Virtual thermal tests of heating devices

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Abstract. To determine the values of the nominal indicators of heating devices, thermal tests are carried out. Analysis of the literature data has shown that, despite the widespread use of mathematical modeling for the study of heat transfer processes in heating devices, there is no comparison of test data and modeling. The purpose of this study is to test a heating device in a chamber (an indoor convector with a natural impulse of air movement) and compare it with the results of modeling. To assess the possibility of using and accuracy of modeling tests of heating devices, the data of tests of the indoor convector with natural convection “Golfstream” KRK 20.11.150 (LLC “Izoterm”), performed by the Institute “HLK Stuttgart” (Germany), were accepted. Modeling of the test chamber and convector is based on the FloEFD software package of “Axis Engineering” company. During virtual thermal tests of the convector, a heat flow was obtained that differs from the data of the convector tests on the test stand by 4.9%. It is concluded that it is possible to conduct virtual tests to optimize the design of heating devices and obtain the thermal characteristics of heating devices under all operating conditions and modes.

1. Introduction
To determine the values of nominal indicators of heating devices to be included in the design documentation, operational documents, as well as catalogs, brochures and other information publications of the manufacturer are examined, thermal tests are carried out [1, 2]. Thermal tests of heating devices are performed in accordance with the requirements [2].

The test stand should consist of [2]:

- closed (unventilated) test chamber with water-cooled internal surfaces to ensure the specified temperature conditions that do not depend on the temperature in the room where the camera is installed;
- devices for cooling and providing cooling water circulation;
- measuring heating circuit;
- means of monitoring, measurement and management.

When determining the passport values of the nominal heat flow, samples of heating devices with a nominal heat flow in the range of 800 - 1200 W are tested. If there is no model that meets this condition, then choose the closest one in size. The values of the nominal heat flow for models not tested during thermal tests are obtained by calculating the established dependencies.
But at the stage of product development, testing of a standard-size range of heating devices, as well as optimizing the design, there is a need to conduct a significant amount of such tests, as well as obtaining characteristics of devices that can not be tested in the chamber.

In work [3], the solution to the problem of determining the nominal heat flow of the radiator (radiator section) under normal by [1] conditions is given by simulating the heat test of the radiator. The analysis of heat transfer processes was performed using the program COSMOSFloWorks (SolidWorks Flow Simulation) [3, 4]. The numerical model was developed in accordance with the requirements of the “Methodology” [5].

The geometric model of the camera is shown in figure 1. When developing the model, a fictitious hole is provided in the lower part of the center of the back wall to simulate the leakiness of the chamber, which acts as a “drain” when the air in the chamber is heated.

Due to the demonstration nature of the calculation [3], the author did not aim at absolutely accurate compliance with the methodology and due to limited computing resources, only two sections of the radiator are considered in the model. At the same time, the radiator model is built without any simplifications. According to the modeling results, the heat flow for two sections is 312 W, and for one, respectively, 156 W. It is noted that “this value is in good agreement with the known experimental results”.

It should be noted that in the Russian normative literature [1, 2] there is no test method for floor-mounted convectors. The correct determination of the characteristics of heating devices largely depends on compliance with the test conditions of heating devices and, in particular, the choice of a test method that is correct for actual operating conditions [6, 7]. In European practice, documents [8-10] are used for testing indoor convectors.

In work [11], a model of a 4x4x2.6 m room with a 2x2.4 m window and an indoor convector installed at a distance of 70 mm from the glazing was made (figure 2). The BITHERM Floor indoor convector was tested with a length of 2000 mm and a width of 245 mm. Air parameters were measured in the center of the room at a height of 1.5 m above the floor. Mathematical modeling was performed in the Fluent program.
The room (test chamber) differs from the established norms [8-10], which is determined by the conditions for using built-in convectors under light openings to protect the room from falling cold air flows.

In work [12], the influence of wall temperature on the development of flows from a built-in indoor convector with forced convection was studied. Modeling was performed and thermal characteristics of the convector were determined depending on the distance between the finned plates [13]. It was concluded that the modeling results should be compared with experimental data.

Mathematical modeling is widely used in solving particular problems, but there was no modeling of standard chambers for testing heating devices and comparison of the results of modeling with the data of tests in such chambers. There are very few publications on the results of studies of indoor convectors (with natural and forced convection) [11-15]. Therefore, the purpose of this study was to test a heating device (an indoor convector with natural air movement) in the chamber and compare it with the modeling results.

2. Materials and Methods

To assess the possibility of using and accuracy of modeling tests of heating devices, the data of tests of the indoor convector with natural convection “Golfstream” KRK 20.11.150 (LLC “Izoterm”), performed by the Institute “HLK Stuttgart” (Germany), were accepted. The test method corresponded to works [8-10]. The test chamber diagram is shown in figure 3.

Modeling of the test chamber and convector is based on the FloEFD software package of “Axis Engineering” company. The convector model is based on the design documentation (figure 4). The convector is placed at a distance of 50 mm from the cooled chamber wall. During tests, the heating element of the convector was located near the casing wall on the side of the cooled wall. To create a directed air flow from the bottom to the top, side bars are installed in the heating element (not shown in figure 4). The test chamber has a single cooled wall for the entire height. The temperature of the cooled wall was set to 16 °C.

3. Results

The results of tests and modeling are shown in table 1.

As follows from table 1 in virtual tests (based on the FloEFD software package), the value of the heat flow is 4.9% less than that obtained during tests in the chamber.
The discrepancy between the calculation results and experimental data is due to the conditions of testing in the chamber: the average temperature of the chamber wall surface during testing (16±0.5 °C) may differ in comparison with the value set in the numerical experiment, both in the higher and lower directions.

**Table 1. Results of testing and calculation of the heating device.**

| Name of values                        | Convention | Unit | Data by tests “HLK Stuttgart” | Data by modeling FloEFD |
|---------------------------------------|------------|------|------------------------------|------------------------|
| Atmospheric pressure                  | P          | kPa  | 97.0                         | 97.0                   |
| Determining air temperature           | t_R        | °C   | 20                           | 20.55                  |
| Water temperature at the inlet of the heater | t_1        | °C   | 85.4                         | 85.4                   |
| Water temperature at the outlet of the heating device | t_2        | °C   | 73.0                         | 73.77                  |
| Water temperature difference in the device | t_1-t_2   | °C   | 12.4                         | 11.63                  |
| Average water temperature in the device | t_m=(t_1+t_2)/2 | °C   | 79.2                         | 79.59                  |
| Difference between the average water temperature in the device and the determining indoor air temperature | ΔT=t_m- t_R | °C   | 59.2                         | 59.04                  |
| Water consumption                     | q_m        | kg/s | 7.4916·10^{-3}              | 7.4916·10^{-3}         |
| Heat flow of the heating device being tested | Φ_e        | W    | 390                          | 371                    |

*Figure 5. Speed fields in the chamber and convector.*
Conducting virtual heat tests (modeling) using software tools allows getting more complete information about heating devices and their operating conditions. For example, figures 5-7 show the speed and temperature fields in the chamber and the convector built into the floor structure, on the basis of which it is possible to optimize design solutions and determine their working conditions. We can set any test conditions in the virtual camera.

Figure 6. Temperature fields in the chamber and convector.

Figure 7. Temperature fields in the chamber.
The study of heating devices in virtual test chambers allows determining the conditions that must be met under arrangement of new test chambers. These conditions include the air temperature and its gradient along the height of the chamber, the temperature of internal surfaces, the presence and intensity of convective currents, the size of the chamber, etc.

Such an assessment would allow the development of a test methodology for heating devices, in particular for convector built into the floor structure, and to make a more accurate selection of the surfaces of heating devices installed in the room.

The actual problem when certifying heating devices is the volume and cost of testing [9]. Conducting virtual tests allows replacing some of the expensive thermal tests of heating devices.

4. Conclusions
1. As a result of virtual thermal tests of the convector built into the floor structure, a heat flow was obtained that differs from the data of the convector tests on the test stand by 4.9%.
2. The results of virtual tests can be used for:
   - optimization of the design of heating devices;
   - obtaining the characteristics of heating devices (thermal and hydraulic) under all operating conditions and modes.
3. A special feature of virtual thermal tests based on numerical methods is ambiguity at all stages of work: when preparing a geometric model, setting boundary conditions, performing sampling, setting parameters for decision procedures, displaying and interpreting results.

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