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CFD simulation of indoor climate

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Summary

The paper presents the experience acquired by the CFD (Computational Fluid Dynamics) simulation of indoor climate in a room heated by a gas space heater. The vertical air temperature difference in room is one of the indoor climate parameters. The simulation presents the non-stationary airflow and the distribution of temperatures in a dwelling room. The main goal of the paper is to identify factors which make a great vertical air temperature difference. Especially in a room which is heated up with high temperature of air. The paper compares results of CFD simulation with the measuring of temperatures and velocities in this room. The results can be considered trustworthy only if proper models of turbulence and radiation are used. The next goal is finding out appropriate turbulence and radiation models which could describe both heat transfer mechanisms in the room. The simulation is solved in the computer program FLUENT.

KEYWORDS: CFD simulations, indoor climate, dwelling room

1. INTRODUCTION

1.1. Indoor climate

The main goal in the field of environmental engineering is to ensure optimal conditions for work, relaxation and residence of people in buildings. Optimal conditions are created artificially by means of heating, ventilation and air-conditioning systems. In this connection we speak about creation of the indoor climate in buildings which can be distinguished as thermal-technical, lighting, acoustic, etc.

The substantial part of HVAC designer’s work constitutes the ensuring of the proper thermal and moisture microclimate in buildings. During winter and transition periods this problematic is ensured by the field dealing with heating systems. The humidity factor is in practice often omitted, therefore only the thermal component of indoor climate is observed. For simplification the problematic of the indoor climate creation during winter and transition period is focused on residential buildings. Factors creating the thermal microclimate within the room are especially temperature, intensity of thermal radiation and air

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turbulence level. The characteristic feature of all these factors is their distinctive time and spatial variability. These physical factors are present in all parts of the room and form the indoor climate of the room. By means of computer simulations and practical measurements can be proven and shown that the state of indoor climate generally varies at individual points of the room and different time periods as well.

Practically it is important to observe the thermal microclimate within spaces occupied by people. This area is designated as the inhabitant's zone.

1.2. Vertical distribution of temperatures as a thermal comfort factor

One of the factors influencing the quality of indoor climate in a dwelling room is the vertical distribution of temperatures. From now on the article deals with this factor. Already the old literature gives attention to this topic. For example [1] recommends the maximal temperature difference between the position of a head (t1,7) and an ankle (t0,1) to be 2,0 K for standing person and 1,5 K for sitting person from the point of view of thermal comfort. In Table 1, there are stated the ascertained vertical temperature differences for various types of heating according to [1]. The legal regulation for working environment requires the maximal vertical temperature difference to be 3 K, see [5].

Table 1. Maximal vertical temperature difference for standing person

Type of heating	Temp. difference between t1,7 a t0,1
Hot water heating – sectional heating element	1,5
Hot water heating – convector	2,7
Local heating – tiled stove	3,8
Warm-air heating	5,5

The requirement for thermal uniformity is easy to satisfy in case of floor heating, well-designed warm-air hating, etc. Generally we can say that the requirement on vertical temperature distribution is easily reachable when the temperature of the heating surface is not too much higher than the temperature of air.

Problematic situations occur by heating systems which produce high temperature in the vicinity of the heating surface. Around very hot heating surfaces (approximately > 90 °C) occurs intensive flow of high air temperature caused by the thermic lifting force. Consequently the vertical temperature difference in the room is greater. Similar situation happens while heating with warm-air heating systems.

2. DESCRIPTION OF THE PROBLEM AND SOLUTION

This article deals with the theoretical and experimental assessment of vertical temperature distribution in a room. We investigate the influence of the heating system with large heating surfaces and high temperatures on the vertical temperature distribution. The problem was solved theoretically and experimentally on a model room in a brick house heated by a gas space heater. The goal is to find out if the requirement on maximal vertical temperature difference according to [1] between the position of a head and an ankle can be satisfied especially at non-stationary conditions.

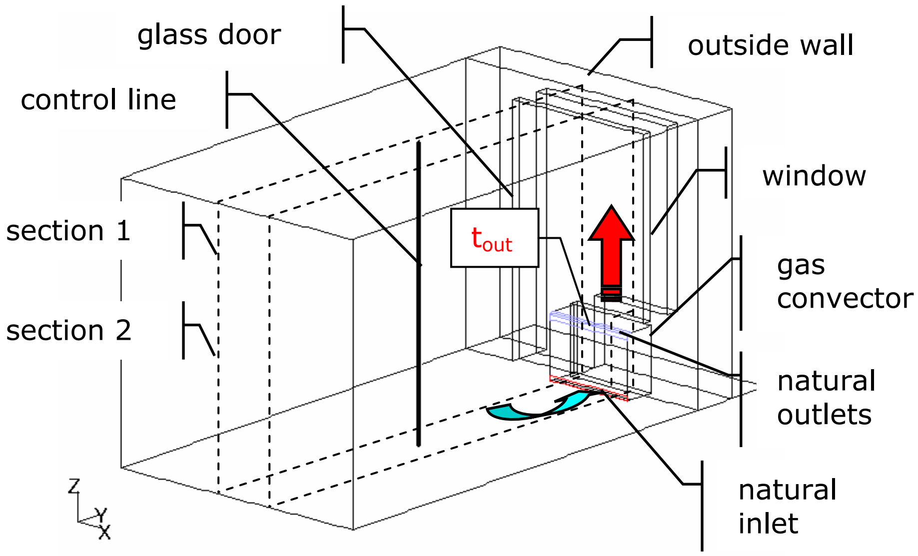

Figure 1. Geometry

Numerical simulation of the airflow and the heat transfer is carried out in the computer software FLUENT on a simplified three-dimensional model of the room.

Theoretical solution

Theoretical solution is based on CFD simulation of the room created in the software Fluent. The calculation is solved for non-stationary conditions and three-dimensional case. The temperature boundary conditions of the model correspond to the condition of the day when the experimental measurement was done. For turbulence calculations the RNG k – e model was used. The heat transfer by long-wave radiation was solved by DO (Discrete ordinates) model.

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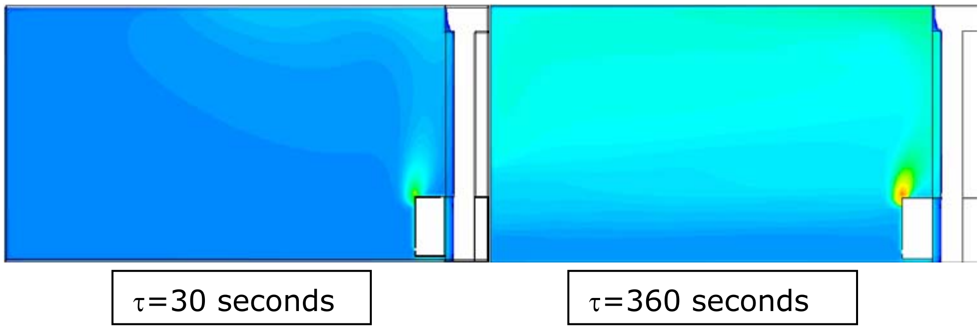

Figure 2. Unsteady temperature fields

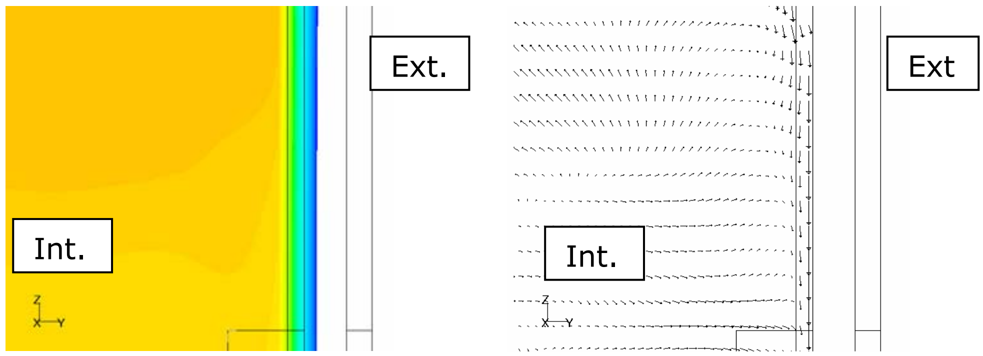

Figure 3. The creation of dropping airflow - section Nr. 1

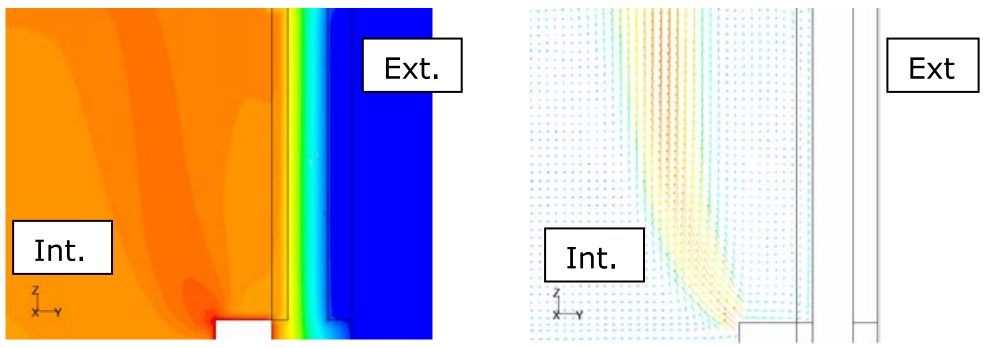

Figure 4. The shading out of dropping airflow - section Nr. 2

Simulation solution enables the illustration of temperature and velocity fields in the analyzed model room.

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3. EXPERIMENT

Methods

The experimental measurement was taken in the winter period of 2005/2006 and was divided in two parts. First of all were measured vertical temperatures in eight height points in the symmetry plane of the room. At the same time the velocity and temperature of air coming out of the gas space heater was measured and recorded. Further the monitoring of temperature fields of building structure surfaces was performed by the digital thermal-vision camera IR FLEXCAM.

The aim of the temperature, velocity and thermal-vision measurements was the identification of some indoor climate parameters and partially the verification of the numerical simulation results. The measurements proceeded as follows. First the model room was pre-heated (see the first temperature wave at Figure 5).

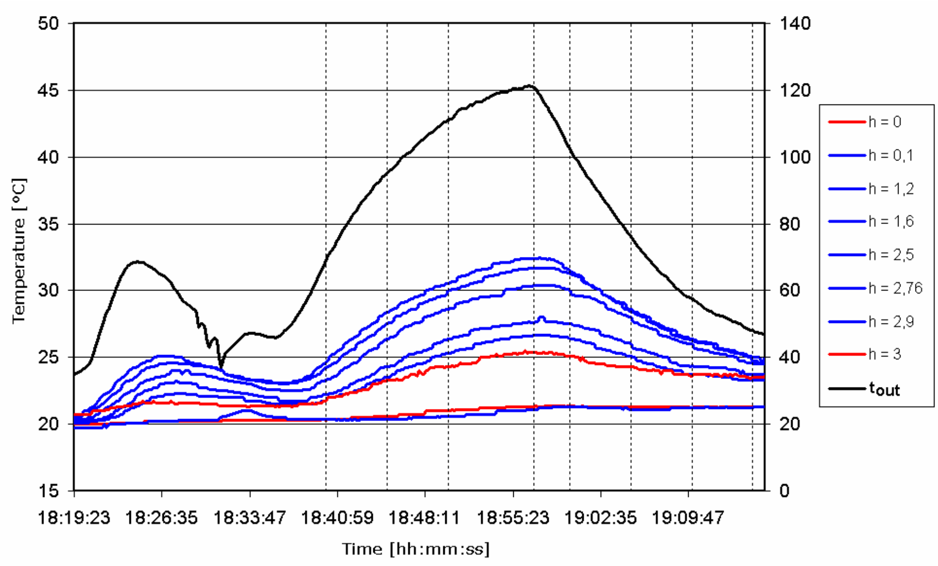

Figure 5. Time flow of the experiment

By this pre-heating the “start” temperature profile of the room was obtained (see the black vertical temperature distribution profile at Figure 6).

By gradual heating the maximal temperature profile was obtained (see the black vertical temperature distribution profile at Figure 7). After shutdown of the gas space heater the temperatures decreased (see the left vertical temperature distribution profile at Figure 7).

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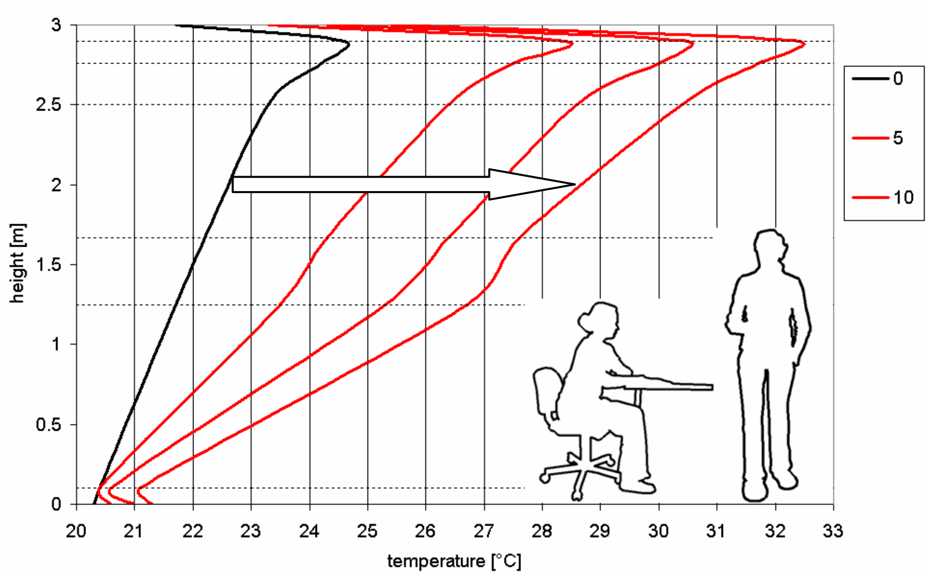

Figure 6. The vertical air temperature difference; warming-up

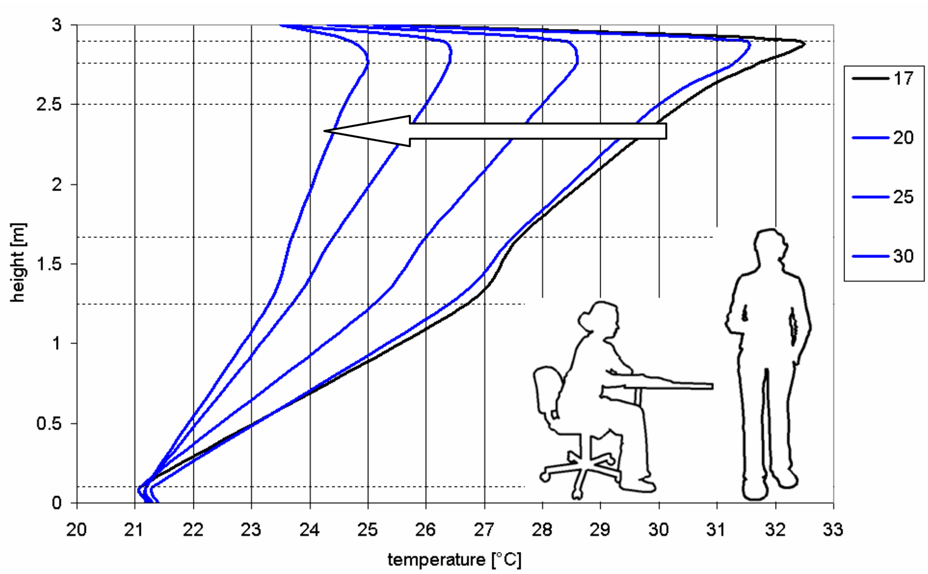

Figure 7. The vertical air temperature difference; cooling

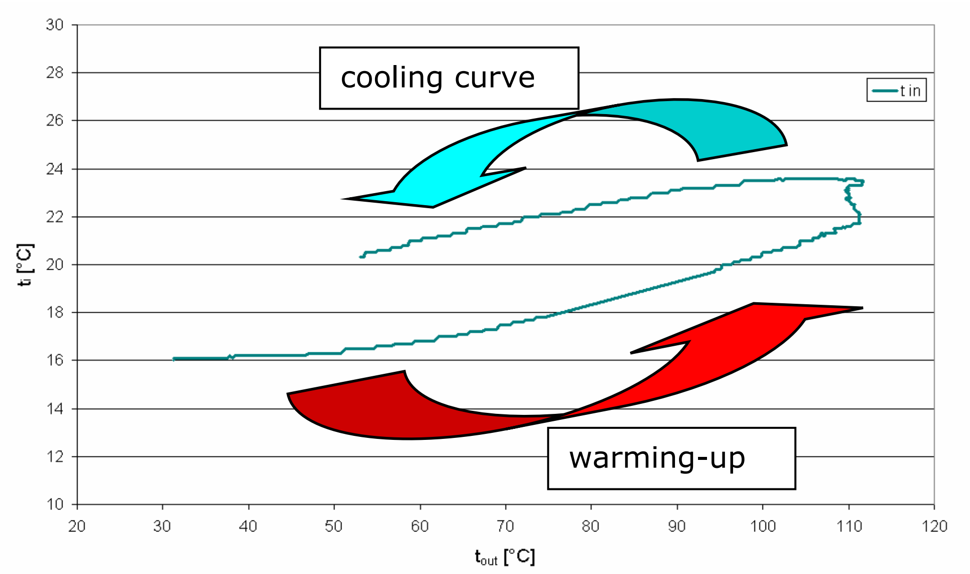

Figure 8. Warming-up and cooling of the interior air temperature t_i and its dependency on the air temperature coming out of the gas space heater t_{out}

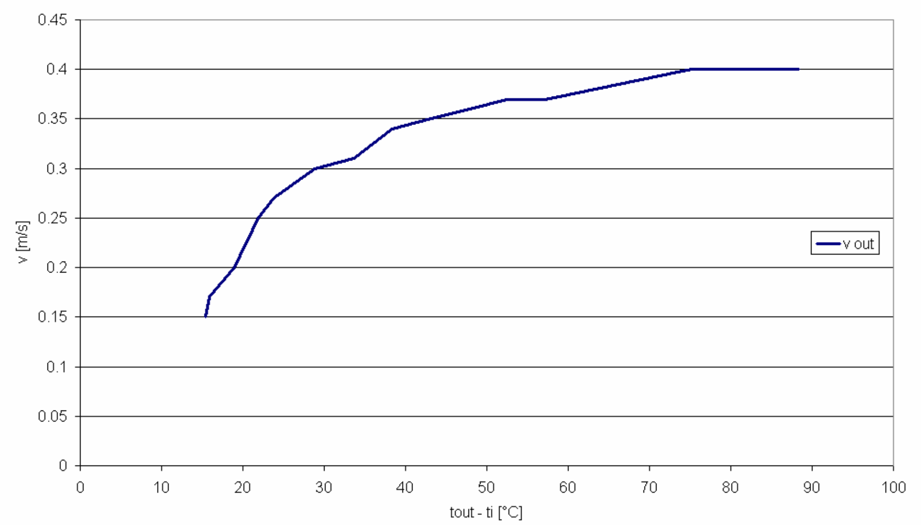

Figure 9. The dependency of the air velocity coming out of the gas space heater on the difference of air temperatures coming out of the gas space heater t_{out} and the interior air temperature t_i

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Also the temperature and velocity of the air coming out of the gas space heater and the interior air temperature were continuously measured. The output temperature on the gas space heater reaches its maximal values up to 120 °C. From the measurement follows that the requirement on the vertical temperature difference between the position of a head and an ankle for standing person was just satisfied at the "start" temperature profile. In all remaining phases the requirement was substantially over-ranged.

At Figure 9 is shown the dependency of the air velocity coming out of the gas space heater on the difference of air temperatures coming out of the gas space heater t_{out} and the interior air temperature t_i.

Figure 8 illustrates the process of pre-heating and cooling of the interior air temperature t_i and its dependency on the air temperature coming out of the gas space heater t_{out}.

4. CONCLUSIONS, DISCUSSION OF RESULTS

Above mentioned and described results prove the unfavorable influence of heating systems with high heating surface temperatures on the state of thermal indoor climate in residential rooms.

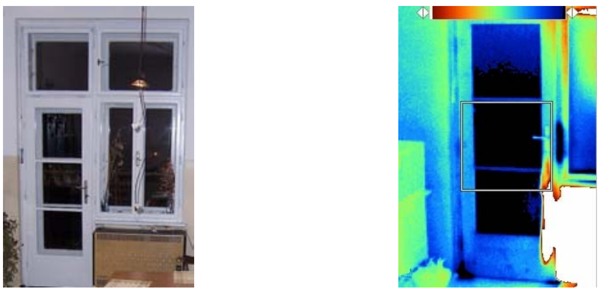

Figure 10. Surface temperatures

Reasons of great vertical temperature difference in the room are following:

- The formation of dropping airflows at the vicinity of cool surfaces (Figure 10) as a result of insufficient thermal insulation properties of the envelope constructions and high air infiltration of the window and door joints
- Insufficient or no shading out of the dropping cool airflows (Figures 3 and 4)
- High temperature (Figure 5) and velocity (Figure 9) of the air coming out of the gas space heater (t_{out}).

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It is not easy to satisfy the requirement on vertical temperature distribution in the room in cases as the one described here. Experimental measurement proves that the worst situation from the point of view of temperature distribution is while dynamic changes of heating system, particularly while heating of the room (Figures 6 and 7).

The results of non-stationary numerical simulation do not correspond precisely to results of the experimental measurements. Nevertheless in principal the simulation results correspond to the measurements and so they give us objective image of thermal processes which take place in the observed model room.

Acknowledgments

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References

1. Cihelka, J. *Vytápění a větrání*, Praha: SNTL, 1969. 610 s. (in Czech)
2. Šikula O., Ponweiser. K. *Modelling of heat transfer in the field of technical facility equipment and calculation using modern techniques*, Civil Engineering Journal Stavební obzor 4/2006, pages 6, Prague, Czech Republic, March 2006.
3. Jokl, M. Teorie vnitřního prostředí budov, ES ČVUT, Praha 1993. (in Czech)
4. FLUENT *User's Guide*, February 2003.
5. Regulation No. 6/2002 Sb. (in Czech)

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