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ACCELERATED ASSESSMENT OF THE THERMAL CONDITION OF A PROTOTYPE CHAMBER FOR TEMPERATURE TESTING

Key words

The prototype testing, numerical simulation, climatic chamber.

Abstract

The article presents the numeric simulation in the process of prototype testing carried out with a virtual model of a chamber for environmental testing. The authors present the results of the numerical analyses of the thermal condition of the chamber obtained with the finite volume method (FVM) in a temperature range from 238 K to 348 K. The obtained results enable the authors to verify the assumptions adopted in the design process. The results of the tests will be used in prototype testing to forecast the necessary time duration for the tests for the basic chamber operation in the real object.

Introduction

The prototype verification and testing process of a unique device is a difficult and laborious task [1, 2]. Time constraints and the minimum amount of data obtained in single solution testing entail the risk associated with the correct functioning of the device in the entire range of adopted technical parameters. In order to reduce the level of risk, the designed and manufactured device in a prototype form is subjected to a testing process [3] even at the stage of the formation of the virtual model using numeric simulations. In the case of a group of devices, the operation of which is related to the heat exchange, the Computational Fluid Dynamics analyses (CFD) application allows the correct assessment of the thermal static and dynamic conditions [4, 5] of the prototype solutions.

1. Chamber for temperature tests

The example of a prototype device designed and manufactured in accordance with the developed methodology [6] is the chamber for temperature testing in accordance with the scientific and manufacturing standards in force [7].

In the designed cuboid chamber of 2.3 m x 3.7 m x 3.2 m, four modules responsible for the proper functioning of the device can be seen (Fig. 1).

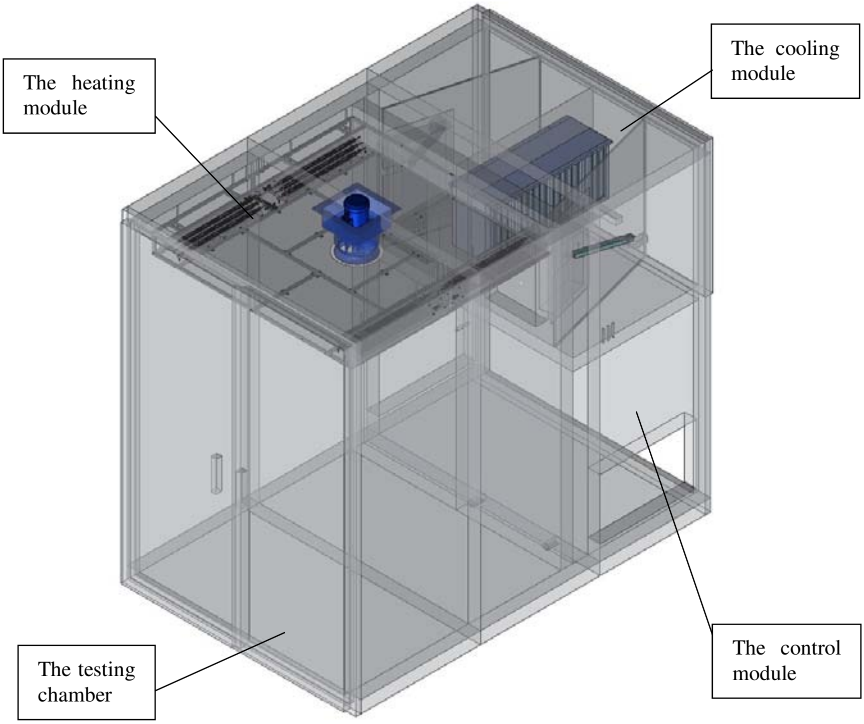

Fig. 1. The virtual chamber model for temperature testing

The first module consists of an appropriate test chamber that allows placing inside objects of dimensions 1.5 m x 1.5 m x 2 m and a weight of 500 kg.

The upper part of the test chamber is equipped with a heating module consisting of four heating sections and fan for proper air circulation in the tested area. The test chamber is connected with a cooling module equipped with an evaporator with two radial fans. Cooled air flowing between the tested area and the cooling module is controlled by electrically operated rectangular fittings, which are closed while tests at high temperatures are carried out. The fourth module contains components of the operation control system of the chamber.

2. Chamber model

After the design was finished, in order to verify the assumptions adopted in the design process, a numeric simulation of the condition of the thermal chamber at the temperature range of 238 K to 373 K was carried out.

The discrete model adopted for calculations (Fig. 2) consists of hexahedral and tetrahedral elements [10]. The length of the edge of the finite element ranges from 5 mm to 50 mm.

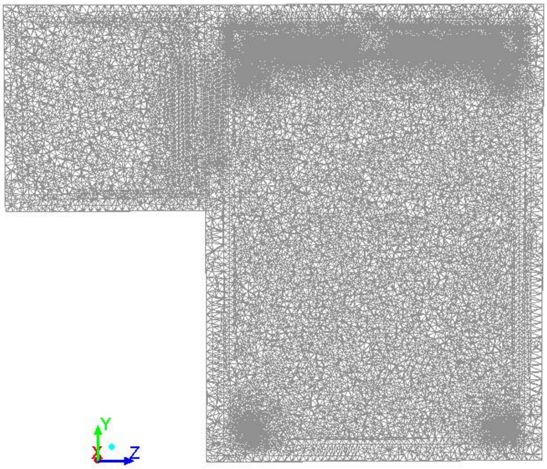

Fig. 2. Discrete chamber model

The numerical grid was concentrated in areas where large velocity and temperature gradients occur (heaters and coolers fans, outlets of supply air grilles) and close to control points (Fig. 3).

The model uses the finite volume method (FVM) [8, 9], and the following assumptions for the simulated process were adapted:

- The thermal edge condition of the first type remained (constant temperature of 293 K) at the external walls of the chamber.
- The cooler was simulated to have a surface of wall temperature of 237 K and a substitutive coefficient of heat penetration of 671 W/m^{2}K.

- Four heaters (each being a battery of 3 heaters) were simulated as a volume heat source of a stream of heat equal to 1200 W.
- Fans for the cooler and the fan in the centre of the ceiling of the chamber were modelled as a surface-edge condition by the third degree function depending on the local pressure gradient on flowing air speed.
- The air was simulated as a gas with a fixed viscosity, appropriate temperature, and thermal conductivity and with variable density in temperature and pressure.
- There are nine locations of control volumes (8 at the corners and one in the centre) in which the average temperatures were calculated in working locations of the chamber.

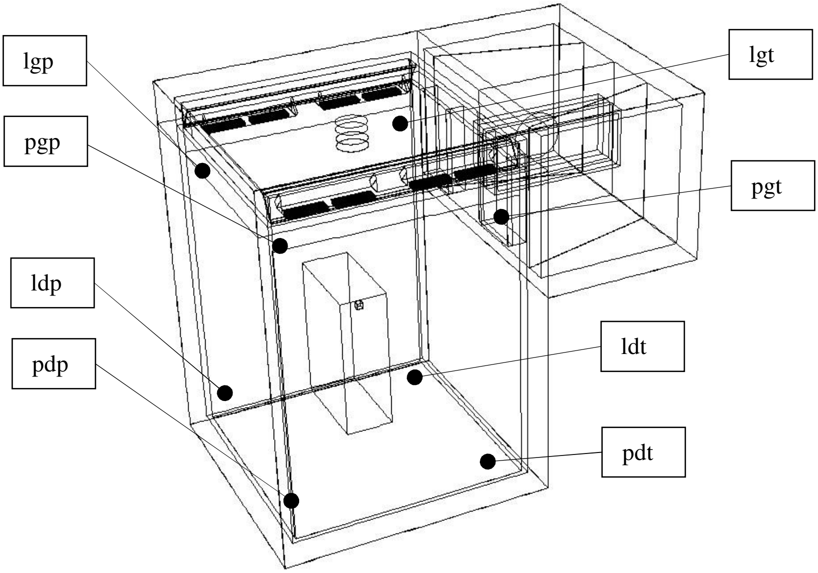

Fig. 3. 3D model of the chamber with labelled control volumes

The aim of the developed numerical simulation was to determine the thermal condition of the chamber as a function of time for the two types of tests carried out in it: cooling and heating. We analysed an unidentified turbulent flow [10, 11] using a k-epsilon model. The calculations assumed a time step equal to 1 s [12].

3. Numerical simulation of the thermal condition of the chamber

In the operating mode of the chamber associated with the tests carried out in sub-zero temperatures, we identified the chamber temperature conditions in time steps associated with airflow between the cooling chamber and the testing chamber (Fig. 4). Numerical analysis was applied to three modules cooperating with each other: testing chamber, cooling module, heating module.

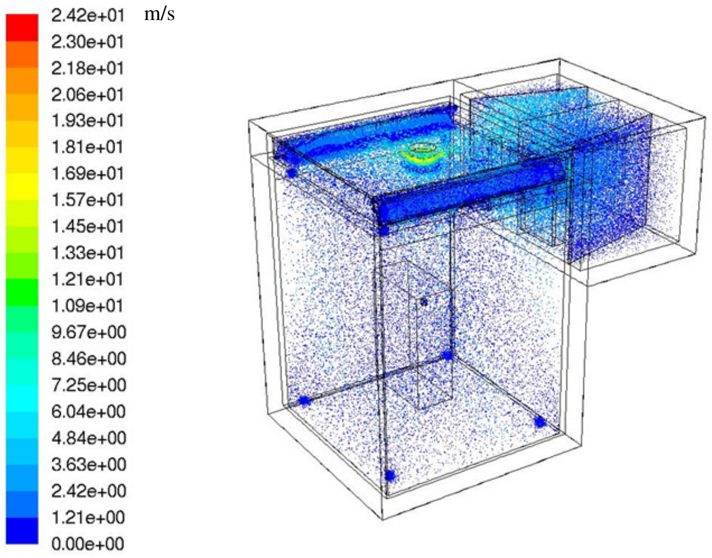

Fig. 4. Distribution of speed vectors – 3D view

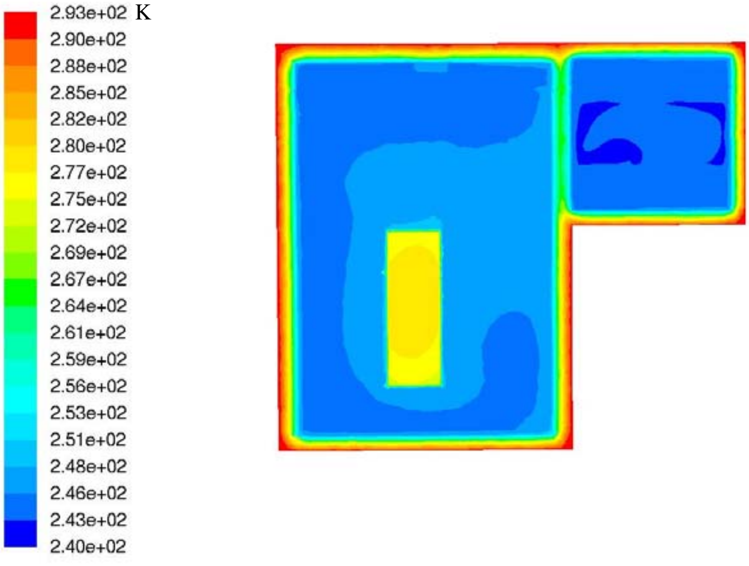

Fig. 5. Temperature field in the chamber’s vertical cross-section after 9600 s

Occurring uneven flow does not significantly affect the distribution of heat and thus the temperature distribution in the chamber in each control volume (Fig. 5 and 6) after a specified time of 9600 s.

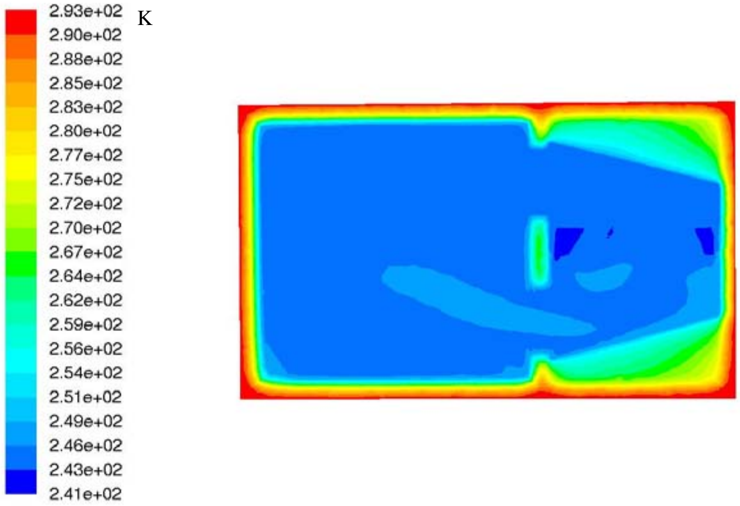

Fig. 6. Temperature field in the chamber's horizontal cross-section after 9600 s

Differences in temperatures in extreme chamber control points, not exceeding 2 K, are the result of the heating and cooling fans operating simultaneously to ensure adequate air circulation (Fig. 7).

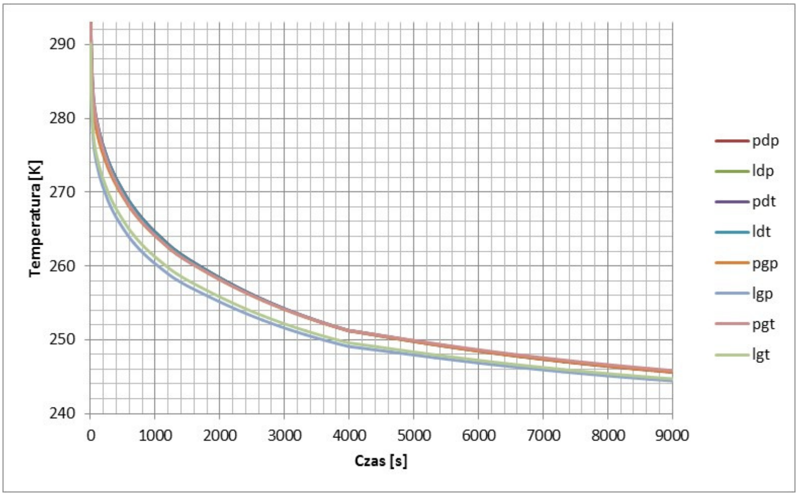

Fig. 7. Temperature dependence of the control volume in relation to cooler operation time

The aims of the simulation carried out in the test conditions associated with the objects during heating were temperature field identification and determining the time at which the temperature difference at control points is less than 2 K. In this case, the analysis concerned only a part of the chamber used in the testing process (Fig. 8), which was separated from the cooling part by blocking passages.

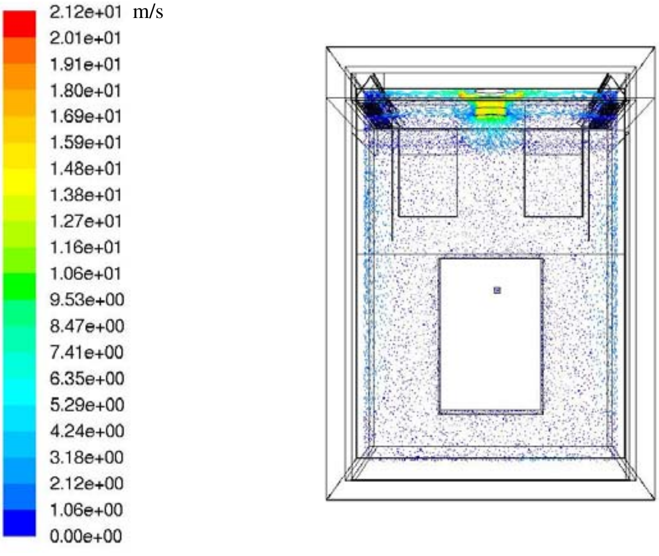

Fig. 8. Distribution of speed vectors – 3D view

An example of a temperature field distribution in the chamber’s vertical cross-section obtained after 7200 s is shown in Fig. 9.

The uniformity of the temperature distribution determined in the adopted control points (the maximum difference equal to 2 K) provides the proper development of the heating circulation system by the heating module. An example of the changes in temperature in one of the control points is shown in Fig. 10.

The presented results of the numerical thermal conditions of the chamber concern only two selected points of the chamber operation: the lowest expected sub-zero temperature and the selected above-zero temperature. The minimum time necessary to reach the desired temperature distribution throughout the chamber space represented by defined control volumes were determined for the selected operating points.

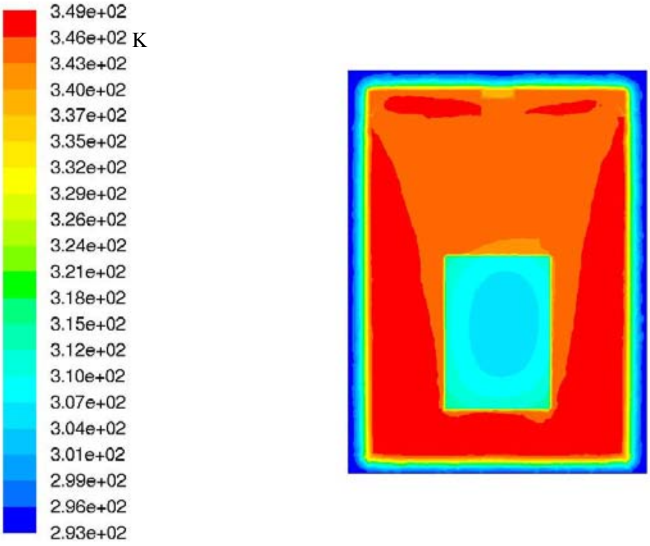

Fig. 9. Temperature field in the chamber's vertical cross-section after 7200 s

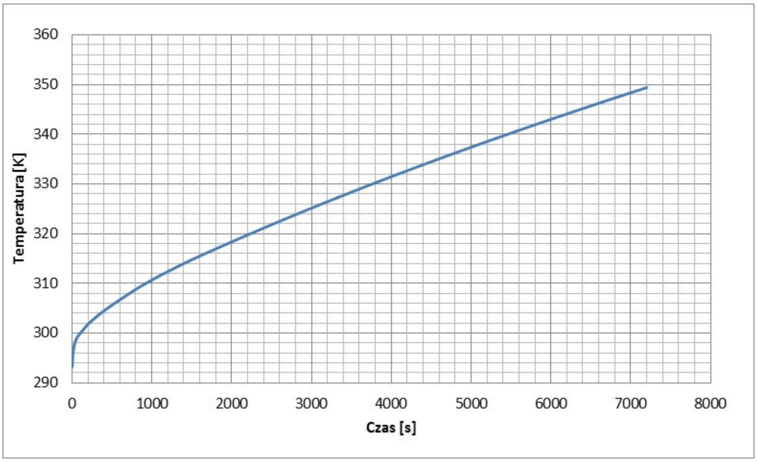

Fig. 10. Temperature dependence on the heating module operation

Summary

Using this numerical method in the early phase of prototype development (virtual model) allows the elimination of errors resulting from incorrect interpretation of the design. In this case, the simulation of the thermal condition of the chamber confirmed the correctness of the applied design solutions.

The results obtained in the simulation, including operating times of individual modules to reach stable temperature conditions, will be used in prototype testing methodology. This will allow the development of the preliminary scheduling necessary to carry out research in physical prototype testing. A properly planned course of tests of the device will allow a reduction in the time needed for the implementation of solutions for practical applications, which reduces expenditures for the implementation of prototype production.

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Przyspieszona ocena stanu cieplnego prototypowej komory do testów temperaturowych

Słowa kluczowe

Badanie prototypu, symulacja numeryczna, komora klimatyczna.

Streszczenie

W artykule przedstawiono wykorzystanie symulacji numerycznej w procesie badania prototypu prowadzonego z użyciem wirtualnego modelu komory do badań środowiskowych. Zaprezentowano wyniki analiz numerycz-nych stanu cieplnego komory uzyskane metodą objętości skończonych FVM (*Finite Volume Method*) w zakresie temperatur od 238 K do 348 K. Uzyskane wyniki umożliwiły weryfikacje założeń przyjętych w procesie projektowania. Wyniki badań symulacyjnych zostaną wykorzystane w badaniach prototypu jako prognoza niezbędnego czasu trwania badań podstawowych parametrów pracy komory, prowadzonych na obiekcie rzeczywistym.