The reduction of convective heat output at panel radiators

Ing. Václav Heis

Supervisor: Prof. Ing. Jiří Bašta, Ph.D.

Abstrakt

Hlavním cílem práce je popsat teplotní a rychlostní pole nad deskovým otopným tělesem opatřeným krycí mřížkou nestandardních otvorů o různých průřezech, a následné ovlivnění proudění v celém prostoru. Experimentálně byl stanoven vliv průtočného průřezu a tvaru otvorů horní krycí mřížky na tepelný výkon deskových otopných těles. Další experiment se věnoval popisu rychlostního pole nad otopným tělesem, za použití integrální laserové anemometrie (PIV). Výsledky měření jsou předkládány graficky jako pokles výkonu v závislosti na parametrech krycí mřížky a ve formě vektorů rychlosti nad otopným tělesem ve dvou navzájem kolmých rovinách. Na základě experimentálně získaných dat bude verifikován model a za použití počítačové mechaniky tekutin (CFD) bude simulováno teplotní a rychlostní pole jak na tělese tak v prostoru.

Klíčová slova: volná konvekce, otopné těleso, krycí mřížka

Abstract

The main aim of the research work is to describe temperature and velocity fields above the panel radiator fitted with non-standard (or design) covering grids with various flow cross-section and the subsequent effect at an air flow throughout the room. The effect of flow cross-section and shape of openings of panel radiators covering grids at their heat output was determined experimentally. The other experiment dealt with description of velocity field above the covering grid, using the method of particle image velocimetry (PIV). The results are presented in a graphic form as a heat output decrease depending on parameters of the covering grid and in the form of velocity vectors placed in two orthogonal planes. Based on experimentally obtained data, the mathematical model will be verified. Then a computer fluid dynamics (CFD) will be used to simulate both temperature and velocity fields above the panel radiator and in the room.

Keywords: free convection, panel radiator, covering grid

1. Introduction

The main goal of the heating surface is to manage an acceptable thermal comfort in the room. Other effect when it is designed correctly is counteracting cold convective plums rising on the windows surface. Currently the most widely used heating surfaces are panel radiators. These are radiators with dominant convective part of their heat output. Colder air flows from below into the space between the plates of panel radiator where it is heated and flows out through the covering grid into the heated room. The covering grid has two functions, safety and design. The second function is the reason that some tendencies to make non-standard covering grids are rising. But the construction of the covering grid is essential to final air flow above the panel radiator or in the room. In my research work I want to describe temperature and velocity fields above the panel radiator fitted with non-standard (or design) covering grids with various flow cross-sections and the subsequent effect at an air flow throughout the room. Based on experimentally obtained data I will simulate both temperature and velocity fields above the panel radiator and in the room using a computer fluid dynamics (CFD).

2. Thermal comfort and indoor climate

The most important parameters of the air in the heated room are air temperature, surface temperature of the surrounding walls and velocity and direction of the air flow. By convective heating the indoor air is heated first and then the walls surrounding the room are heated (opposite is radiant heating). The velocity and the direction of the air are mainly affected by the size and location of heating surfaces (panel radiators in our case) and cold surfaces (most often windows). An ambient air from the room flows from below into the space between the plates of panel radiator where it is heated and flows out through the covering grid into the heated room (warm convective plum). There it interacts with cold falling convective plums rising on the window. These plums are mixing together and such mixed plum is spread to the heated space. The ratio of warm and cold plums is essential for the overall flow field in the indoor space. This process is shown on fig.1.

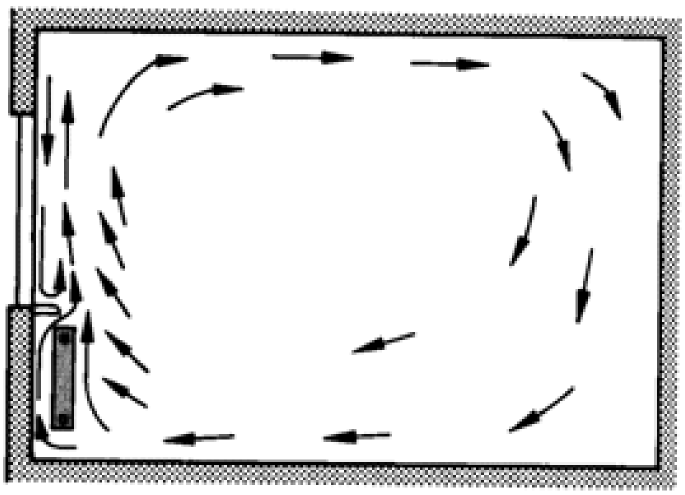

Fig. 1 *Mixing of warm and cold convective streams.*

In 2006 published prof. Bašta [L2] simulations results, focusing on the correct positioning of the panel radiator in the heated space. He proved that the most appropriate position of panel radiator is by the exterior wall, under the window (see fig. 2). To sufficient counteracting the cold convective plums is necessary to design the panel radiator with the same length as the length of the window.

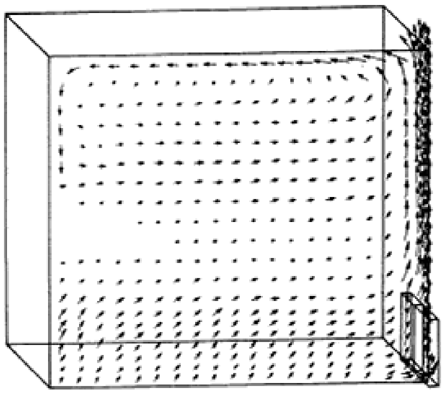

Fig 2 *Velocity vectors, vertical plane in the middle of the room*
w_{min} = 0,041.10^{-2}m/s, w_{max} = 0,54 m/s *[L2]*

In 2008 published Myhren and Holmberg [L3] simulation results of flow patterns in the heated space. They used a model of the room 4 x 4 x 3 m and 4 cases of heating surfaces (floor heating, wall heating, panel radiator – high temperature, panel radiator – medium temperature). The results are shown on fig. 3. From the figure is evident that only panel radiators placed under the window can turn the cold falling plums rising on window surface sufficiently.

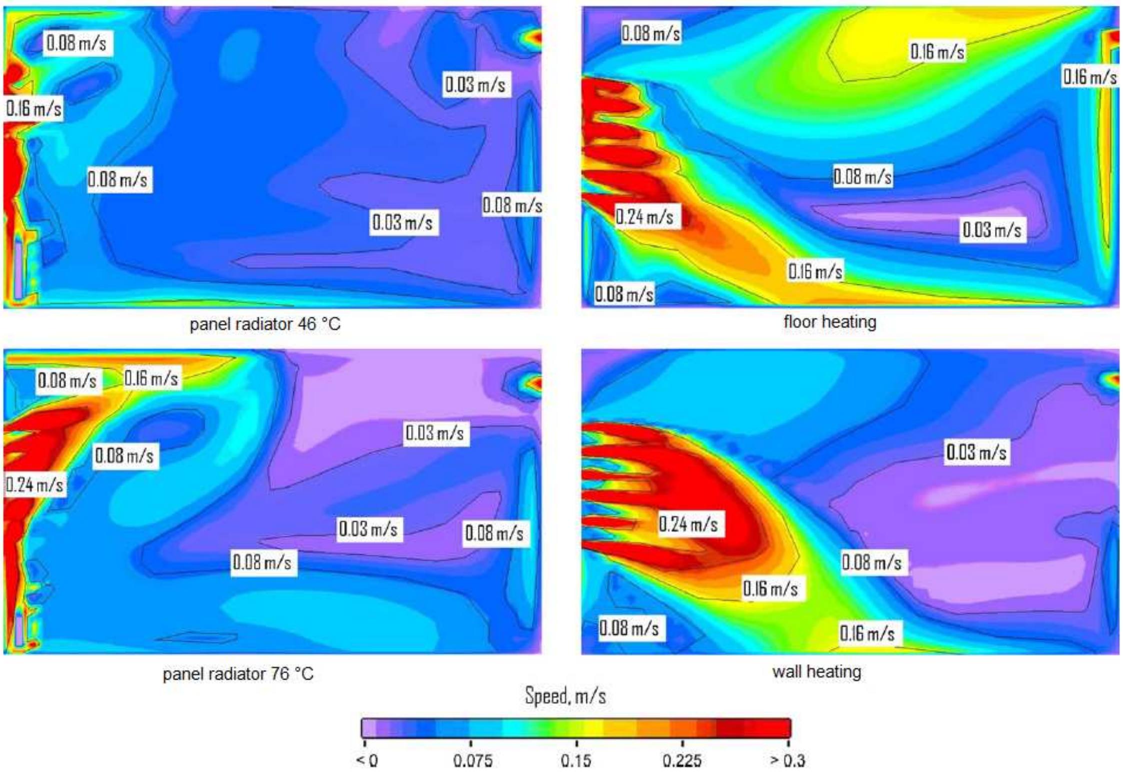

Fig. 3 *Simulated air speed, vertical plane, middle of the room [L3]*

These conclusions were considered in my research work. As a heating surface I chose panel radiator placed under the window, the length of the panel radiator was the same as the length of the window.

3. Present research

3.1 Effect of flow cross section of panel radiator covering grids at their heat output

The measuring was realized in industrial laboratories department of environmental engineering in the building of the Faculty of Mechanical Engineering CTU in Prague. It was measured panel radiator “Korado Radik Klasik” type 20, 21, 22 and 33. All radiators were connected single-sided top. Reducing the flow-cross section was achieved by covering grid made of plywood with a thickness of 5 mm and length of 975 mm. The depth (width) of the grids depended on the depth (width) of the panel radiator. The flow-cross section was reduced by moving the stack of two grids.

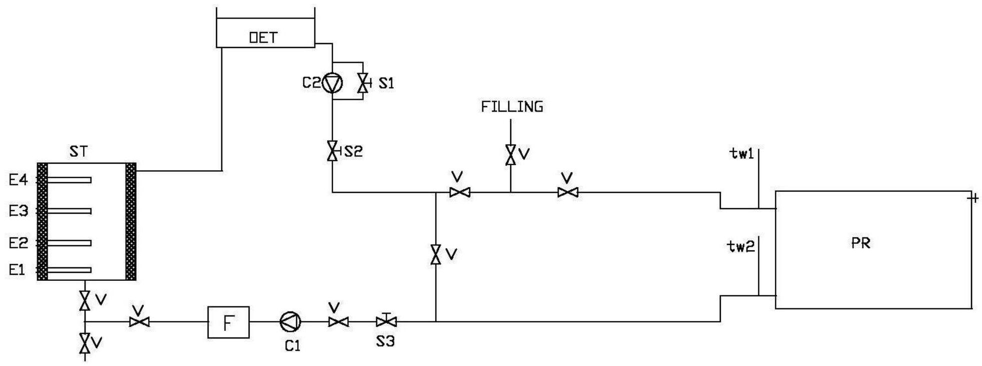

Fig. 4 *Mobile heating source*
ST – storage tank 60 l, OET - open expansion tank, F – ultrasonic flow meter, PR – panel radiator, C1, C2 – circulation pumps, E1-E4 – electrics heating rods, S1-S3 – STAD valves, V – ball valve

First, the whole system was pre-heated to 70 °C and then vented. Subsequently, it was determined nominal heat output of the panel radiator from the formula

$$Q = \dot{V} \cdot \rho \cdot c_{w2} \cdot (t_{w1} - t_{w2}) \text{ [W]}. \tag{3.1}$$

It is the heat output of the panel radiator without a covering grid for nominal temperature conditions (t_{w1}/t_{w2} = 75/65 °C). Other measured values were related to this nominal heat output. Then was the panel radiator fitted with the covering grid. By moving the grid was achieved the specific value of flow-cross section. At a constant flow and constant inlet temperature t_{w1}, the change in heat output is reflected by changes in outlet temperature t_{w2}. So established heat output was converted at nominal temperature conditions 75/65/20 °C and compared with the nominal heat output (without covering grid) for each type of panel radiator.

Results:

The results are expressed as a relative decrease of total heat output of the panel radiator ΔQ_N [%] depending on the relative flow cross section of the covering grid S_i/S_0 [-].

$$\Delta Q_N = \frac{Q_N - Q_C}{Q_N} \cdot 100 = 1 - \frac{Q_C}{Q_N} \cdot 100 \text{ [%]}. \tag{3.2}$$

Q_N is the nominal heat output (without covering grid); S_0 is the flow cross section between plates of panel radiator (without covering grid). Measured and calculated values are fitted by the polynomial 5th order; the polynomial coefficients are determined using least squares.
Figure 5 shows a decrease the heat output depending on the relative flow cross section covering grid for all measured panel radiators. The results confirm the presumption that the rate of heat output decrease is direct proportional to the share of convective part heat output for each panel radiator.

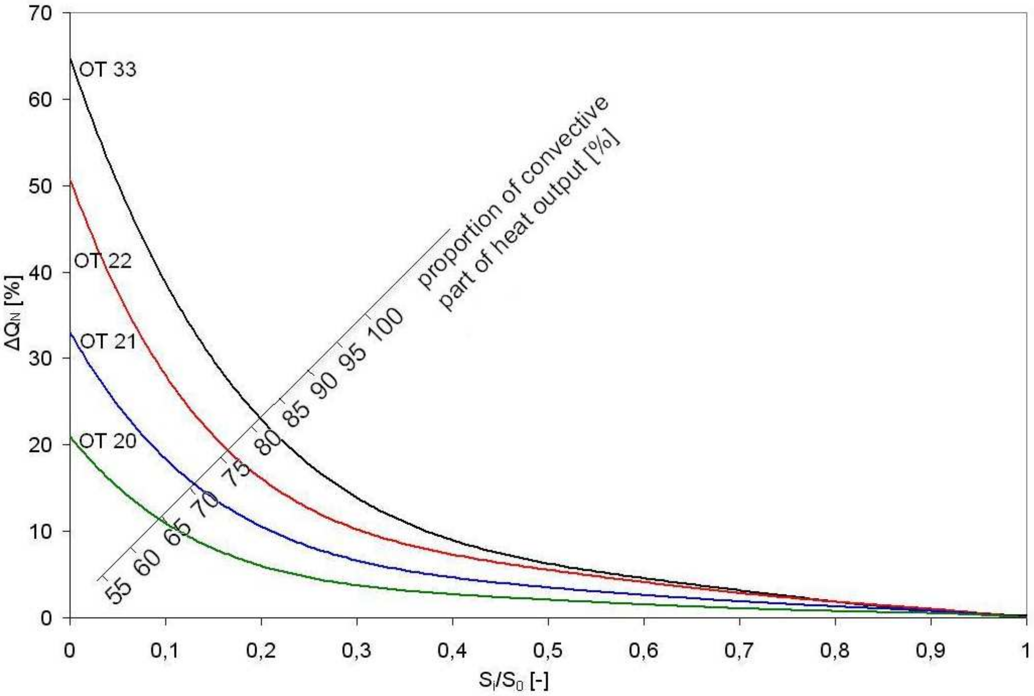

Fig. 5 *Decrease the heat output depending on the relative flow cross section covering grid*

Table 1 shows values of output decrease for selected values of relative flow-cross section of the covering grid. In design practice can be drawn from these results, especially at design grids with small flow-cross section.

Table 1 *Selected values of heat output decrease*

Type of panel radiator	**S_i/S_0 [-]**			
	0,7	**0,5**	**0,3**	**0**
20 – 600 x 1000	1 %	2 %	3,7 %	21 %
21 – 600 x 1000	2 %	3,5 %	7 %	33 %
22 – 600 x 1000	3 %	6 %	10 %	51 %
33 – 600 x 1000	4 %	7 %	14 %	64 %

3.2 Flow field upon a panel radiator

This experiment dealt with description of velocity field above the panel radiator, using the method of particle image velocimetry (PIV). It was measured panel radiator type 22; the measuring place was the same as in a previous case. The panel radiator was fitted by covering grids with various shapes of openings (two "round shapes" – star and circle; two "oblong shapes" – rectangle and crescent), the overall flow-cross section S_i/S_0 of all grids was 25 %. The grids with various shapes of openings are shown on the figure 6.

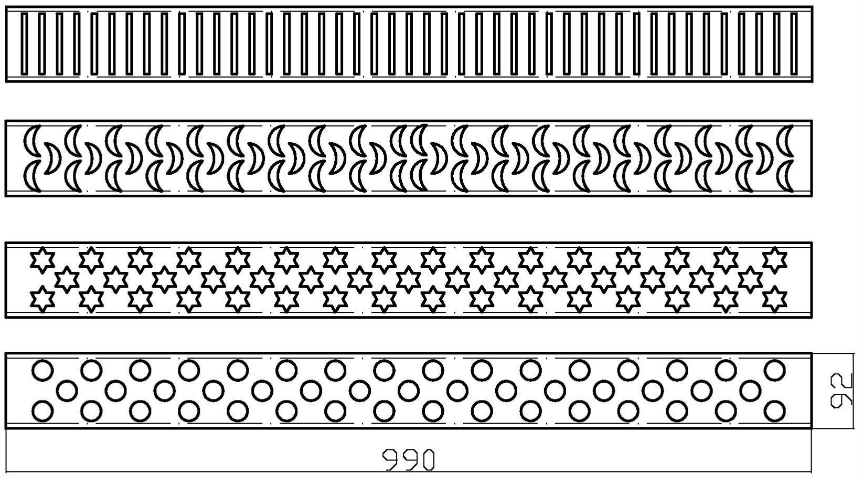

***Fig. 6** Covering grids*

After heating the measuring system a marker (safex) was blown under a panel radiator and the CCD camera took photos of the convective plum rising from the radiator. The photos were taken in two orthogonal planes (frontal and lateral view on the radiator); two areas were measured in each plane. Description of planes and areas of measurement is shown in Figure 7. The measured data were evaluated in software Flowmanager (DANTEC). The process of measurement is shown on fig. 8.

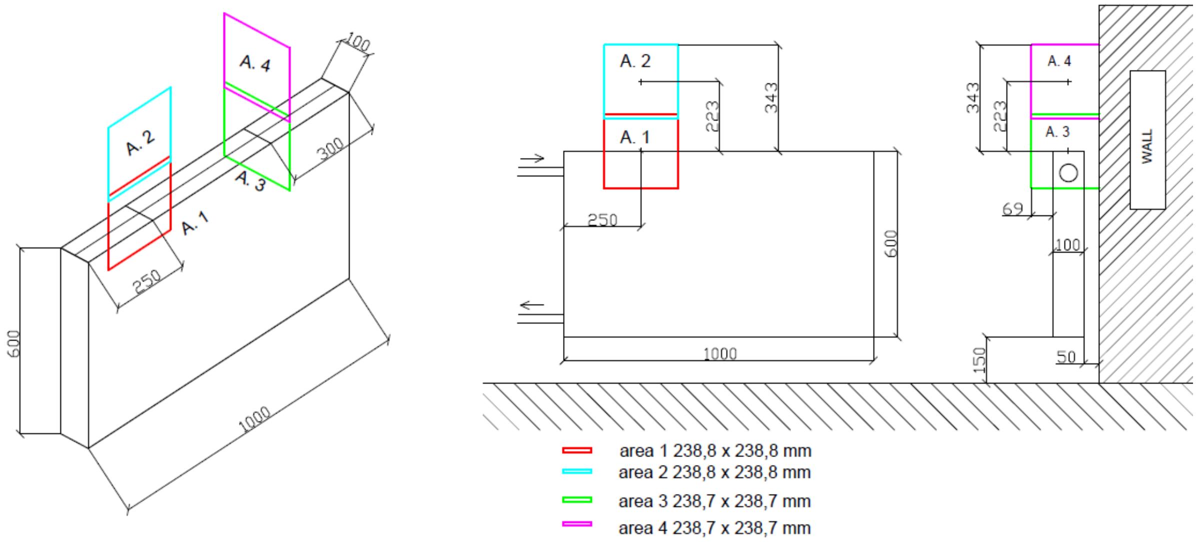

***Fig. 7** Measured areas*

Fig. 8 *Measuring place, process of measurement*

The results of the experiment are presented as a velocity vectors field above a panel radiator in measured areas. Figure 9 shows velocity vectors field for all grids in area 1 – vertical plane parallel to the back wall. It is evident, that the velocity profile evens fastest by using a grid with the rectangular openings. This is due to the lower distance between openings (approximately half) than in the other grids. This leads to more intensive mixing of individual plums at lower altitude above covering grid (approximately 22 mm). For other grids (star, circle, crescent) we can see the same mixing at altitudes from 45 to 50 mm. At an altitude about 105 mm, one mixed convective plum rises while still occurring an increase in flow velocity up to 336 mm, where this trend is reversed and the velocity begins to decrease.

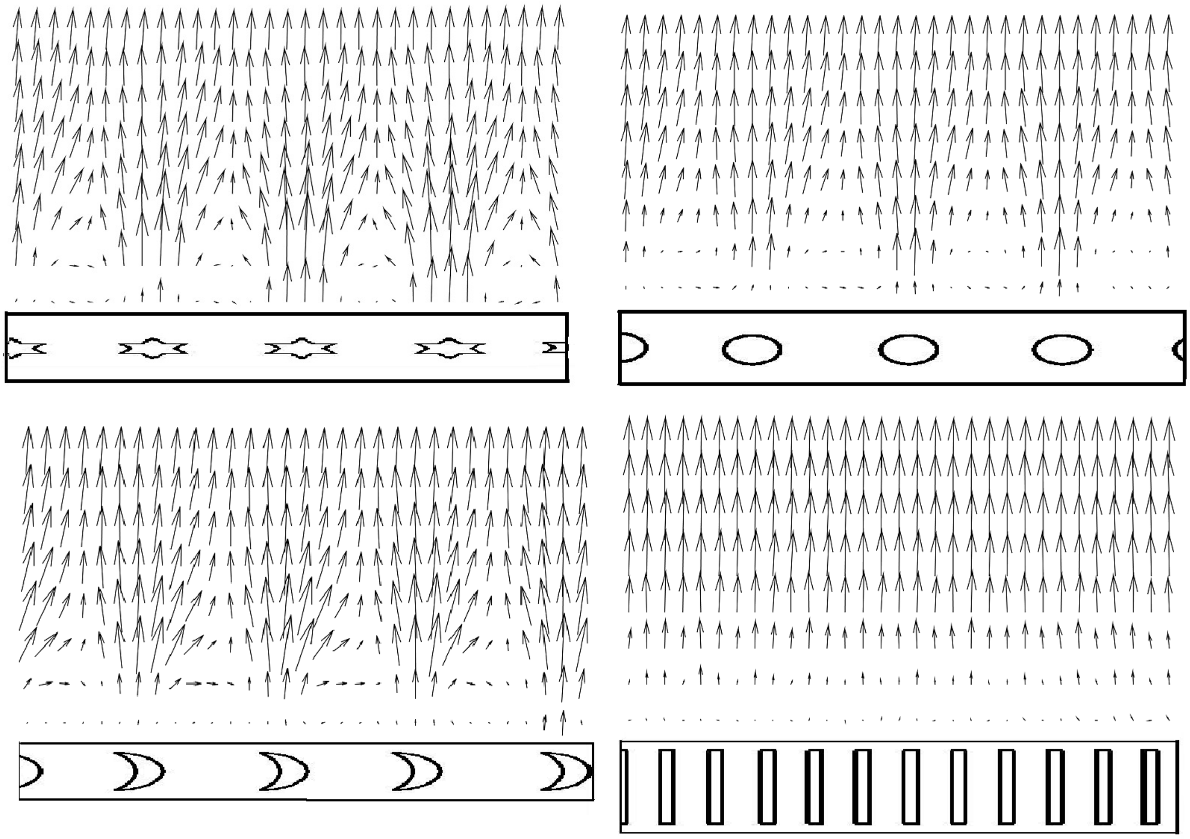

Fig. 9 *Velocity vectors - area 1, all grids*

Figure 10 shows velocity vectors field for all shapes in area 3 – vertical plane perpendicular to the back wall. It can be seen, that the main convection plum “draws” ambient air from the heated room, but also in space between the panel radiator and back wall. Due to this we can see that the peak of velocity profile is moving toward the back wall with the increasing altitude.

For grid with rectangular shape of openings we can see the highest maximum velocity, v_{max} = 0,96 m/s at an altitude of 22,4 mm above the panel radiator. On the other side for this grid the most rapid decrease in velocity with increasing altitude was measured. Another important effect is more intensive intake of ambient air for grids with “round shapes” of openings (star, circle), then for the grids with “oblong shapes” (rectangular, crescent). In areas 2 and 4 (at altitudes more than 110 mm, see fig. 3.4) the velocity profile is fully mixed (developed).

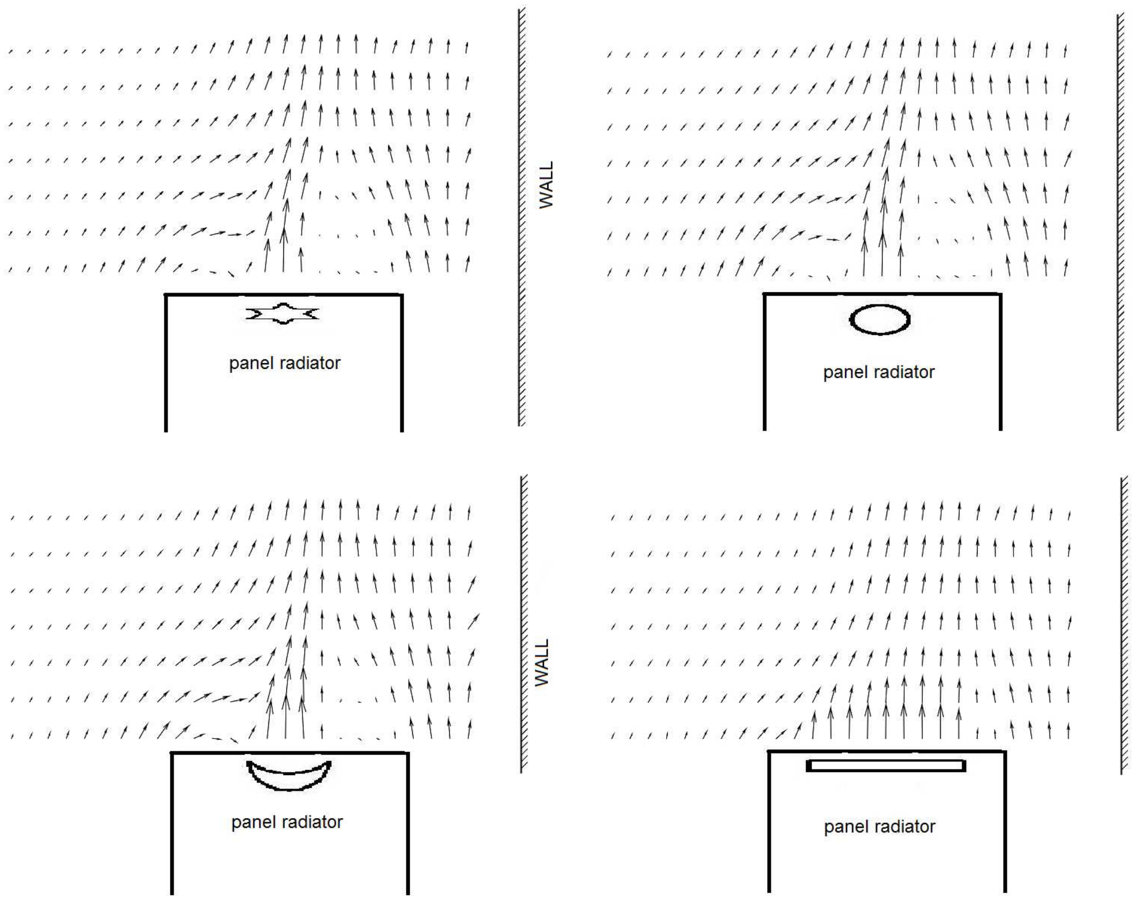

Fig. 10 *Velocity vectors - area 3, all grids*

Other presentable results are the velocity profiles for various grids in various altitudes above the panel radiator. For illustration, the profiles in altitude 22,4 mm, in area 3 (maximum stream velocity for all grids) are presented on figure 11. From this picture is more evident the intake of ambient air both from heated space and from the space between the panel radiator and back wall. In table 2 are presented the values of maximum velocity for all shapes in selected altitudes.

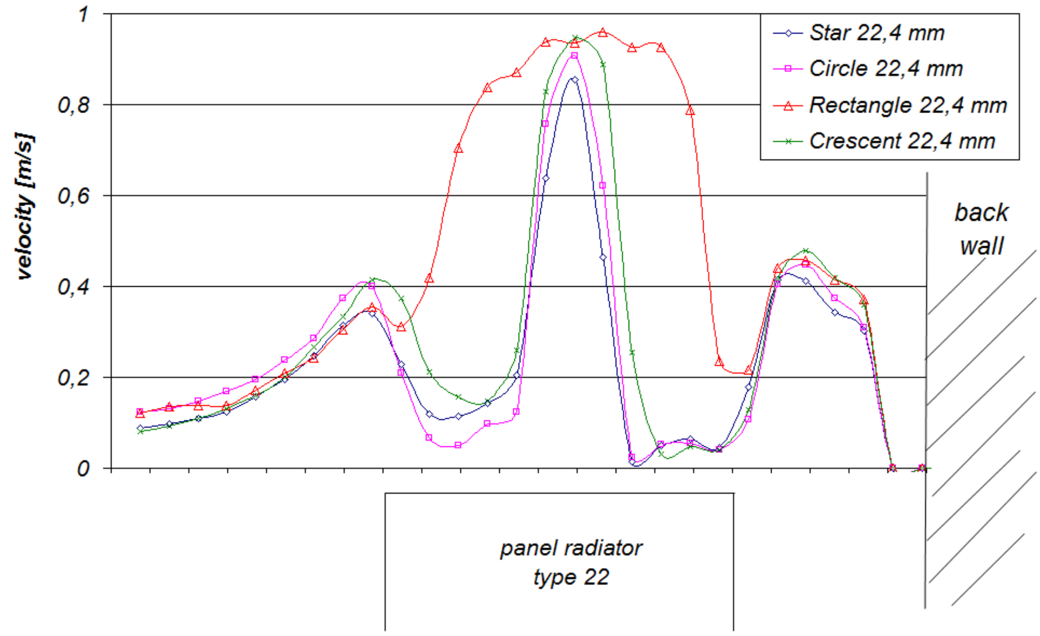

Fig. 11 *Velocity profiles, area 3, all grids*

Table 2 *Values of maximum velocity for all shapes*

v_{max} [m/s]	**Altitude above the panel radiator [mm]**					
	14,9	**22,4**	**44,8**	**104,5**	**261,2**	**335,9**
star	0,73	0,85	0,66	0,48	0,69	0,72
circle	0,80	0,91	0,78	0,50	0,70	0,72
rectangular	0,79	0,96	0,69	0,51	0,67	0,72
crescent	0,94	0,95	0,53	0,54	0,71	0,74

5. Conclusions

Presented experiments described the behavior of convective plums rising from the panel radiator fitted with non-standard covering grids. Based on the experiment, a decrease of panel radiators heat output, depending on the relative flow cross section of the covering grid was determined. It was also described the flow field above the panel radiator. Subsequently the computer fluid dynamics (CFD) will be used. In accordance with studies mentioned previously, it will be used the model of the room with dimensions 4 x 4 x 3 m. Then will be simulated temperature and velocity fields above panel radiator fitted with grids used in the previous experiments. The calculations will be performed for two temperature conditions (75/65 °C and 50/40 °C) and for two values of intensity of ventilation (0,1 and 0,5 1/h). Based on these results, the optimal design of covering grid will be presented. The greatest importance will be placed for optimal air flow in a heated room and for optimal mixing of warm and cold convective plums.

This research has been supported by SGS grant No 10 802540

Symbols

c	Specific heat capacity	[J/kg·K]
t	Temperature	[°C]
w	Velocity	[m/s]
Q	Heat output	[W]
S	Cross-section	[m^2]
V	Volume flow rate	[m^3/h]
ρ	Density	[kg/m^3]

Index

min.	minimal
max.	maximal
w1	supply water
w2	return water
i	individual
0, c	overall
N	nominal

References

[L1] Bašta, J.: *Otopné plochy*. Praha: ČVUT 2001, 328 s., ISBN 80-01-02365-6

[L2] Bašta, J.: *Umisťování otopných těles ve vytápěném prostoru*. In: VVI, 2006, roč. 15, č. 5, s. 237-241, ISSN 1210-1389

[L3] Myhren, J., A., Holmberg, S.: *Flow patterns and thermal comfort in a room with panel, floor and wall heating.* In: Energy and Buildings, 2008, vol. 40, p. 524-536

[L4] Berounský, V.: *Vyšetření vlivu otopných těles na tepelnou pohodu vytápěného prostředí*. Praha: SVÚTT, 1963, s. 211 – 226. ISBN 06-13-63

[L5] Idelchik, I. E.: *Handbook of hydraulic resistance*. New York: Begell House, 1996, ISBN 1-56700-074-6

[L6] Fanger, P.O.: *Thermal Comfort*. Kopenhagen: Danisch Technical Press, 1970, 224 s.

[L7] Bašta, J., Pospíšilová, V., Schwarzer, J. *Vytápěný prostor a varianty návrhu otopných těles*. In: VVI, 2009, roč. 18, č. 3, s. 109-114, ISSN 1210-1389

[L8] Bašta, J.: *Zákryty otopných těles a jejich vliv na tepelný výkon*. In: VVI, 1999, č. 3, ISSN 1210-1389

[L9] Bašta, J.: *Nový přístup k navrhování otopných těles*. In: Vytápějme levně a bezpečně IV. Pardubice: I. Hovorková s.r.o. s. 81 - 92

[L10] Beck, S.M.B., Grindsted, S.C., Blakey, S.G., Worden, K.: *A novel design for panel radiators.* In: Applied Thermal Egineering, 2004, vol. 24, p. 1291-1300

[L11] Bašta, J.: *CFD und neue Auffassung des Heizkörperentwurfs.* In: Heizung Lüftung/Klima Haustechnik, Bd. 54, 3/2003. s. 36-41. ISSN 1436-5103.

[L12] Dalal, R., Naylor, D., Roeleveld, D.: *A CFD study of convection in a double glazed window with an enclosed pleated blind.* In: Energy and Buildings, 2009, vol. 41, p. 1256-1262

[L13] Borutzky, W., Barnard, B., Thoma, J.: *An orifice flow model for laminar and turbulent conditions.* In: Simulation Modelling Practice and Theory, 2002, vol. 10, p. 141-152

[L14] Floryan, J. M., Novak, M.: *Free convection heat transfer in multiple vertical channels.* In: Int. J. Heat and Fluid Flow, 1995, vol. 16, p. 244-253

[L15] Gan, G.: *Impact of computational domain on the prediction of buoyancy-driven ventilation cooling.* In: Building and Environment, 2009, p. 1-11