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Roman Yakovchuk[1], Andriy Kuzyk[1], Taras Skorobagatko[2], Sergiy Yemelyanenko[1], Olexander Borys[2], Olexander Dobrostan[2]

[1]Lviv State University of Life Safety, Lviv, Ukraine;
[2]The Ukrainian Civil Protection Research Institute (UkrCPRI), Kyiv, Ukraine.
E-mail: yakovchukrs@ukr.net, andrij_k@yahoo.com, tarasskorobagatko@gmail.com, ldubgd@i.ua, undicz@dsns.gov.ua, dob2009@ukr.net

COMPUTER SIMULATION OF FIRE TEST PARAMETERS FAÇADE HEAT INSULATING SYSTEM FOR FIRE SPREAD IN FIRE DYNAMICS SIMULATOR (FDS)

Abstract. This paper considers issues related to fire hazard of constructions of external walls fit with façade heat insulation and finished with rendering which is dependent on constructive solution of the heat insulating system and type of heat insulating material. Appropriate works aimed at use of “Fire Dynamics Simulator” (FDS) software for the computer simulation of fire spread across façade system surfaces and comparison of experimental and calculated data were analyzed.

A number of full-scale fire tests were conducted of the external wall constructions fit with façade heat insulation and finished with rendering for fire spread while using 150 mm wide slabs fabricated of expanded polystyrene of “PSB-S-25” type as heat insulating material. Computer simulation of fire dynamics using FDS numeric tool was implemented and results obtained were compared with experimental data in order to check possibility of use of appropriate software for the reproduction of real conditions of fires at dwelling houses.

Key words: expanded polystyrene, heat insulation, façade heat insulating system, construction fit with façade heat insulation and finished with rendering, standard temperature/time curve, external fire, computer simulation, fire spread across façade, FDS, PyroSim.

Introduction. Arrangement of constructions of external walls fit with façade heat insulation and finished with rendering is rather a widespread measure not only at our state but abroad as well. Work purposed at heat insulation can be performed during new construction as well as while conducting reconstruction or general overhaul of existing buildings. State-of-the art heat insulating materials have wide range of application and heat insulation of roofs, external, internal and basement walls as well as that of ceilings and floors are performed using them. One of the most common uses of heat insulating materials is heat insulation of façades of the buildings and, hence, issues related to their fire hazard require appropriate attention and studying in order to lower risk of fire occurrence and its negative consequences. Examples of fires accompanied with fire spread across façade systems of the buildings denote their special fire hazard [1]. This hazard is related directly with constructional specific features of the specific building, type of heat insulating material used and parameters of the fire itself [2]. The most frequent cause of ignition of constructions of external walls fit with façade heat insulation and finished with rendering is spread of fire from the window opening due to intensive fire inside the room. Convection heat flows are able to ignite combustible finishing of external walls under these conditions. A number of factors influences process of fire spread across façade systems. The following ones can be specified amongst them: external conditions (heat flows coming from the window opening, temperature regimes of burning of the heat insulating material), fire hazard indices of the heat insulating material (ignition temperature, fire spread velocity across the material, self-ignition temperature etc.), and architectural and space-and-planning characteristics of the building.

Problem definition. Based on the results of analyzing thermal and physical characteristics of heat insulating materials we can affirm that not all of them meet fire safety requirements. In particular, expanded polystyrene demanded in the construction sphere at present has significant drawbacks related to fire hazard indices: it is a combustible material, a number of toxic substances are evolved from it during fire and, moreover, it increases a great deal fire hazard of buildings fit with façade heat insulation [3]. Burning of polymers is complicated physical and chemical phenomenon; it includes processes of heat and mass transfer, chemical kinetics of reactions taking place both in condensed and gas phases as well as a number of other factors. Wide assortment of polymer materials characterized by their chemical composition and structure, availability of a number of components within them, and their combination with other construction materials and wide application in the construction sphere make for special conditions of occurrence, development and extinguishing of fires involving facades of the buildings [4].

Constructions of external walls fit with façade heat insulation and finished with rendering using heat insulating materials and finishing layer belonging to "non-combustible" combustibility group can be used for buildings and constructions of 47 m conditional height without any limitations [5]. Adherence to fire safety requirements standardized for external envelopes is met in full in such the façade systems and fire spread across the surface has virtually no place. Fire occurrence and development can take place as result of violation of fire safety requirements while arranging façade systems using some layer of combustible heat insulation and finishing layer composed of some combustible materials because of non-adherence to or otherwise violation of the general rules of arrangement and use of buildings with façade heat insulating systems of external walls.

Hence, issues related to ensuring fire safety of constructions of external walls fit with façade heat insulation and finished with rendering as well as development of organizational and technical measures aimed at increasing fire safety of such objects gain significant actuality.

Analysis of the recent studies and publications. A number of domestic and foreign researches were engaged in studying issues of fire safety of façade systems. It becomes rather widespread recently not only to conduct full-scale tests of façade systems for fire spread as specified by appropriate international standards but to use Fire Dynamics Simulator (FDS) [6] special software for the computer simulation [7,8] of fire spread across the surfaces of heat insulating and finishing systems and to compare experimental and calculated data [9-19].

Paper [9] contains description of the results of a number of studies derived using FDS software (Fire Dynamics Simulator, version 4.0) being compared with experimental data. Purpose of the work was check-up of FDS software capabilities for the simulation of flame spread as well as determination of optimum values of the combustible load material for the engineers' use of FDS. Experimental studies included both conduction of tests as specified in [10] and full-scale tests for fire spread according to [11].

R.Jansson and J.Anderson in their papers [12, 13] studied fire resistance of façade constructions by experimental and computational methods. The test installation simulated three-floor building fit with external heat insulating and finishing system. Numeric model was created in FDS CFD software with similar geometry and instruments. The authors managed to reproduce in due manner real test conditions in their model, but temperatures nearby the fire source could not be have been taken into account duly.

Authors of papers [14,15] compare results of full-scale fire tests of façade systems conducted as specified by Swedish (SP Fire 105) and British (BS 8414-1) methods. Results of experimental studies and computer simulation represented by them take into account some variations of fire impact, fire load and type of fuel. CFD (Computational Fluid Dynamics) simulation in FDS allowed reproduction of the temperature values determined experimentally both qualitatively and quantitatively.

Test of façade system was conducted in [16] as specified by the method demanded by French technical specification (IT 249) for labour safety regulations. It is aimed at limitation of fire risks of fire spread across facades to the upper levels. Simulation of fire dynamics was conducted using FDS for the two full-scale experiments having been performed by "Efectis France" testing laboratory. Principal purpose of the mentioned study was estimation of the ability of the computational model to reproduce quantitative results of measuring gas temperatures and heat release rate at test façade for further evaluation of characteristics of fire impact upon the façade. Satisfactory results for temperature and heat release rate (HRR) were derived when comparing experimental data with those obtained by numeric calculations.

In papers [17-19] the authors studied experimentally impact of horizontal separating elements installed at various heights between exposed openings at the building façade upon external fire spread and compared derived data using Fire Dynamics Simulator (FDS) numeric tool. Numeric study was subdivided into that for validation and comparative analysis. Validation study was conducted for the estimation of FDS as instrument used for the calculation in order to simulate external fire spread; it was fulfilled using experimental data for large-scale fire test having been conducted using SP FIRE 105 test bench in the town of Buros (Sweden). SP FIRE 105 test bench is used for façade systems testing which simulates impact of fire involving ground floor of a three-floor dwelling house upon the upper façade. Conclusion was made that FDC version 6.2.0 could reproduce experimental results with high degree of detailing.

Principal purpose of this work was determination of the parameters of fire test of the construction of external wall fit with façade heat insulation and finished with rendering for fire spread using computer simulation, reproduction of the conditions of fire tests in due manner and check-up of the model developed by comparison of the derived data and results of the experimental studies.

Methods. Tests for fire spread were conducted on an external wall construction fit with façade heat insulation and finished with rendering using slabs fabricated from expanded polystyrene as heat insulating material.

The tests were conducted as specified by [20]. Essence of the test method lied in the determination of the sizes of the damaged section of the façade heat insulating system and temperature rise inside the heat insulating and finishing system having been applied to a fragment of two-floor building (figure 2) of 5.6 m total height at ground floor of which (fire chamber) temperature-time curve was being created close to standard temperature/time curve standardized by [21].

Type K thermocouples with 1.5 mm wires were used for measuring temperature inside the fire chamber; these ones were suitable for measuring temperature in the range of 0 °C to 1300 °C. Temperature inside the fire chamber was measured at least at nine point. Measuring junctions of the thermocouples were installed 190 mm to 210 mm from the surfaces of the walls. Layout of the thermocouples (T1 to T8) positioning in the fire chamber is shown on figure 1.

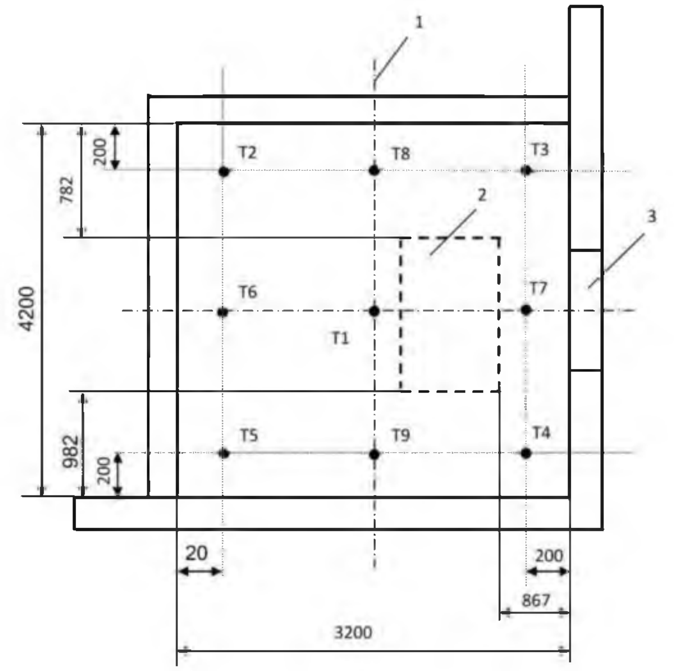


Figure 1 – Layout of the thermocouples positioning within the fire chamber:
1 – symmetry axis of the fire chamber; 2 – crib fabricated from wood bars; 3 – window opening;
T1 to T5 – thermocouples located at a distance of 200 mm from the ceiling surface;
T6 and T7 are thermocouples located at a distance of 850 mm from the ceiling surface;
T8 and T9 are thermocouples located at a distance of 1,500 mm from the ceiling surface [20]

Numeric simulation of the fire development and spread dynamics across the surface of heat insulating and finishing system was implemented using PyroSim instrument which is widely used software for fast and accurate operation of Fire Dynamics Simulator (FDS). PyroSim is graphical interface to FDS and it allows quick and convenient creation, editing and analyzing of complicated fire development models. Fire Dynamics Simulator (FDS) package of software was developed for the simulation of the processes of ignition and spread of fire [22,23]. The algorithms laid in its base are grounded upon physical laws of hydro dynamics and heat transfer. Smokeview software [24] was used for the two- and three-dimensional visualization of the fire dynamics simulation.

Fire Dynamics Simulator (FDS) realizes computational fluid dynamics model (CFD) of heat and mass transfer during combustion. Heat release rate is being calculated by finite elements method within three-dimensional mesh (simulation area). This software helps to reproduce real fire conditions in dwelling and commercial premises. Principal FDS purpose is solution of applied tasks in the sphere of fire safety and provision of the instrument necessary for the studying of fundamental processes during combustion.

Results. Measuring and recording of the temperature inside the building fragment was conducted at intervals not exceeding 1 min. Supervision of the test specimen was conducted as well and chronological description of its changes was compiled specifying, in particular, deformations, crippling, flame occurrence, cracks, smoke, softening, melting, materials charring and so on.

Figure 2 shows photos of the building fragments during the full-scale test at various moments.

a b c d

Figure 2 – Appearance of the building fragment at the time of testing at the following moments from the commencement: a – 5 min.; b – 20 min.; c – 30 min; d – upon removal of finishing and protective layer of façade heat insulation

Visual examination of the specimen was conducted following the test and dimensions of the damaged sections were determined which appeared within the specimen as result of fire impact. We considered damage to be charring and burning-out of the façade heat insulation materials as well as their melting. In order to determine sizes of the damaged sections of the internal heat insulation layer we removed external finishing and protective layer and made photographic survey of the specimen before and following the opening (figure 2 d).

Discussion. Maximum temperature rise values at the reference points within the heat insulating material (expanded poly styrene) layer compared with initial temperature at these points were 347 °C (T34) at 2.7 m height, 215 °C (T37) at 3.5 m height, 186 °C (T40) at 4.3 m height and 84 °C (T43) at 5.1 m height.

Dependency of the heat output of fire on time and appearance of the building fragment during computer simulation at various moments of time are shown on figure 3.

It was determined as result of computer simulation that maximum heat output of fire is reached at approximately 1,200 s (20 minutes) point of time and it is equal to 4600 kW. Local temperature values corresponding to maximum heat output reach 660 °C to 960 °C. Average temperature value within the burning area (fire chamber) at 20th minute equals to 760 °C to 780 °C.

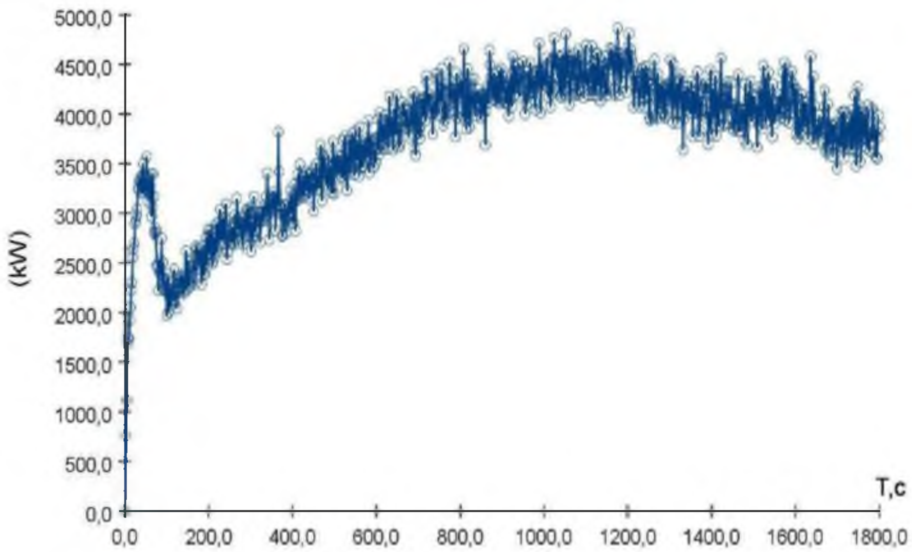
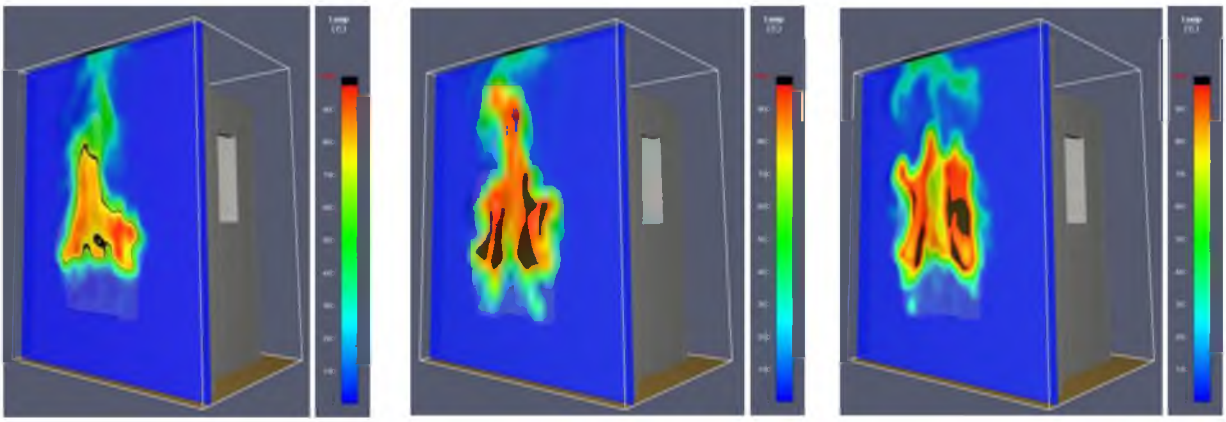


Figure 3 – Heat release rate versus time plot

We fulfilled prognostication of dynamics of development and spread of dangerous factors of fire (smoke, heat, carbon monoxide etc.) using computer simulation; moreover, we derived numeric values and graphic representations of temperature of combustion products and heat release rate, temperature distribution within the fire chamber, inside the façade heat insulation system as well as at its surface (figure 4), and heat release rate (figure 3). Derived results of computer simulation of the dynamics of fire development and spread across the surface of the heat insulating and finishing system conform rather well with the results derived by foreign authors.



a b c

Figure 4 – Temperature distribution on the surface of the building wall at the time of simulation at the following moments from the commencement: a – 5 min.; b – 20 min.; c – 30 min

Results of FDS simulation are used for numeric evaluation of the temperature values within the fire chamber, inside and nearby the surface of the construction of the façade heat insulation and their comparison with the data derived empirically (figures 5-7).

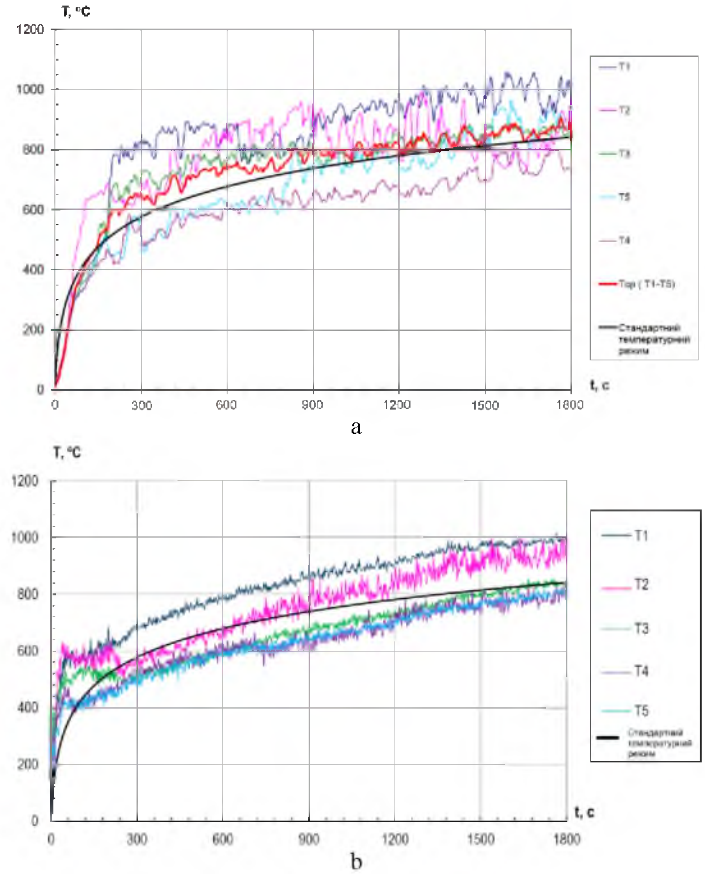


Figure 5 – Temperature evolution within the fire chamber (thermocouples T1 to T5): experimental results (a), FDS simulation results (b)

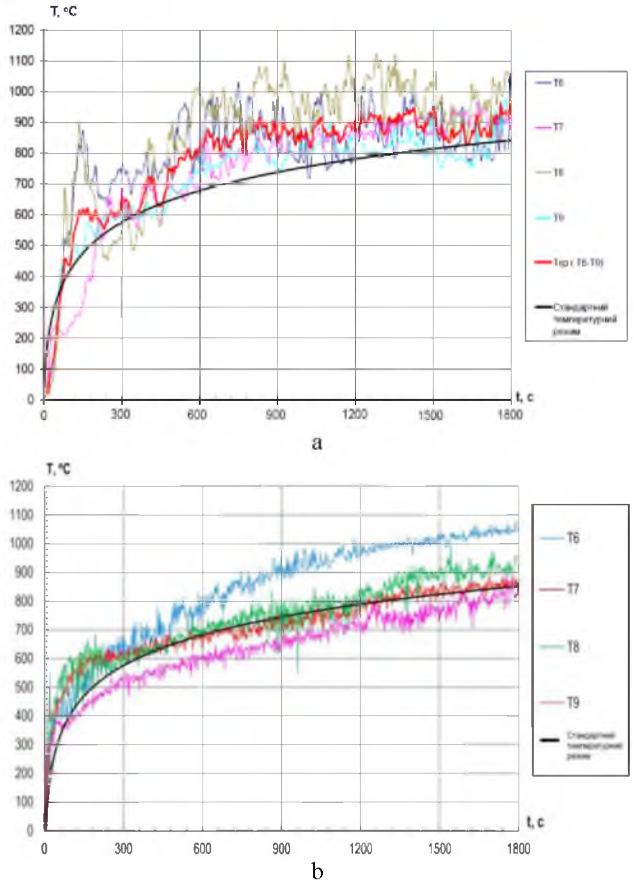


Figure 6 – Temperature evolution within the fire chamber (thermocouples T6 to T9): experimental results (a), FDS simulation results (b)

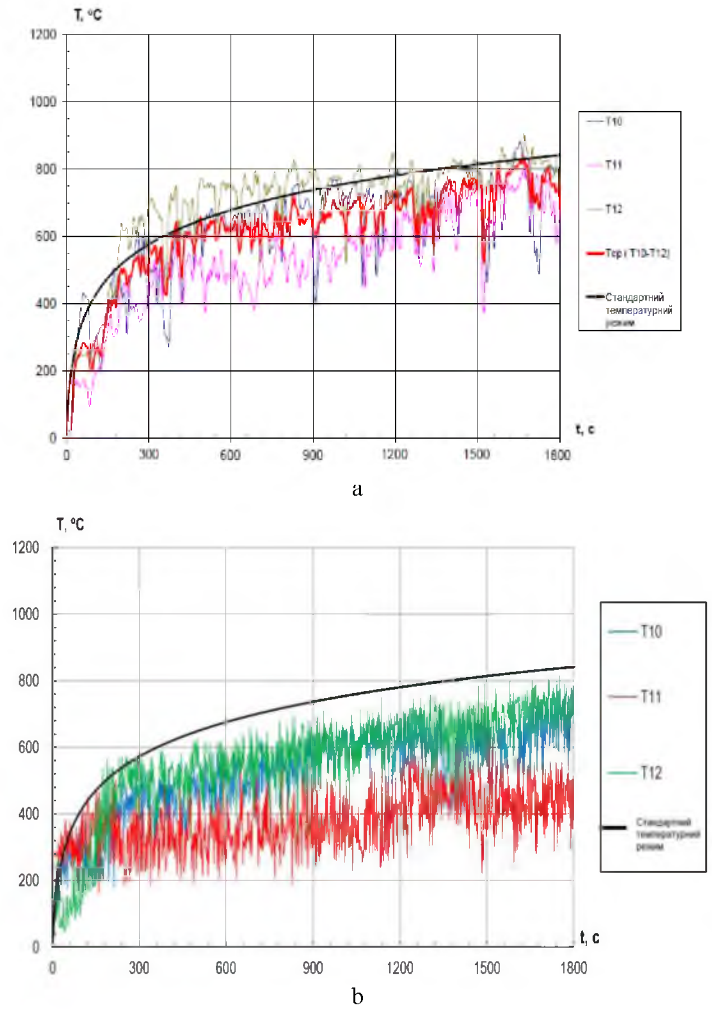


Figure 7 – Temperature evolution within the fire chamber (thermocouples T10 to T12): experimental results (a), FDS simulation results (b)

Conclusion. 1. Using computer simulation of the fire test parameters of the system of façade heat insulation for fire spread in FDS environment numeric and graphic performance were derived which characterize processes of occurrence, spread and development of fire across the surface of the system of façade heat insulation of a building. Simulation results derived allowed reproduction in due manner real conditions of testing, and when comparing experimental data and numeric calculations satisfactory results were obtained.

2. It was revealed as result of full-scale fire tests of a construction of external wall fit with façade heat insulation and finished with rendering and heat insulating material fabricated from expanded poly styrene slabs for fire spread that fire spread across the surface of the façade heat insulation did not take place beyond the boundaries of its direct contacting with flame generated inside the fire chamber.

3. Maximum values of temperature rise at the reference points within the heat insulating material layer (expanded poly styrene) compared with initial temperatures in these points are 347 °C (T34) at 2.7 m height, 215 °C (T37) at 3.5 m height, 186 °C (T40) at 4.3 m height, and 84 °C (T43) at 5.1 m height; these values do not exceed boundary one.

4. Results of the numeric simulation of fire test parameters of façade heat insulating system for fire spread in the FDS environment showed that general deviation within the theoretical calculations was not higher than that derived as result of the experimental researches. General temperature values within the fire chamber derived experimentally and numerically were different by 12 % to 16 %, value of the temperature in the window opening was underestimated by 16 % to 24 %, and temperature nearby the surface of the heat insulating and finishing system within the model was both overestimated by 22 % (T16 and T20) and underestimated by 18 % (T17, T21 and T19). Temperature values inside the façade heat insulating system did not exceed experimental data and deviation of average temperature values was equal to 16 %.

Роман Яковчук[1], Андрей Кузык[1], Тарас Скоробагатько[2],
Сергей Емельяненко[1], Александр Борис[2], Александр Добростан[2]

[1]Львов мемлекеттік тіршілік қауіпсіздігі университеті, Львов, Украина;
[2]Украина азаматтық қорганыс гылыми-зерттеу институты, Киев, Украина

ӨРТ ДИНАМИКАСЫ СИМУЛЯТОРЫНДА (FIRE DYNAMICS SIMULATOR (FDS) ОТ ТАРАТУ ҮШІН ҚАСБЕТТІК ЖЫЛУ ОҚШАУЛАГЫШ ЖҮЙЕСІНІҢ ОТТЫ СЫНАУ ПАРАМЕТРЛЕРІН КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

Роман Яковчук[1], Андрей Кузык[1], Тарас Скоробагатько[2],
Сергей Емельяненко[1], Александр Борис[2], Александр Добростан[2]

[1]Львовский государственный университет безопасности жизнедеятельности, Львов, Украина;
[2]Украинский научно-исследовательский институт гражданской защиты, Киев, Украина

КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПАРАМЕТРОВ ОГНЕВОГО ИСПЫТАНИЯ СИСТЕМЫ ФАСАДНОЙ ТЕПЛОИЗОЛЯЦИИ НА РАСПРОСТРАНЕНИЕ ОГНЯ В FIRE DYNAMICS SIMULATOR (FDS)

Аннотация. Особенность пожарной опасности теплоизоляционно-отделочных систем фасадов зданий, где в качестве теплоизоляционного материала используется пенополистирол, заключается в возможности распространения огня на выше и ниже расположенные этажи здания. Во время пожара происходит разрушение слоя декоративно-защитной отделки и возгорания большой площади горючего утеплителя обуславливает образование высоких температур и значительного задымления.

Угроза распространения пожара по теплоизоляционно-отделочной системе обусловлена не только пожарной опасностью материала, который в ней используется, но зависит также и от конструктивных особенностей конкретного здания и параметров самого пожара. Частыми причинами возгорания теплоизоляционно-отделочных систем наружных стен является опрокидывания огня из оконного проема здания в результате интенсивной пожара в помещении. В таких условиях конвективные потоки тепла способны занять горюче облицовки наружных стен.

На процесс распространения огня фасадными системами влияет ряд факторов. Среди них можно выделить следующие: внешние условия (тепловые потоки из оконного проема, температурные режимы горения теплоизоляционного материала) пожарно-технические характеристики материала теплоизоляции (температура воспламенения, скорость распространения огня по материалу, температура самовоспламенения и др.) архитектурные и объемно-планировочные характеристики здания.

В данной работе рассмотрены проблемы, связанные с пожарной опасностью конструкций наружных стен с фасадной теплоизоляции с отделкой штукатуркой, которая зависит от конструктивного решения системы теплоизоляции и вида теплоизоляционно материала. Проанализированы работы, направленные на использование программного обеспечения Fire Dynamics Simulator (FDS) для компьютерного моделирования распространения огня поверхностью фасадных систем и сравнения экспериментальных и численных данных.

Проведены натурные огневые испытания конструкции наружной стены с фасадной теплоизоляцией с отделкой штукатуркой на распространение огня, где в качестве теплоизоляционного материала использовали пенополистирол марки «ПСБ-С-25», средней толщиной 150 мм. Исследованием подлежала скрепленная фасадная теплоизоляция с отделкой штукатуркой и утеплителем из пенополистирольных плит. Сущность метода испытаний заключалась в определении размеров повреждения теплоизоляционно-отделочной системы и значение повышения температуры внутри теплоизоляционно-отделочной системы, нанесенная на фрагмент двухэтажного дома общей высотой 5,6 м, на первом этаже которого создавали в течение 30 минут температурный режим, близкий к стандартному температурного режима.

Численное моделирование динамики развития и распространения пожара поверхностью теплоизоляционно-отделочной системы выполняли с помощью инструмента PyroSim, который является популярным программным обеспечением для быстрой и точной работы с Fire Dynamics Simulator (FDS). PyroSim является графическим интерфейсом для FDS и позволяет быстро и удобно создавать, редактировать и анализировать сложные модели развития пожара. Пакет компьютерных программ FDS (Fire Dynamic Simulator) разработан для моделирования процессов воспламенения и распространения пожаров. Алгоритмы, которые вошли в его основу, основанные на физических законах гидродинамики и теплопередачи. Для трехмерной и двухмерной визуализации результатов моделирования динамики пожаров применяли программу Smokeview.

Основной целью данного исследования было получение числовых показателей, характеризующих процесс возникновения, распространения и развития пожара теплоизоляционно-отделочной системы внешней стене дома. Полученные результаты компьютерного моделирования позволили воссоздать должным образом реальные условия испытания, а при сравнении экспериментальных данных с многочисленными расчетами было получено удовлетворительные результаты температуры и теплового потока.

В результате численного моделирования было определено, что максимальная мощность пожара достигается на 1200-й секунде (20-я минута) и составляет 4,6 МВт. При максимальном значении мощности выделения тепла при пожаре локальные значения температуры достигают 660-960 °С. Среднее значение температура в зоне горения (огненная камера) на 20-ю минуту составляет 760-780 °С.

С помощью компьютерного моделирования было выполнено прогнозирование динамики развития и распространения опасных факторов пожара (дыма, температуры, угарного газа и т.п.), а также получено многочисленные и графические значения температуры продуктов горения и теплового потока, температурного распределения в огневой камере, внутри и на поверхности системы фасадной теплоизоляции, мощности выделения тепла (HRR). Полученные результаты численного моделирования динамики развития и расспространения пожара поверхностью теплоизоляционно-отделочной системы достаточно хорошо согласуются с результатами исследований зарубежных авторов.

Результаты FDS моделирования использовались для численной оценки значений температуры в огневой камере, внутри и у поверхности конструкции фасадной теплоизоляции для сравнения их с данными, полученными экспериментальным путем.

Ключевые слова: пенополистирол, теплоизоляция, система фасадной теплоизоляции, конструкция с фасадной теплоизоляцией с отделкой штукатуркой, стандартный температурный режим, пожар, компьютерное моделирование, распространения пламени по фасаду, FDS, PyroSim.

Information about authors:

Yakovchuk Roman, Lviv State University of Life Safety, Lviv, Ukraine; yakovchukrs@ukr.net; https://orcid.org/0000-0001-5523-5569

Kuzyk Andriy, Lviv State University of Life Safety, Lviv, Ukraine; andrij_k@yahoo.com; https://orcid.org/0000-0003-0118-9493

Skorobagatko Taras, The Ukrainian Civil Protection Research Institute, Kyiv, Ukraine; tarasskorobagatko@gmail.com; https://orcid.org/0000-0001-5651-1975

Yemelyanenko Sergiy, Lviv State University of Life Safety, Lviv, Ukraine; ldubgd@i.ua; https://orcid.org/0000-0002-2766-8428

Borys Olexander, The Ukrainian Civil Protection Research Institute, Kyiv, Ukraine; undicz@dsns.gov.ua; https://orcid.org/0000-0003-1236-7785

Dobrostan Olexander, The Ukrainian Civil Protection Research Institute, Kyiv, Ukraine; dob2009@ukr.net; https://orcid.org/0000-0001-8908-0729

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