Chapter 23

The Heat Radiation of Wooden Facing on Facades

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Abstract

The chapter deals with the heat radiation of wood during fire. The aim is to verify the theoretical assumption about the heat radiation of spruce wood. For the purpose of verification, the temperatures and radiation were measured under laboratory conditions. The results were compared with the theoretical calculation.

Keywords: wood, heat radiation, temperature, heat flux density

1. Introduction

The natural material, wood, has been newly and increasingly used in the construction industry in the Czech Republic. In the world, particularly in the USA and Canada, there are buildings from wood (i.e. wooden building) common. Under the conditions prevailing in the Czech Republic, there has been an increase in the number of wooden buildings in recent years, especially with regard to their cost and rapid implementation in the construction. Ever more popular is the use of wood as the cladding material even though the negative qualities of wood as a low biological resistance and high flammability are pointed out. The situation is not so tragic from the perspective of fire-safety engineering. Although it is a flammable material, the wood has fire resistance when it is properly used. In the construction industry, it can be used safely with the proper implementation of construction and compliance with other regulations. To prevent the spread of fire from the burning object, the safety distance between the objects should be defined. Around the burning object, there is fire danger zone where there is the risk of transmission of fire, thanks to heat radiation. In the Czech Republic, as well as in many places in the world, there exists some codex of standards that address this problem. The Czech technical standards for the area of safety distances and their settings are based on the principle of restricting the fall of flammable structures and limiting heat flux density from the adjacent building. The aim of the article, based on a series of experiments, is to evaluate that standard values of a heat flux density are realistic for the calculation of safety distances from outside wooden wall.

1.1. Theoretical analysis

According to Jönsson et al. [1], the fire spreading between buildings is caused mostly due to radiation. However, the influence of radiation can cause an ignition of the material at a much longer distance than by convection–thus a direct contact of the flame, as was described by McGuire [2] already in 1965. The characteristic value for radiation when there is an ignition of wood is 33.5 $kW.m^{-2}$ for the auto-ignition (i.e. the inflammation with the absence of sources of ignition) and 12.5 $kW.m^{-2}$ for the ignition in the presence of sources of ignition, that can be, for example, sparks as presented by Barnett [3]. These values are commonly used worldwide.

Carlson [4] states that factors influencing the transmission of the radiation between the burning object and vulnerable object are the effect of the flame from holes, the emissivity of the flame, the configuration factor and the intervention of fire fighters. From the basic physical relationship of heat transport, $E = \varepsilon\sigma T4$, it is obvious that the temperature has the greatest influence on the size of the radiated energy. As given in Refs. [5, 6], the rates of burning depend on the wood species, its density, its moisture content and the type of facades and their ways of using. Clark, in 1998 [7], conducted a series of experiments that showed the temperature of ignition of the material is caused by radiant heat. Clark also dealt with the effect of wood moisture on its radiation. He found out that higher wood moisture has an effect on the value of heat flux and on the ignition timing. Clark points out on the study deals with the influence of wood moisture carried out by Janssens in 1991 that has been found that the heat flux is approximately between 10 and 14 $kW.m^{-2}$.

Most of the studies show three situations how a fire spreading occurs along the surface of the facade. The first one is a case where the object catches fire from outside (so along the facade); it occurs either by radiation or by the action of the flames from the adjacent building. The second situation of the initiation is due to the sources of ignition that are from the nearby buildings such as fire dustbins, cars etc. The third one is the fire inside the building, while there is spreading of fire out of the window. Therefore, the most building regulations in the European countries limit the using wood and its products on low buildings–maximally on three-storey buildings. There is a small percentage of limitation on the total surface of the facade for using wooden facing. According to the European harmonized classification, for facing materials, the material should be of class B-S3, D2, while the wood-based panels are generally classified as D-s2, d0 [8]. There is the national standard for fire protection called ÖNORM in Austria, for example ONR 22000 Fire Safety in High–Rise Buildings or ÖNORM B 3806 Requirements for fire behaviour of building products (building materials) valid from 01.07.2005. There are also the OIB Guidelines of Austrian Institute of Construction Engineering that deal with general requirements and stability of fire, behaviour of construction materials when on fire, requirements for fire resistance of building materials etc. According to the standard ÖNORM B 3800-5, the aim of the protection of object against the fire spreading is:

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Fire behaviour of building materials and components–part 5: Fire behaviour of facades: The fire cannot spread along the surface, large parts cannot fall down and people cannot be endangered.

1.2. Solving the issue in Czech conditions

In the Czech Republic, the walls that are having a heat flux density on the surface higher than 15 kW.m^{-2} [9] are considered as fully or partially open danger surface and the safety distance depends on them. The fire danger zone is formed around burning objects where there is a risk of transmission of fire due to heat radiation or falling of construction parts of burning objects. The size of fire danger zone is defined by the safety distance from open danger surface of the fire section of the object. The fire danger zone cannot interfere over the border of building land, but it can interfere in the public spaces such as streets, squares, parks, etc. In this space could be other objects only when the peripheral walls of these objects dispose with an open danger surface with the species DP1 or when the walls have surface covering of other products wide at least 20 mm and with the fire classification A1 or A2. The peripheral wall with insulation must have these types of modifications with a flame spread index (FSI) of 0 mm.min^{-1}.

Fully open danger surface of peripheral wall or its part is defined as the surface with heat flux density greater than 60 kW.m^{-2}, at the time required for fire resistance for outer side of the peripheral wall. This fully open danger surface could also be considered if there is no fire resistance and outer side of walls is made from materials of the fire classification E or F. The amount of heat released is higher than 150 MJ.m^{-2}. From the calculation of heat flux density, another classification of peripheral wall could be established. The same applies for peripheral wall species DP1 or DP2 that have materials from outer side of fire classification B to D with the amount of the released heat higher than 350 MJ.m^{-2}.

A partly open danger surface is the surface of peripheral wall or its part that reports the heat flux density from 15 to 60 kW.m^{-2} at time required for fire resistance for outer side of the peripheral wall.

The main criteria for determining the fully or partly open danger surface are the amounts of released heat from the products (materials) and the heat flux density on outer side of the peripheral wall. The amount of heat Q [MJ] released from 1 m^2 of flammable products of outer side of the peripheral walls is dependent on the calorific value of products H_i [MJ.kg^{-1}] and basis weight M_i [kg.m^{-2}]. This amount of heat is calculated using Eq. (1) [10]:

$$Q = \sum_{i=1}^{j} M_i \cdot H_i [\mathrm{MJ} \cdot \mathrm{m}^{-2}] \tag{1}$$

The determination of heat flux density I [kW.m^{-2}] from the burning surface of the peripheral wall may take into account the speed of burning surface m_v [kg.m^{-2}-min^{-1}] and this heat transfer [9]. This heat flux density is calculated using Eq. (2):

$$I = 0.35 \cdot \frac{m_v \cdot H_i}{60} [\mathrm{kW} \cdot \mathrm{m}^{-2}] \tag{2}$$

The total heat flux density is multiplied by the coefficient, 0.35. This coefficient shows the quotient of radiant component in heat transfer. A burning speed (m_v) is experimentally determined or it is used in the tabular values.

The released heat from 1 m^2 of the outer side of the peripheral wall of flammable products is determined with Eq. (1) [10]. The calculation is applicable for peripheral walls from spruce wood.

$$Q = 0.02 \cdot 470 \cdot 17 = 159.8 \text{ MJ} \cdot \text{m}^{-2} \tag{3}$$

$$Q = 0.02 \cdot 470 \cdot 17 = 159.8 \text{ MJ} \cdot \text{m}^{-2} \tag{4}$$

The released heat that is higher than 150 MJ-m^{-2} but less than 350 MJ-m^{-2}, it is typical for the walls that are determined as partly open danger surface. However, it is still necessary to take into account a heat flux density. This heat flux density is calculated according to Eq. (2).

$$I = 0.35 \cdot \frac{0.45 \cdot 17}{60} = 44.63 \text{ kW} \cdot \text{m}^{-2} \tag{5}$$

1.3. Experimental verification

To verify the calculated values, a set of tests under laboratory conditions was conducted. The first seven tests were unsuccessful mainly because of insufficient sources of ignition and an improper disposition of the sample. Therefore these data are not mentioned. This chapter mentions only the data from two measurements that do not have the identified deficiencies from previous measurements.

2. Materials and methods

The measurements were realized under the same conditions at the temperature 20°C, humidity and pressure. Spruce wood with 10.3% of humidity was used as the test material. The test sample with dimensions of 1400 mm × 450 mm was assembled from the laths with the width of 45 mm and a thickness of 20 mm (see **Figure 1**).

The back side of the sample was joined by continuous surface of boards and with 10 mm of space between particular boards. The test sample was installed on the wall in a vertical position and at 30 mm above the floor. On the floor was placed the source of ignition with a volume of about 300 ml and there was a mixture of flammable liquids (n-heptane (V = 50 ml) and a mixture of hydrocarbons–petroleum (V = 250 ml)).

The temperature and radiation during the testing were measured. The thermocouples of type K were used for the process of temperature measurement. They were distributed as follows: the first thermocouple was placed at a height of 650 mm and another at 250 mm above the other on the axis of the sample (see **Figure 2**).

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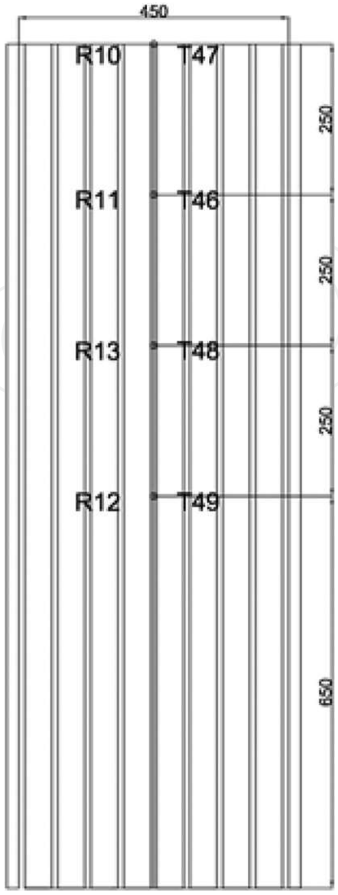

Figure 1. Experimental setup.

Figure 2. Radiometer setup.

The radiation was measured using radiometers Hukseflux SBG01 with a range of 0–100 kW.m^{-2}, which were placed at the same positions of height as thermocouples and 300 mm away from the sample. To score the process was used the measuring system ALMEMO 5690-2. The basic calibration of sensors of the heat flux was carried out at the full measuring range of the system. The initial calibration accuracy is ±3%. There are other errors which are caused by non-linearity, convection and radiation balance. The radiometer SBG01 shows the error caused by non-linearity of signal ±4.5% in the measurement range up to 44 kW.m^{-2}.

3. Experimental results

In **Figure 3**, there is appreciable process of heat radiation on a particular radiometer. The first growth is associated with burning of the sample as well as with a source of ignition. The values at the even combustion of sample without an ignition source for the verification of values of heat radiation with the theoretical calculation were used. The highest values were achieved by radiometer R12 which was placed at the lowest position at a distance of 650 mm from the edge of the sample. The maximum value of heat radiation was 43.81 kW.m^{-2} at this radiometer and it was reached at the time 3:16 min after the ignition of the source. A maximum value of heat radiation was also measured at the radiometer R13 positioned 250 mm above, almost at the same time. The maximum value of heat radiation at the other radiometers that were placed at a height of 1150 and 1400 mm was reached about 10–20 seconds later. This was caused by the absence of combustion at the upper part of the sample. There are differences always about 10 kW.m^{-2} at the radiometers. The temperature increase at that time corresponding to the theoretical assumption can be seen in **Figure 4**.

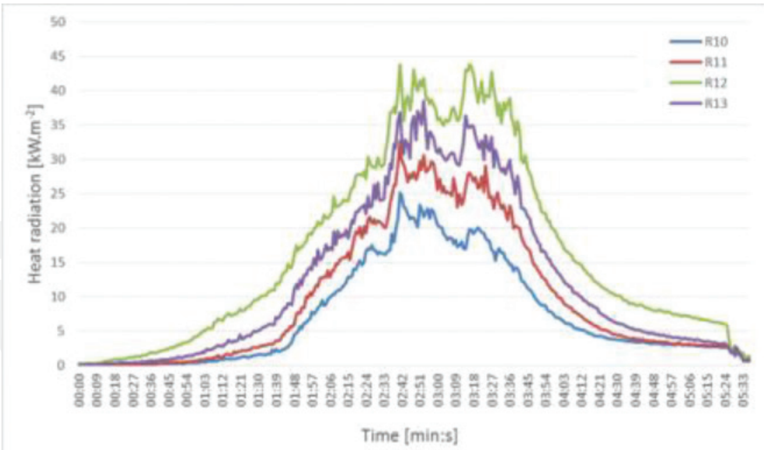

Figure 3. The values of heat radiation on various radiometers during test no. 01.

An initial increase of temperature corresponds to the combustion of the sample together with the source of ignition. Therefore there are used data of 3 min for realistic description of the temperature during fire. The highest temperature about 740°C was measured at the thermocouple T48 and T49 at the time 3:20 min. The lowest temperatures were measured at the thermocouple T47 which was placed at a height of 1400 mm, and that it also shows the effect of the absence of combustion in the upper part of the sample.

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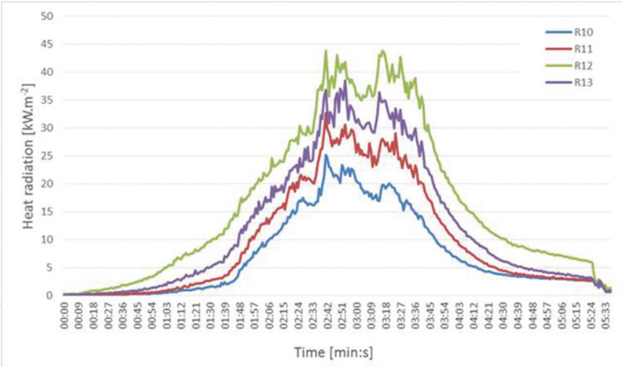

Figure 4. The measured temperature on thermocouples during test no. 01.

During the second test, as it is obvious in **Figure 5** and **Figure 6**, a lower heat radiation was achieved, while the temperature at the thermocouples was higher by about 50°C. Processes of heat radiation and temperatures that are a little different in time are also seen. In the second test, there was a gradual increase of radiation already from the first min and a rapid increase of values already before the second min. The maximum of heat radiation 36 kW.m^{-2} was measured at the thermocouple R12 that was placed in the axis on the lowest place, at the time 2:49 min when the temperature reached almost 800°C. There was a significant increase of radiation at the time 3:28 min at the thermocouple R13 and R11 that was caused by a rapid movement of the flames due to changes in the ventilation of a test chamber.

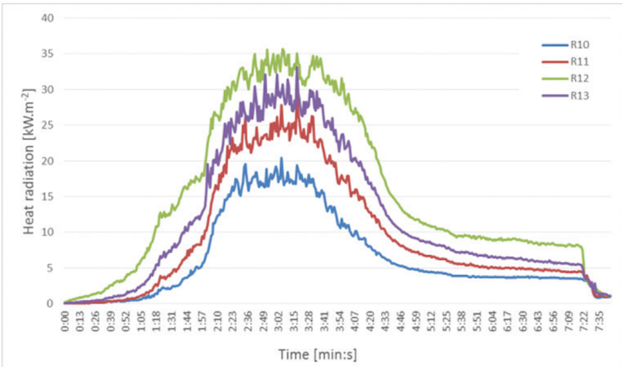

Figure 5. The values of heat radiation on various radiometers during test no. 02.

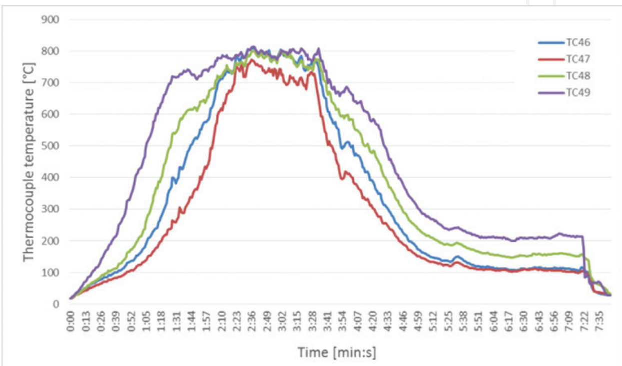

Figure 6. The measured temperature on thermocouples during test no. 02.

4. Conclusion

The aim of the article was to verify the theoretical assumption about heat radiation of spruce wood. The authors also wanted to test and possibly upgrade the information that has been obtained from the measurements. The calculated value of heat flux density is 44.63 $kW.m^{-2}$ assuming that during a diffuse combustion with good access of air there is 35% of the heat shared from the flame of radiation. Maximum value of heat flux density, which was measured, is 43.81 $kW.m^{-2}$. This maximum value is influenced by an action of heat that is released from source of ignition. It means that measured heat radiation achieves a calculated value only at the most adverse measured place. These values are affected by the measurement error that is affected by a measuring technique which was used to take measurements of values at lower values than is the half of the measuring range that affects the measurement errors. It has not been possible to use the heat flux sensors with a lower measuring range, without the verification of the actual values of heat flux density, as it may cause damage to the equipment. There is also difficult to achieve the uniform spreading of flames on the surface in condition of sample. In fact, it is assumed that flames come from windows during the under-ventilated fire. An initiation of the facade is caused by very intensive action of flames. Test conditions were limited by a possibility to use powerful source of ignition it the test chamber. The sample was modified in the way to ensure better burning-off (by using the vertical spaces). Actually the wooden facing gradually dries on the facades and the burning surface on old facades is significantly higher than on the new facades. It means that an artificial increase of surface partially stimulate the actual condition of the wooden facing. Based on the tests, it is possible to conclude that the calculated values of the heat flux density are closed to real values. It is necessary to focus on a measurement at different combination of shapes and samples for further experiments. Also it is necessary to consider realization of the large size test.

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