Fire resistance limit for wood constructions in high-rise buildings

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Abstract. A significant problem in the construction area in the Russian Federation is a ban on high-rise wooden buildings. To solve this problem, it is necessary to study the state of the issue in the world and in the Russian Federation, and analyze the development prospects of this area. The necessity to optimize the existing methods for testing wooden building structures is shown. Examples of various documents regulating the production and use of wooden and composite building structures are given. The work reflects in detail the international experience in the implementation of the main provisions of regulatory documents and European tests for fire resistance, which shows the possibility of implementing such an experience in the Russian Federation. To develop a regulatory framework for wood structures in high-rise construction, it is necessary to conduct large-scale experiments on wooden structures to study their fire resistance. In this case, it is necessary to take into account the features of combustible building materials.

1 Introduction

The study of fire resistance limit for wood constructions in high-rise buildings is based on the review of modern facilities (in Berlin, London, Melbourne, and other cities), reflecting the state of high-rise wooden construction worldwide. In the buildings considered, together with the predominant wooden structural and wood-containing finishing materials, reinforced concrete structural elements necessary for the implementation of complex technical systems are used, which can significantly reduce the time of their construction. In addition, the chosen approach allows to enhance environmental friendliness of buildings and structures, – due to the use of wood-containing materials, huge volumes of carbon dioxide are preserved, and its emissions into the atmosphere during construction work are significantly reduced.

Recent investigations reflect the main provisions of technical regulation in the field of fire safety of building materials and structures in the Russian Federation. It is shown that the main reasons for the ban on using wooden structures in high-rise buildings are related to the peculiarities of technical regulation in the Russian Federation. In particular, it is the lack of the necessary testing and certification methods of wooden building structures in high-rise construction.

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In the recent years, large high-rise buildings and complexes have been under construction in many cities (for example, Moscow-City). These buildings include groups of premises for different functional purposes (residential, administrative, office, cultural and entertainment, health care, parking, etc.). One of the most important aspects in fire safety analysis is an investigation of real fire resistance limit for building constructions according to requirement:

\[ R_f > R_{req} \]

where \( R_f \) – real fire resistance limit,
\( R_{req} \) – required fire resistance limit.

A perspective direction in the investigation of fire resistance of building constructions is the analysis of the behavior of wood constructions at high temperatures.

To ensure fire safety and limit the spread of combustion products to other premises outside the fire area, the building is divided into fire compartments:
- for parts of the building of a certain functional fire hazard class (residential, public, car park, etc.);
- for groups of premises of one functional fire hazard class, if their area exceeds the maximum allowable floor area.

Volumetric planning solutions of modern multifunctional buildings are becoming more and more complex, buildings now include multi-level atriums, arcades, premises of large volumes and areas, fully glazed facades.

The implementation of fire safety requirements for fire resistance and for wood design, as well as for designing atriums (multi-storied) involves the use of innovative solutions, the introduction of new technologies to limit the spread of fire hazards.

High-rise buildings are designed mainly with the I Fire Resistance Rating. In accordance with the requirements of the regulatory and technical documentation of the Russian Federation, buildings of the I Fire Resistance Rating must have load-bearing and enclosing structures made of natural or artificial stone materials, concrete or reinforced concrete with the use of sheet and slab non-combustible materials. Wooden structures for buildings of the I Fire Resistance Rating are not provided. They can be used in buildings of III degree of fire resistance.

Buildings of the III Fire Resistance Rating have load-bearing and enclosing structures made of natural or artificial stone materials, concrete or reinforced concrete. It is allowed to use for floors wooden structures protected by plaster or low-combustible sheet, as well as plate materials. The elements of the coatings are not subject to requirements for the limits of fire resistance and the limits of fire spread, while the elements of the attic flooring made of wood are subjected to fire retardant treatment.

Buildings of the III Fire Resistance Rating with a frame structural scheme allow frame elements made of solid or glued wood, subjected to fire retardant treatment, which ensures the required limit of fire spread. Fencing structures can be made from panels or element-by-element assemblies, with the use of wood or materials based on it. Wood and other combustible materials of building envelopes must be subjected to fire retardant treatment or protected from fire and high temperature exposure in such a way as to ensure the required limit of fire spread.

According to the statistics of fires in buildings of various fire resistance ratings in Russia (2014-2019), the largest number of fires was registered for buildings of the III Fire Resistance Rating; the number of fires for buildings of II and III Fire Resistance Ratings is significantly higher than for buildings of the I; the largest number of deaths was registered for buildings of III Fire Resistance Rating.
But in international experience there are perspectives for wooden constructions use for high-rise buildings with the I Fire Resistance Rating (Canada, France, Japan, Australia etc).

It’s well-known that charing depth directly influences fire resistance limits of wooden constructions.

Charing depth change \( Z \) depends on heating time linearly. Charing depth value is equal to

\[
Z = \tau V,
\]

where \( V \) – charing rate.

Strength service characteristics of wood (resistibility; elastic module; folding strength) at standard fire mode prove that wooden construction fire resistance is closely equal to reinforced concrete construction fire resistance.

Modern technologies allow to create wooden structural elements of different sizes and profiles, but the original wood has a high fire hazard. The flammability of wood has historically limited its use as a building material, which is reflected in the building codes of most countries, especially for high-rise buildings.

In some foreign countries wood has been actively used for many years for construction of high-rise buildings and structures, including residential ones. The very significant role in the wide use of such structures in high-rise construction is due to their exceptional performance characteristics and environmental aspect, which is reflected in many scientific research works.

In the present work the most significant high-rise wooden facilities are given.

In the seven-storey E3 residential building in Berlin, built in 2008, all the floors except for the basement, are constructed of prefabricated wooden structural elements. The supporting structure is a frame made of glued wooden columns and beams with a section of 30x30 cm, in which massive wooden slab panels and blind walls are installed, made using the brettstapel method (boards are placed on the edge and nailed). All spaces between columns are blind panels or glazed ones, with wide "French" windows. After installing the wooden floor slab panels of each floor, the reinforcement was laid on them and the concrete part of the slab was poured. Thus, the inter-floor construction is hybrid: the lower part is wooden, and the upper part is monolithic reinforced concrete. The wooden surface was later left open at the finishing stage, resulting in all ceilings in the apartments being made of wood. There is one apartment on each floor. The layouts of all the apartments are different. There is an open reinforced concrete staircase outside the building. The walls are insulated with mineral wool and plastered. The open columns are made of steel and also covered with plater on mineral wool mats.

The Stadthaus nine-storey building in London, built in 2009, was constructed using laminated timber elements (figure 1,2). A large number of structural elements and openings were manufactured using high-precision equipment at the factory, which ensured their high quality. This structure was erected in less than 50 weeks, and it would have taken approximately twice as long for a building made of similar reinforced concrete structures. In addition, only four builders were needed to erect the supporting elements. Construction costs were significantly reduced due to the possibility of using less complex hoisting devices.
The Bridport multi-storey building in London was erected in 2011 (figure 3). Due to the peculiarities of the construction site it was impossible to place heavy reinforced concrete structures. A sensible alternative was to use laminated wooden panels as the main building material. It took only 12 weeks to erect the structure. For this purpose, Stora Enso factory in Austria produced 1576 m3 of CLT panels, which were brought to London and delivered to the site with natural fibre thermal insulation boards already attached. The outside of the building is lined with bricks. The exterior design is beautifully complemented by metal balcony consoles. The building looks as if it was built of bricks, like many buildings in London. The building project has received a number of public awards, including for environmentally responsible construction (in particular, for minimizing the so-called carbon footprint). Wilmott Dixon has calculated that 2,113 tons of carbon dioxide have been preserved in the timber as a result of its choice instead of concrete.
The nine-storey residential complex Via Cenni was erected in Milan in 2013. Its name can be translated as "a building with a well-thought-out life cycle". The technology proposed by Cree GmbH involves the use of hybrid structural elements made of glued wood, timber frame structures and reinforced concrete. The elevator stairway and plinth of the building are made of reinforced concrete (figure 4). An original solution has been used for the walls - frame wooden panels with glued wooden columns already attached to them. For prefabricated floor panels, the lower part is made of glued beams and the upper part is made of reinforced concrete. These parts are connected by fittings and work as a whole, which provides high load-bearing and noise-proofing capacity with significant saving of basic building materials. The glued beams of the slab panels at the bottom remain open, being, along with wooden columns, a decoration of the interior, and the space between the beams is used for concealed communications.
The fourteen-storey residential building Treet Bergen was erected in Bergen in 2015 (figure 5). According to the developer Bergen and Omegn Building Society (BOB), half of the 62 apartments of the house were already sold at the beginning of construction. A special feature of the project is the combination of the wooden frame modules supplied from the Kodumaja factory (Estonia) with finished interior decoration and installed engineering systems) and a powerful external frame made of glued wooden elements of one meter thickness in the form of large-size trusses supplied from the Moelven factory (Norway). In the final phase of construction, a glass and concrete facade was erected.

The Brock Commons building in Canada, built for students, is a combination of wood and reinforced concrete construction techniques. The foundation is concrete and the structure is supported by reinforced concrete core elements to create a stable building. In addition, elements such as elevator shafts and stairwells, which are essential for the safety of people, are not without metal structures. The rest of the building is constructed exclusively from timber. This feature of the building, together with a large number of
wood-based finishing materials, ensures its high environmental friendliness, which was also observed during construction - a significant reduction in carbon dioxide emissions was noted due to the use of a large number of wood-based materials instead of traditional ones.

The HoHo Wien wooden complex is 84 m high and has an area of 25,000 m², consisting of three buildings. The skyscraper has residential and business areas, a hotel, restaurant, sports, beauty and wellness centers. About 75% of the building (frame, facade, walls, interior decoration) is wood. According to the technology, the wooden building is erected around a reinforced concrete well with elevator shafts, stairs, communications and engineering systems.

Ten-storey residential complex Banyan Wharf with one-, two- and three-bedroom apartments is made of steel and laminated wood.

8-storey building “Wood Innovation and Design Centre” in Prince George, Canada (architect Michael Green), – the highest wooden building in Northern America and one of the highest in the world: the height is 29.5 m (figure 6). Wooden floorings in the building have two layers: CLT panels are located on beams with big gaps, and other panels are laid upon them. Communications and fire sprinklers are located between the layers.

![Fig. 6. Wood Innovation and Design Centre.](image)

American company Skidmore, Owings and Merrill LLP (SOM) developed the project of 42-storey building, in which all construction elements, except for beams, are wooden. Such solution was called “Concrete Joined Timber Frame” (figure 8). Concrete beams allow to exclude shrinkage and swell of wood throughout the height of the construction.

![Fig. 7. Concrete Joined Timber Frame.](image)
Two low storeys are considered to be done from concrete. Other storeys contain 70% of wood, 30% of concrete.

Canadian bureau CEI Architecture presented the project of office building “Office Building of the Future” (40 storeys).

Building construction contain two concrete lift and stair combinations and four strong concrete beams with all the height of a building. Horizontal elements are frameworks from glued laminated wood and based on them CLT panels. Glued laminated columns are considered on the façade as an additional support for cantilever framework.

Every ten storeys are splitted with the recreative storey with green terrace.

The use of wooden constructions provides:
- environmentally friendly construction;
- building stability;
- heat resistance of the building;
- economical manufacture of elements;
- mounting speed.

While evaluating actual fire resistance limit for wooden construction, calculated charing depth $Z$ is equal to:

$$Z = Z_f + \delta,$$

$\delta = 5$ mm – wooden layer behind the charing front, which doesn’t resist loads on the element, $Z_f$ – wooden charred layer depth.

Experimental research demonstrated that temperature distribution at the section of glued wooden construction element can be presented as following:

\[\text{Fig. 8. Temperature distribution from the edge of the top layer to the center of the section of a glued wood element under heat exposure: 1 – within 30 min; 2 – within 60 minutes.}\]

Charring rate influence fire resistance limit, taking into account structural section. Structural fire safety engineering should use reliable calculation methodologies for fire resistance limits of the constructions. Building construction should maintain its load-bearing function during a period of time longer than the time required to be safe:

$$R_f > R_{req},$$

where $R_f$ – real fire resistance limit for loaded constructions,

$R_{req}$ – required fire resistance limit.
Fire resistance limit for wooden element or construction on the assumption of bearing-capacity failure is equal to:

\[ R_f = \tau_0 + \tau_c = 4 + \frac{(Z_c - \delta)}{V} = 4 + \frac{Z_{fc}}{V}, \]

\( \tau_0 \) – time from the beginning of flame impingement till wood ignition (taking into account standard temperature mode of fire and wood selfignition temperature, 3 of 4 minutes are considered in the calculation for various timber species with the humidity 2-12% respectively), \( \tau_c \) – time from the beginning of selfignition (charing beginning) till limit state at fire, min, \( \delta \) – depth of wooden layer, heated up to temperature values 230-250°C and located behind the charring front (in calculations 5 mm).

Actual fire resistance limit assessment in accordance with standard methods based on temperature values (selfignition, standards fire mode) is insufficiently accurate comparing with the values for real fires with real fire load, taking into account building functionality.

The authors suggest scenario modeling for large-scale fire tests with simulated fire load, taking into account building functionality (offices, residential buildings, sport facilities etc.).

Based on results of ignition time assessment for glued laminated wood specimens with external heat flow of various rates (20, 30, 40 kWt/m2), critical areal heat flow density values were determined. This value is characterized by minimal heat flow density, at which stable flame ignition of the specimens is observed.

Glued laminated wood specimen (№ 1) should be classified as “medium-combustible” with critical areal heat flow density 12 kWtBr/m2, close to parameters of natural wood of coniferous species, with average value of critical areal heat flow density – 13,0 kWt/m2.

While evaluating flame spread index it is important to determine time for fire front location at each part of the specimen surface, exit gas temperatures, time values for maximal temperatures, fire spread rate at the specimen surface.

Fire test results demonstrate that the elements of glued laminated constructions are characterized by low stability against ignition and high fire spread rate at the specimen surface at high-temperature exposure or fire. These results prove that it is necessary to develop effective methods for fire resistance limit increasing to achieve required values, including use of various fire-proof coatings.

The main approach to fire resistance assessment for glued laminated wooden constructions should be based on scenario modeling for large-scale fire tests with real fire load. This modeling is necessary for the development of normative requirements for fire resistance limits of wooden constructions (building material “wood”).

In general, there have only been limited studies of the fire resistance of wooden structures compared to traditional building structures (metal, reinforced concrete), as wooden structures were very rarely used in the design of high-rise buildings.

The main regularities needed to study the limits of fire resistance of wooden structures are: the temperature of the beginning of wood charring (270°C), which is achieved on the wood surface in 4 minutes after the beginning of the standard thermal impact of fire, the conditional speed of charring (the speed of the charring front advancing), including the influence of angular curves (for coniferous wood – 0.7 mm/min).

Speed of charring if it is one-sided is constant in time. Calculated value of charring depth \( b \) of conditional charring depth is determined by the formulae.

In order to establish the fire resistance limit of wooden structures and assess the depth of charring under the conditions of standard fire tests in Russia, a series of tests were conducted.

After the fire tests to determine the fire resistance limit, charring of the structure to a depth of 40 mm was fixed. The average charring speed was 0.69 mm/min.
For the inside load-bearing wall structure, the limit states in the fire resistance test are: loss of load-bearing capacity (R) due to a structural collapse or limit deformation (the limit vertical deformation for a given fragment of the inside load-bearing wall structure is 23.0 mm); loss of integrity (E); loss of thermal insulating capacity (I).

During the testing of prototypes, the following characteristic features of their behavior have been fixed. At the 5th-7th minute of testing the beginning of thermal decomposition of glued laminated timber of prototypes characterized by intensive smoke formation was fixed; at the 22nd-24th minute - charring of the surface layer of wood to a depth of 5-7 mm; at the 63-65th minute - achievement of the limit state of integrity loss (E) of the structure as a result of burning the joints of the wall lumber and penetration of products of combustion and flame into the unheated surface. The vertical deformation of the 1st and 2nd prototypes was 7.8 and 7.3 mm, respectively. The average temperature (at the controlled points) on the unheated surface of the samples at the moment of the fire effect end did not exceed 29°C.

Fire resistance limit of the inside load-bearing wall fragment made of glued bar, REI 60.

The fire tests carried out on various wooden structures showed that they have fire resistance limits sufficient for use in construction of multi-storey buildings of various functional purposes.

One of the promising directions to assess the fire resistance of wooden structures for high-rise buildings is to analyze the behavior of building fragments under conditions of large-scale fire tests.

The possibilities of conducting large-scale specialized research with on-site testing of building fragments attract the attention of a large number of specialists in the field of integrated safety. Internationally, there is a need for large-scale specialized testing, the results of which can be shared among different countries. Large-scale specialized equipment is available from NIST, FM Global, the Canadian National Research Council and Carlton University in Ottawa, France, Japan and Australia.

International experience has shown that the choice of building height is crucial when conducting large-scale specialized studies with on-site testing of fragments. For low-rise buildings, ensuring the safety of people means meeting the conditions for safe evacuation from a building. In high-rise buildings, many people may be trapped above the floor on fire. For buildings up to 8 floors (height of fire escape ladders) there is the possibility of extinguishing and rescuing people by means of stairs, but it becomes difficult to use these methods when the height of the building is increased by more than 3 or 4 floors. The higher the building, the higher is the probability of a fire occurring on the upper floors and the higher is the probability of blocking people on the floors above the floor on fire [1]. When designing wooden buildings with the height of more than 8 floors, it is necessary to provide for increased fire resistance of structures in comparison with normative.

Thus, the main focus of international research is on fire resistance of wooden structures and wooden structural elements for units and joints and fire behavior of composite wood-containing materials for wooden facade panels.

A full-scale research project TF2000 (Timber Frame 2000) was carried out in the UK to study a multi-storey wooden building. The project's program included a study of the building's stability during and after construction, under various static and dynamic influences, and a study of the building's acoustic performance and fire hazard.

The aim of the building fire safety program was to investigate fire development and the possibility of using wooden stairs for evacuation. The experiment simulated the development of a real fire in an apartment on the third floor. The temperature, heat flux density, visibility and gas composition of combustion products were measured. Maximum temperatures in the apartment reached 1000 °C, and in the structural voids that form the boundaries of the compartment, in general, remained below 100 °C.
The experiment was discontinued at the 64th minute after the destruction of the protective plasterboard layer on the ceiling directly above the place of ignition, when the load-bearing wooden beams were exposed to open fire, which lasted for a given time. The results of the experiment showed that a multi-storey building with a wooden frame met the requirements of the UK building regulations. Despite the more intense fire conditions than at standard temperatures, the fire compartment has retained its integrity and the supporting structures remained strong. Plasterboard sheets have shown their effectiveness in protecting wood from open fire.

An experiment to assess the feasibility of using wooden escape stairs in multi-storey residential buildings was aimed at checking the possibility to use them for evacuation of residents as well as for firefighters. For this purpose, all components of the wooden stairs were treated with flame retardants and a thermal hardening adhesive was used to join the components. The stairs were finished with one layer of 12.5 mm thick GPB, fixed after 150 mm. Several ignition sources were installed in the stairwell and on stair steps. The fire test lasted 31 min. Experiments have shown that the integrity of the staircase design is preserved during the time required for evacuation of people and fire extinguishing works.

However, in Europe there is a steady trend towards increasing the number of storeys of wooden buildings. Normalization of the number of storeys in some European countries is shown in Table 1. Thus, in Sweden, France and the Netherlands, construction of eight-storey wooden buildings is allowed without automatic fire extinguishing systems [2-30].

Table 1. Normalizing the number of storeys of wooden buildings in Europe.

<table>
<thead>
<tr>
<th>Building characteristics</th>
<th>Permissible number of storeys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Czech Republic</td>
</tr>
<tr>
<td>Number of storeys without fire extinguishing</td>
<td>3</td>
</tr>
<tr>
<td>Wooden facades (without fire extinguishing)</td>
<td>3</td>
</tr>
<tr>
<td>Wooden partitions:</td>
<td></td>
</tr>
<tr>
<td>— in apartments</td>
<td>8</td>
</tr>
<tr>
<td>— on evacuation routes</td>
<td>No</td>
</tr>
<tr>
<td>Wooden partitions:</td>
<td></td>
</tr>
<tr>
<td>— in apartments</td>
<td>8</td>
</tr>
<tr>
<td>— on evacuation routes</td>
<td>No</td>
</tr>
<tr>
<td>Possibility of increasing the number of storeys with fire extinguishing</td>
<td>No</td>
</tr>
</tbody>
</table>

Classification in the field of fire resistance of building structures in Russia and Europe does not have serious differences, but in the field of fire hazard of building materials the European classification has its distinctive features. The European system of classification of building materials by fire hazard is based on a set of European standards (EN) of testing. Realization of this system in national building norms and rules differs, but the majority of the countries use the European classification alongside with national.

2 Test methodology

In the Russian Federation the possibility of using wood in construction is determined by a group of tests, which are divided into tests of wood as a building material and as a building
structure. Accordingly, wood is assigned both the fire hazard class of building materials and the fire hazard class of building structures.

In the Russian Federation, the main document regulating the testing of wooden building structures is GOST 30403-2012. When testing other types of building structures, the fire resistance limits of metal and reinforced concrete structures are assessed. However, the Russian regulatory documents do not contain the provisions and requirements necessary for testing such wooden structures.

In GOST 30247.1-94 the limiting condition for loss of bearing capacity (R) is a collapse of the structure or its limiting deformations. Besides, in this document limiting conditions on thermal insulating ability (I) are regulated, which is limited to achievement of limiting temperatures on an unheated surface, and also on loss of integrity (E) at occurrence of through apertures and cracks, that leads to penetration of products of combustion and a flame.

GOST R 53295-2009 "Fire protection means for steel structures. General requirements. Method for determination of fire protection efficiency" describes the method of determining the time of achieving the limit state, characterized by the critical temperature inside the sample or on its unheated surface.

The method given in GOST 30403-2012 allows to estimate the behavior of a building structure in natural conditions: a part of the sample is in a fire chamber that simulates a fire, and a part is separated by a partition with an opening that allows to estimate the behavior of unheated structures in case of a fire. Based on the results of such tests, the building structures can be assigned a fire hazard class [31-49].

To solve the problem, it is necessary to optimize the regulations governing the testing of wooden constructions.

Thus, when testing bendable structures in accordance with GOST 30247.1-94, the limiting state for loss of bearing capacity is the structural collapse or limiting deformations, which can be used in the study of wooden structures. It is known that the calculated criterion for determining the fire resistance limit of wooden structures (e.g., wooden beams) is the time to reach the limit section area, at which the strength of the section is equal to the calculated bending moment from the load. Obviously, modern calculation methods must have experimental confirmation, which in turn requires the development of appropriate test methods.

The issue of determining the class of fire hazard of building materials, which is formed of fire hazard groups, is sufficiently developed in the Russian Federation. The class of structural fire hazard of a building is established according to the combination of fire hazard characteristics of the materials used for construction [3-5, 7]. In the European countries within the framework of the "Wooden Europe" program and similar programs various documents, regulating the production and use of wooden and composite building constructions, are developed.

3 Results

Issues of fire safety of wood materials and structures are considered in a large number of foreign scientific papers [1, 2, 6]. Vancouver architect Michael Green (2012) presented possible projects of 10-, 20- and 30-storey wooden buildings in the document "The Case for Tall Wood Buildings - How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures" [1].

Skidmore Owings and Merrill (SOM, 2013) prepared a feasibility study for a 42-story timber building in Chicago, The Timber Tower Research Project, based on an analysis of an existing reinforced concrete tower of the same size. The work emphasizes the need to
analyze the time of burnout and avoid the spread of fire over the floors [1]. Flammability tests are also recommended.

Buchanan (2001) in "Structural Design for Fire Safety" identifies four criteria that are considered when determining the fire resistance level depending on the size and type of building:

- the time for safe evacuation;
- the time of rescue by firefighters;
- the time of firefighters' containment and liquidation of fire;
- complete burnout of the fire compartment without intervention of fire units.

Thus, when implementing projects with the specified technical and economic indicators, various national fire safety regulations contain the following requirements:

- fire resistance limits of structures and fire resistance level of the building, specified by technical regulations;
- fire safety equivalent to a steel or concrete structure that meets the standards;
- actual fire resistance limits (to ensure safe evacuation and/or fire extinguishing);
- fire resistance to complete burnout in the absence of fire extinguishing.

High-rise buildings should be designed in such a way as to provide very low probability of fire spread to the upper floors and very low probability of destruction of the structure at any moment of fire, regardless of whether there are ways to influence the development of fire (fire departments, fire extinguishing systems) [1].

4 Conclusion

The analysis of modern multi-storey wooden buildings shows that it is necessary to take into account the fire-resistant properties of wooden structures. For example:

- to investigate mechanical and chemical properties of wood (taking into account its structure, type, place of origin) under high-temperature (fire) and seismic effects;
- determine the behavior of wooden structures (taking into account the cross-section, type of timber, structure type) in a fire;
- study the processes of new growths in the surface layers of wooden structures (layer-by-layer in the wood section) with and without fire-protective coatings under the influence of man-caused factors (in combination with high-temperature impact for different fire modes with seismic impact);
- determine the rate of charring as a function of fire exposure and study the conditions of self-extinction of the charred wooden structure to model the calculated values of fire;
- study the peculiarities of fire development in the presence of voids in vertical and horizontal wooden constructions;
- determine the impact of active and passive fire protection on the possibility of reducing the fire resistance limits of wooden structures and the fire resistance of the building;
- study the stability of different types of structural schemes of wooden buildings with different number of storeys in fire conditions.

Important areas of research in the field of fire safety of wooden buildings are:

- development and substantiation of standard technical solutions to ensure the required fire hazard parameters and fire resistance of wooden structures;
- creation and development of a database of fire safety characteristics of wooden structures on the basis of experimental research.

The development of normative provisions on the possibility of using wooden structures in high-rise construction includes:

- conducting large-scale experiments on wooden structures.
- analysis of "burnout of fire compartment" model and research of destruction of structures and vertical fire propagation.
- optimization of methodological provisions in the technical regulation of this issue.

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