fire torch. In addition, the wind, which has a direction towards the building, will create a prop and a zone of high pressure, in which cold air due to edging will fall into the heating zone of the façade and, accordingly, will cool the wall of the building.

5. Results of studying the spread of fire from external air conditioner units on the facades of buildings

5. 1. Building a typical model of a fragment of the façade for calculations

As a result of the construction of the model, a fragment of a typical façade of the building with a height of three floors was recreated. In addition to the external cladding material, the main structural elements of the building were reproduced, namely windows, balcony doors, and decorative aluminum composite panels.

When entering the initial parameters for the start of the calculation, it was accepted that the fire spreads to the maximum area throughout the entire simulation time, namely 720 seconds (12 minutes). In this case, the windows in all rooms are closed, which meets the requirements of the rules of operation of air conditioners. The estimated duration of fire modeling is justified by the time of normative arrival of fire and rescue units in a city according to [25], which is 10 minutes, and additional time (2 minutes) for deployment of forces and means.

Fig. 5 shows a photograph of the created 3D FDS model of the façade of the house.

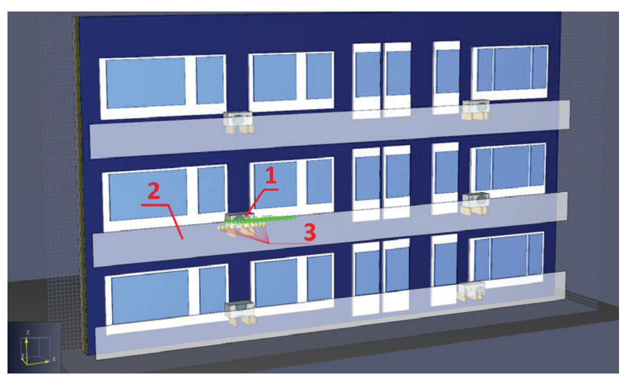


Fig. 5. Visualization of the model of the fragment of the façade of the building and external air conditioning units: 1 – external air conditioning unit, which is also the calculated initial site of the fire; 2 – solid horizontal decorative aluminum composite panel; 3 – thermal meters in the gas environment, which record a change in the temperature values of the structure of the aluminum composite panel over time

The chosen criteria for the maximum value of the temperature of heating the surface of the façade of the house is 250 °C, which corresponds to the temperature of deformation of the structure of the material with the lowest temperature resistance, namely the structure of metal-plastic windows according to data from [25]. For adjacent external units of the air conditioner, a critical temperature value is 75 °C of the heating of the body, which corresponds to the emergency temperature of the shutdown of the external air conditioner unit due to the high probability of a short circuit inside the body. For aluminum composite panels, the critical ignition temperature and, accordingly, the destruction of the structure is a value of 350 °C.

5. 2. Results of studying the impact of rising heat flow during the fire of an external air conditioner unit

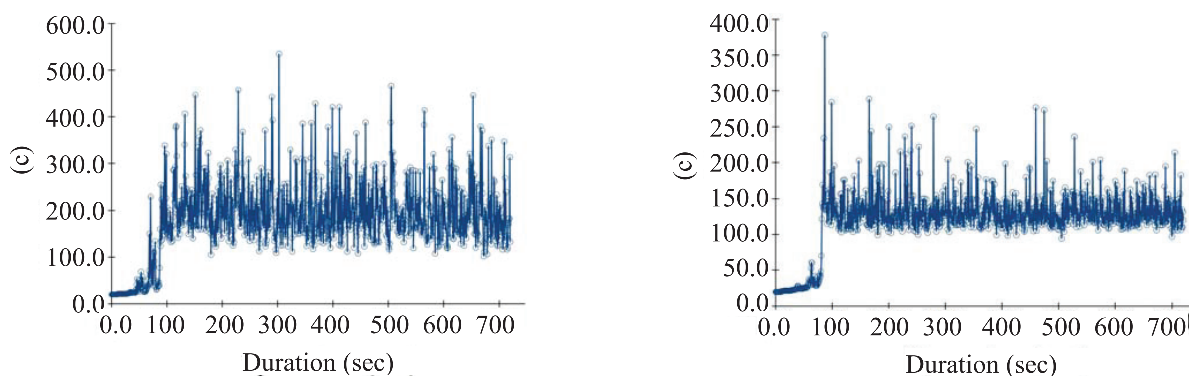
As a result of modeling, temperature distributions on the outer part of the façade of the building were determined, as well as the dynamic indicators of sensors placed on the surface of aluminum composite panels for facades and on the body of the air conditioner, which is located directly above the floor of the fire. Fig. 6 shows plots of the average temperature values on the surface of the air conditioning unit and on the surface of aluminum composite panels for facades that are located directly above the fire floor.

According to the analysis of the dynamics of fire evolution and the study of data on the intensity of heat release, it was determined that the greatest intensity of heat release occurs in the period between 120 and 720 seconds of modeling. The results of the calculation are reflected in the visualization of thermal distributions on the surface of the façade over time, shown in Fig. 7.

According to the results of the simulation, it was established that the existing fire load ensures a constant combustion temperature of the external air conditioning unit in the range of 700–710 °C from second 140 to second 720 inclusive.

At the same time, the thermal distribution of heating of the façade surface for aluminum composite panels increased throughout the duration of the simulation. The vertical projection of the thermal distribution on the surface of the façade indicates that the combustion of the air conditioner unit provides vertical heating of the façade surface within 250–265 °C with a width of 1.2 m to 1.7 m. The height of the thermal distribution was about 7.8–8.1 m. Visualization of the described results is shown in Fig. 8.

The data given in Fig. 6, 7 make it possible to analyze the critical heating temperatures of façade systems and determine the minimum required fire distances between external air conditioning units.



a *b*

Fig. 6. Plots of averaged temperature values on the surface over the duration of the simulation: *a* – temperature plot on the surface of aluminum composite panels for facades; *b* – temperature plot on the surface above the located external air conditioning unit

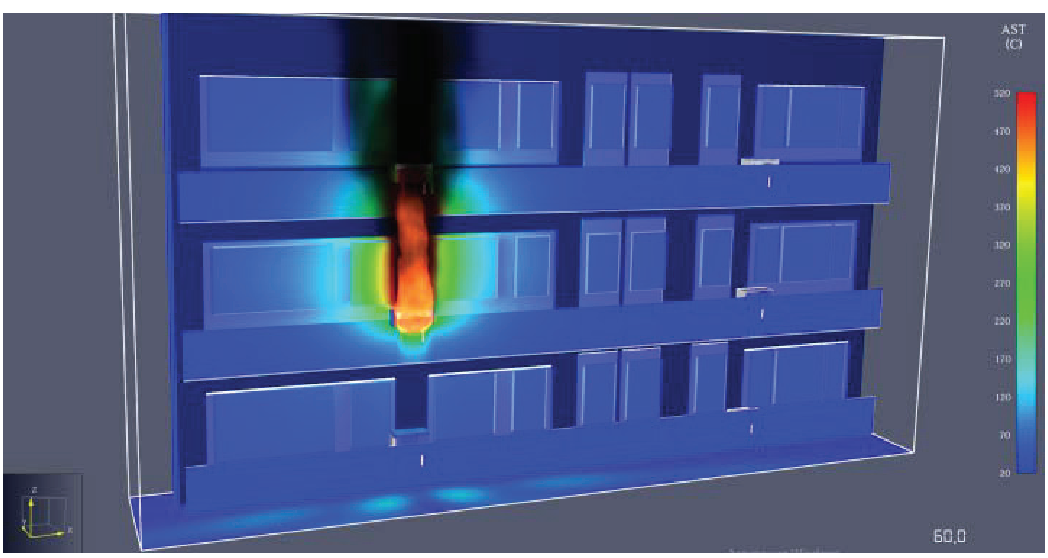


Fig. 7. Visualization of the fire of the external air conditioner unit and a change in the temperature distribution on the façade on second 300

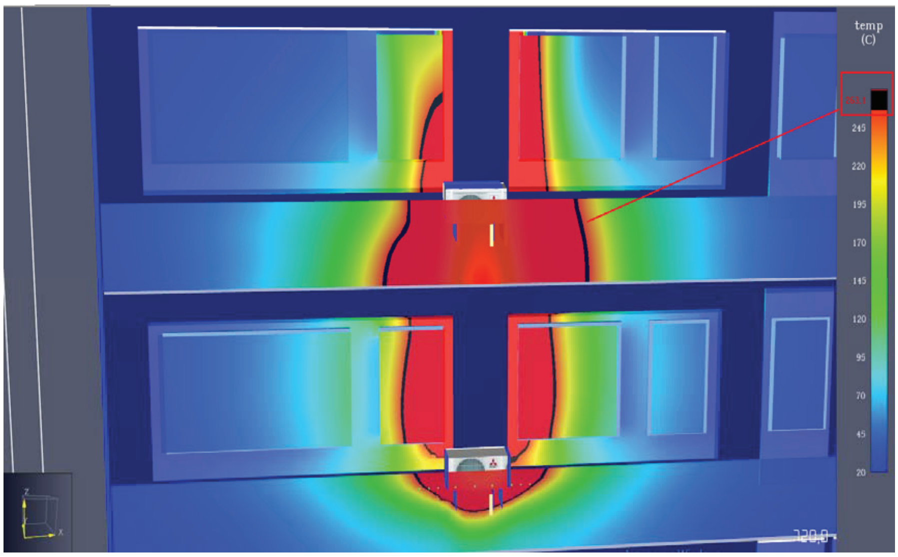


Fig. 8. Visualization of the temperature of the upward flow from the combustion of the external air conditioning unit on second 720 of modeling

5. 3. Proposals for the structural parameters to arrange air conditioner baskets to ensure the restriction of the spread of fire

Our analysis of the established dependences of the distribution of critical temperatures of heating the façade on a given model of the building revealed a high probability of destruction of external aluminum composite panels, both on the floor of the fire and on the floor above it. At the same time, it was established that the ignition of the air conditioning unit, which is located above the floor of the fire, occurs during the period of seconds 220–240 of modeling. The results of the analysis of horizontal temperature distributions from the fire of the external air conditioner unit show that the minimum fire distance between the external air conditioning units horizontally along one axis should be at least 2.5 m.

At the same time, the horizontal distance of the location of the external air conditioner unit, which is located above the floor on which the fire occurred in the air conditioning unit, should be at least 4.5 m from the axis vertically. This requirement is due to a greater projection of the horizontal distribution of thermal impact for the floor, which is located above the floor of the fire. Fig. 9 provides a diagram with an example of the safe arrangement of external air conditioning units based on our results of modeling.

Fig. 9. Diagram with an example of the safe arrangement of external air conditioning units

The results reported here are relevant under our modeling conditions, as well as for the accepted type of façade systems and their geometry. At the same time, these results must be verified by conducting field tests to confirm the temperature distributions received.

6. Discussion of results of modeling the spread of fire from external air conditioner units on the facades of buildings

Our analysis of temperature plots, which are shown in Fig. 6, showed that at the level of the façade, which is located above the floor of the fire, the heating temperature of the surface of the air conditioner body is in the range of 240–270 °C. The stable nature of the temperature curve can be explained by the fact that this type of fire can be attributed simultaneously to categories B (combustion of liquid substances) and C (combustion of gaseous substances). The metal structure of the body of the external air conditioner unit creates a clear vector of vertical distribution of the heat flow to the higher external unit, which is reflected in the visualization in Fig. 7, 8. Given the value of the critical temperature of 75 °C for the air conditioner body, we can assume a high probability of ignition above the located air conditioning unit, which, as a result, will contribute to the further evolution of the façade fire.

In addition, the temperature mode of the fire from the air conditioning unit can cause the destruction of the structures of filling the light openings according to the temperature criteria [25], and, as a result, cause the spread of fire inside the premises in the building. However, studying this hypothesis requires separate analysis and field tests for a more informed pattern of the problem covered.

The practical significance and implementation of the results is to identify the features of the potentially dangerous impact of the fire of an external air conditioning unit on the fire safety of the structure. The established temperature distributions will make it possible to assess the potential danger that can cause a façade fire, as well as to provide for promising measures to limit it.

The proposed example of the structural parameters for the arrangement of baskets of air conditioners to ensure the restriction of the spread of fire is designed on the basis of the vertical projection of the thermal distribution on the surface of the façade of the building. Specifically, the data that are given in Fig. 9 indicate that the combustion of the air conditioner unit provides vertical heating of the façade surface within 250–265 °C with a width of 1.2 m to 1.7 m, and a height of about 7.8–8.1 m. The scheme with an example of the safe arrangement of outdoor air conditioning units, shown in Fig. 9, is designed with a safety factor of 1.2 but without taking into account wind effects.

It should be considered that the potential impact on façade systems from a possible fire may vary depending on the types of external air conditioning units and the amount of fire load they include. In other words, further research and field tests could make it possible to determine the dependence of changes in the geometrical parameters of facades for the safe arrangement of external air conditioning units, depending on their type. In addition, there is an actual task to revise procedures for testing façade systems for the spread of fire, taking into consideration the possible presence of an additional fire load from the outside, which was not previously taken into consideration.

Separately, it should be noted that our studies require field tests and verification for the possibility of comparing the results of theoretical studies and modeling with the real conditions of the fire. In particular, it is advisable to conduct a study for façade systems of different types of configurations and materials of structures.

7. Conclusions

1. As a result of the analysis of the fire load of the standard components of the external air conditioning unit, its typical FDS model was reproduced, and a reaction of its initial combustion was created. Based on the example of the façade system of a building, its geometric and structural parameters are reproduced, taking into consideration the presence of baskets for air conditioners. When creating a model, one of the most dangerous typical incorrect examples of air conditioning device arrangement was considered, namely, when the air conditioners are placed sequentially on top of each other. The main criteria for assessing fire danger for the façade system of this type and the boundary states for its elements have been substantiated.

2. According to the results of our research, the possibility of spreading the fire by vertical construction structures in buildings was determined and it was shown that the structural parameters of the arrangement of air conditioners affect the fire safety of façade systems.

The simulation showed that the thermal distribution of heating of the façade surface for aluminum composite panels increased throughout the duration of the simulation. The spot of the vertical projection of thermal distribution on the surface of the façade of the building indicates that the combustion of the air conditioner unit provides vertical heating of the façade surface in the range of 250–265 °C with a width of 1.2 m to 1.7 m, and a height of about 7.8–8.1 m as well as inside the premises.

3. We have substantiated, for the specified modeling conditions, safe parameters for the installation of external air conditioning units in horizontal and vertical projections of the façade. It is determined that the minimum fire-proof distance between the external air conditioning units horizontally along one axis should be at least 2.5 m. In the case of the arrangement of air conditioning units on several floors, it should be borne in mind that the temperature impact and thermal distribution for the floor under which the fire occurred will actually be 1.8 times greater than for the floor where the fire occurred. Thus, it is advisable to place them in a chess order so that the upper air conditioner is 4.5 m to the side relative to the axis of the lower air conditioner.

References

1. Analitychna dovidka pro pozhezhi ta yikh naslidky v Ukraini za 12 misiatsiv 2018 2021 roky. Available at: https://idundcz.dsns.gov.ua/statistika-pozhezh/analitichni-materiali
2. Protecting your home from an air conditioner fire. Available at https://www.conditionedairsolutions.com/protecting-your-home-from-an-air-conditioner-fire/
3. Hunt, C. 6 Top causes of electrical fires (With Official Statistics): https://firefightergarage.com/electrical-fire-causes/#5_Air_Conditioners_3
4. Fires involving air conditioning fan coil units (2008 – 2014) (2022). Fire Analysis Report, 1 (2). Available at: https://www.scdf.gov.sg/docs/default-source/scdf-library/far-issue-2.pdf
5. 6 Air conditioner fire prevention measures. Available at: https://americanhomewater.com/air-conditioner-fire/
6. 8 Old air conditioner dangers and potential hazards. Available at: https://climateexperts.ca/blog/8-old-air-conditioner-dangers-and-potential-hazards/
7. The 5 Biggest HVAC Fire Hazards. Available at: https://www.irishheatandair.com/5-hvac-fire-hazards
8. DBN V.1.1-7:2016 Fire safety objects of con-struction. General requirements (2016). Kyiv: Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine, 12–36.
9. BS 8414 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to, and supported by, a masonry substrate (2020). doi: http://doi.org/10.3403/02713743u
10. DIN 4102-20 Fire behaviour of building materials and building components – Part 20: Complementary verification for the assessment of the fire behaviour of external wall claddings (2020). Available at: https://www.sis.se/en/produkter/environment-health-protection-safety/protection-against-fire/fireresistance-of-building-materials-and-elements/din-4102-20/
11. Dréan, V., Schillinger, R., Auguin, G. (2016). Fire exposed facades: Numerical modelling of the LEPIR2 testing facility. MATEC Web of Conferences, 46, 03001. doi: http://doi.org/10.1051/matecconf/20164603001
12. DBN V.2.2-15:2019 Budynky i sporudy. Zhytlovi budynky. Osnovni polozhennia. Z Popravkoiu. Nakaz No. 87. 26.03.2019. Available at: http://online.budstandart.com/ua/catalog/doc-page?id_doc=59627

13. Ning, Q., He, G., Sun, W., Fan, M., Li, X., Hong, Z. (2022). R290 leakage hazards assessment of a 1 HP split-type household air conditioner by concentration detection and ignition experiment. International Journal of Refrigeration. doi: http://doi.org/10.1016/j.ijrefrig.2022.04.005
14. Jia, L., Jin, W., Zhang, Y. (2017). Experimental study on R32 leakage and diffusion characteristic of wall-mounted air conditioners under different operating conditions. Applied Energy, 185, 2127–2133. doi: http://doi.org/10.1016/j.apenergy.2016.01.041
15. DBN V.2.2-9:2018 Budynky i sporudy. Hromadski budynky ta sporudy. Osnovni polozhennia (2018). Nakaz No. 260. 28.09.2018. Available at: https://dbn.co.ua/load/normativy/dbn/1-1-0-405
16. Pro zatverdzhennia Pravyla pozhezhnoi bezpeky v Ukraini (2014). Nakaz MVS vid 30.12.2014. No. 1417. Available at: https://zakon.rada.gov.ua/laws/show/z0252-15#Text
17. Li, K., Wang, J., Luo, S., Wang, Z., Zhou, X., Fang, J. et. al. (2020). Experimental investigation on combustion characteristics of flammable refrigerant R290/R1234yf leakage from heat pump system for electric vehicles. Royal Society Open Science, 7 (4), 191478. doi: http://doi.org/10.1098/rsos.191478
18. Yang, S. C., Chuah, Y. K., Lei, M. Y. (2016). Feasibility study of using air-conditioning ducting for smoke exhaust. Paper presented at the ACRA 2016 – 8th Asian Conference on Refrigeration and Air-Conditioning.
19. Gao, Z. M., Gao, Y., Chow, W. K., Wan, Y., Chow, C. L. (2018). Experimental scale model study on explosion of clean refrigerant leaked in an underground plant room. Tunnelling and Underground Space Technology, 78, 35–46. doi: http://doi.org/10.1016/j.tust.2018.04.010
20. EN 13501-1:2007+A1:2009 Fire classification of construction products and building elements – Part 1: Classification using data from reaction to fire tests. doi: http://doi.org/10.3403/30348263
21. Ballo, Ya., Yakovchuk, R., Nizhnyk, V., Sizikov, O., Kuzyk, A. (2020). Investigation of design parameters facade fire-preventing eaves for prevent the spread of fires on facade structures of high-rise buildings. Fire Safety, 37, 16–23. doi: http://doi.org/10.32447/20786662.37.2020.03
22. Anderson, J., Bostr m, L., Jansson, R., Milovanovi ́c, B. (2015). Fire dynamics in facade fire tests: Measurement, modeling and repeatability. Applications of Structural Fire Engineering. doi: http://doi.org/10.14311/asfe.2015.059
23. Nilsson, M., Mossberg, A., Husted, B., Anderson, J. (2016). Protection against external fire spread - Horizontal projections or spandrels? 14th International Fire Science & Engineering Conference, Royal Holloway College, 2, 1163–1174. Available at: https://www.researchgate.net/publication/306078631_Protection_against_external_fire_spread_-_Horizontal_projections_or_spandrels
24. Fire statistics and study on air conditioning fires. Available at: http://www.nfec.org.sg/events_past/NFEC%20Prevention%20of%20Air%20Con%20Fires%20Workshop%202016.pdf
25. DBN B.2.2-12:2019 Planuvannia ta zabudova terytorii (2019). Kyiv: Ministerstvo rehionalnoho rozvytku, budivnytstva ta zhytlovo-komunalnoho hospodarstva Ukrainy, 185.