THE EFFECT OF ROOM THERMAL ENVIRONMENT ON THE PERFORMANCE OF COOLED BEAMS

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Abstract

Cooled beams are used to provide cooling of the spaces by means of natural or forced convection. Cooling capacity of static beams, which are working by natural convection, strongly depends on the thermal environment of the room they are installed in. The effect of the cooled beams location in the room and distribution of heat sources on the cooling performance of the beams is illustrated by the computational fluid dynamics - CFD calculations with reference to measurements.

Terminology and cooled beam design

Since there is a variety of terms used to describe the similar devices (chilled ceilings, cooled panels, chilled beams, static beams, active beams, etc.) we present definitions of the terms that are going to be use in this paper.

Cooled beam - device with heat exchanger, used to cool room air by means of convection (radiant compound of the heat exchange between the cooling device and surrounding surfaces is less than 15% of the total heat exchange rate). There are two types of cooled beams:

1. **Static cooled beam** - water cooled finned heat exchanger enclosed in a beam shaped casing. Heat exchange between the beam and room air is provided by means of natural convection, no air is supplied through the device.
2. **Active (ventilated) cooled beam** - a device combining functions of a cooled beam and room air terminal. Air is supplied through the beam to provide room with fresh air and increase the circulation of the room air through the heat exchanger thus intensifying heat transfer within the finned heat exchanger (Fig. 1).

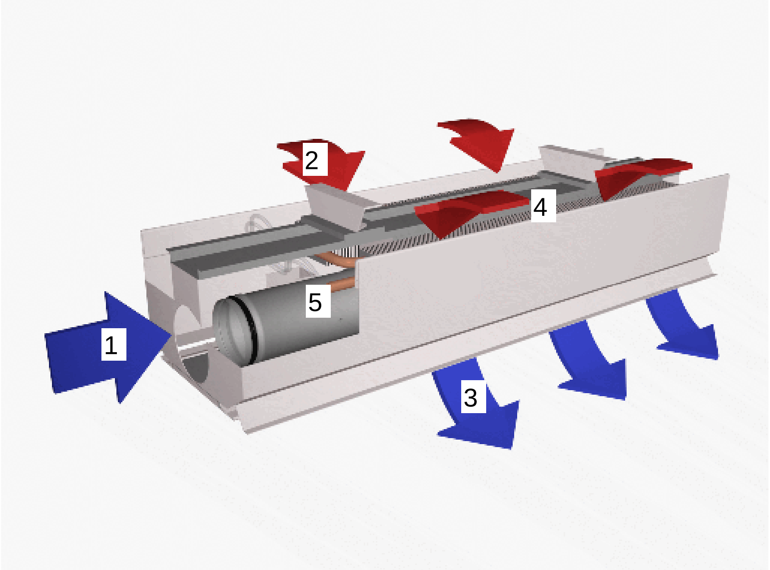


Fig. 1 Active ventilated cooled beam, principle design. 1 - primary supply air; 2 - secondary room air, induced by primary air; 3 - mixed air (1+2) supplied into the room; 4 - finned coil heat exchanger that cools air 2.

Introduction

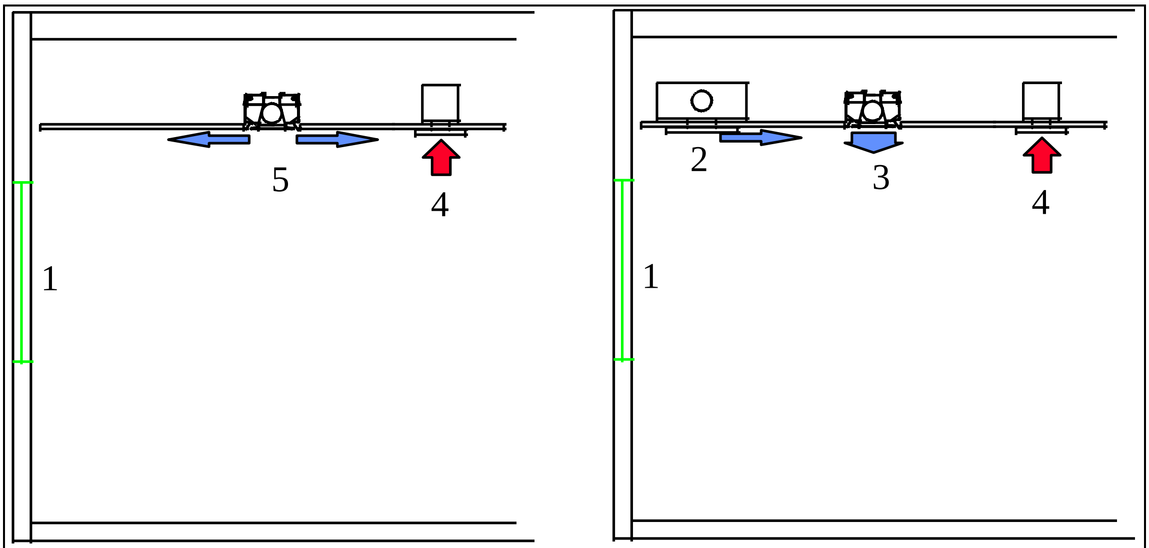
Over the last 5 - 7 years the range of decentralized comfort cooling systems has been expanded by the application of cooled beams. We believe that one of the main reason for growing popularity of these devices is the stringing of indoor climate regulations towards lower velocities in the room occupied zone especially in

Scandinavia, UK, Germany, Switzerland. Indeed, cooled beams provide “smooth” distribution of coolth within the room ensuring a comfortable level of temperatures, velocities and noise levels within the occupied zone. Cooled water is used as the cooling media in cooled beams, the water inlet temperature is selected around 14-15°C under normal design conditions to avoid condensation on the surfaces of the heat exchanger.

Having the above mentioned advantages, cooled beams require more sophisticated approach while designing a room air conditioning system. Static beams, working with low temperature differences under conditions of natural convection, perform differently in rooms with variations of the thermal environment. It is not a surprise that there are publications (1,2,3) revealing some disagreement between the technical documentation and field measurements. The truth is that no matter how sophisticated a measurement standard is, it would fail to reproduce the variety of thermal environments of real application cases. The more a cooled beam system is dependent on room thermal conditions the more likely its cooling performance will vary depending on the location of the heat sources in the room. Selection of an air distribution scheme and location of air terminals will also affect cooling capacity of a static cooled beam.

Active beam versus static beam + ceiling diffuser, system comparison.

Lets compare the performance of two system solutions in a typical office (fig 2). For the system comparison we have selected an open office space with a heat load of 70 W/m^2. Part of the load is transferred from the outside wall with intencity 50 W/m^2, the



a b

Fig. 2 characteristic cross-sectional view of the office. a - with active cooled beam installation; b - with static cooled beam + ceiling diffuser installation
1 - outside wall with the window; 2 - diffuser; 3 - static cooled beam; 4 - exhaust valve; 5 - active ventilated cooled beam

rest of the load is distributed in the room as a volumetric heat source. Cooled beams are positioned in the office parallel to the outside wall. In case #1 (fig. 2a) the total amount of fresh air supply 30 l/s, with a temperature 18 °C is distributed through an active ventilated cooled beam (8 l/s per meter length of the beam), in the case #2 (fig 2b) static beams are installed and supply air is distributed into the room through a conventional ceiling diffuser. In both cases air is extracted through an exhaust valve, installed in the ceiling.

CFD software package Aflow2f developed by ANES Group at Moscow Power Engineering Institute for modelling of convection processes in two-phase systems is used for simulations. Simulation results at the characteristic cross-section view are presented in fig. 3,4. Temperature and velocity distribution within the occupied zone are presented in table 1.

Table 1 Simulation results, average temperature and velocity distribution within the occupied zone

System	Average temperature, °C	Average velocity, m/s
case #1 active ventilated cooled beam	28.5	0.15
case #2 static cooled beam + ceiling diffuser	33.4	0.16

As can be seen from the above table the similar setup in terms of the equipment selection (in both cases beams were selected from the diagrams to achieve the same cooling performance) produces vastly different results. Average temperature in the occupied zone in case #2 is 4.9 °C higher compared to case #1.

In case #2 the flow from the ceiling diffuser is blowing away the dropping convective plume thus reducing circulation of air through the beam heat exchanger and preventing cooled convective air flow from penetrating into the occupied zone. On the other hand in case #1 where air distribution device and cooling unit are combined air, supplied through the active beam does not disrupt the circulation of the air through the heat exchanger. Another advantage of the ventilated cooled beam is that the primary air supplied through the nozzles located below the heat exchanger coils is utilized to increase circulation of secondary air through the heat exchanger. Thus heat exchange between the secondary air and beam heat exchanger is being intensified and one can achieve a higher cooling output from a meter length of an active beam compared to a static beam with the similar heat exchanger.

The effect of convective heat source location in the room on cooling performance of a static beam.

It is a common practice and the requirements of measurement standards (4) that cooling performance of cooled beams is presented as function of average water temperature circulating through the heat exchanger and average room temperature at height 1.1 m. The measurements to estimate beams cooling performance (4) are being made in the measurement room with smoothly distributed heat load - heat flux is distributed evenly through all walls and floor into the room. These measurement conditions are very rarely reproduced in the field where multiple local heat sources are forming convective plumes affecting circulation of air in the room and cooling performance of static beams. To illustrate the above statement we have produced the following set of numerical simulations of the static beam performance:

Case #3: the ceiling and floor are thermally isolated (adiabatic), constant temperature is set on the room walls.

Case #4: all room outer surfaces are thermally isolated (adiabatic), heat source is located on the floor in the middle of the room under the beam.

Room dimensions 2.8 x 2.72 x 4.3 m (width x height x length), half of the room is being calculated. Static cooled beam is installed in the middle of the room, bottom of the beam is 2.41 m from the floor level. Finned coil heat exchanger of the beam is modeled as an air penetratable porous structure with specific flow resistance and heat exchange characteristics from water to fins and to the air.

Simulation results are presented in Table 2.

Table 2 Static beam cooling capacity, simulation results on cases #3,4

Case #	Walls temperature, Tw, °C	Beam cooling output, Q_{coil}, W/m	Average temperature at height 1.1 m, T1.1, °C	Temperature difference[1], dT, °C
Case #3 - heat flux through the walls				
3.1	26	48	20.2	6.2
3.2	34	102	23.4	9.4
3.3	40	150	25.8	11.8

Case #	Heat source output, Q, W/m	Beam cooling output, Q_{coil}, W/m	Average temperature at height 1.1 m, T1.1, °C	Temperature difference, dT, °C
Case #4 - heat input through the heat source on the floor, outer surfaces are adiabatic				
4.1	48	48	21.7	7.7
4.2	60	60	22.7	8.7
4.3	120	120	27.5	13.5

Cooling capacity of the static beam as a function of temperature difference[2] dT is presented on fig. 6

[1] Temperature difference between average room temperature at height 1.1 m and average water temperature circulating in pipes of the heat exchanger. In both cases water temperature was 14°C

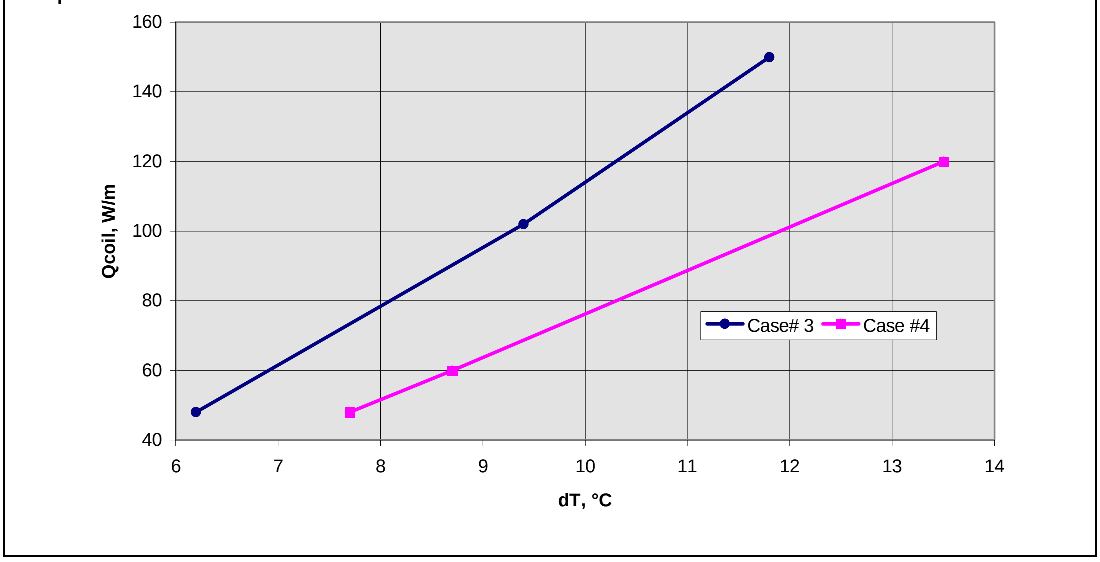


Fig. 6 Cooling capacity of the static beam Q_{coil} as function of temperature difference dT

Vertical temperature gradient in the room at a distance of 0.7 m from the beam axis (beam is installed along the room centreline) is shown on fig. 7 for cases #3.1 and #4.1. It can be seen that although the static beam provide the same cooling output in both cases (48 W/m - cases #3.1, 4.1), the temperature gradient in the room and the temperatures in the occupied zone are different.

Such a difference in the temperature of the occupied zone is explained by the fact that the cold dropping convective plume is dumped by the warm convective plume raising from the heat source in case #4.1 and two circulation zones are being formed within the room (fig 8a). On the contrary in case #3.1 only one circulation zone is being formed in the room and the cold convective plume from the beam reaches the occupied zone (fig 8b).

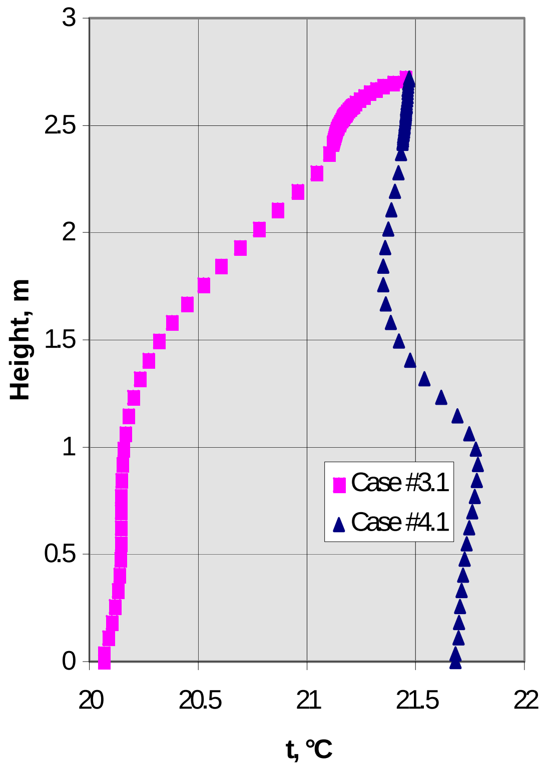


Fig. 8 Vertical temperature gradient in the room, cases #3.1 and 4.1

Conclusions.

- The cooling performance of a static beam depends on the thermal environment of the room it is being installed in. Location of the air distribution devices and heat sources in a room has to be taken into account while designing a room cooling system with static beams.
- Active ventilated cooled beam is characterized by stable cooling performance since air distribution device is combined within the beam and circulation of the secondary air through the beam heat exchanger is enforced by the primary air supply.
- Active ventilated cooled beam, where the supplied air increases circulation through its heat exchanger, has a higher cooling output compared to a static beam with the similar heat exchanger.

References

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3. Swedish National Testing and Research Institute, test report SP - rapport 1995:64 “Fullskaleprov ger rättvisande bild av kyleffekten hos kyltak”
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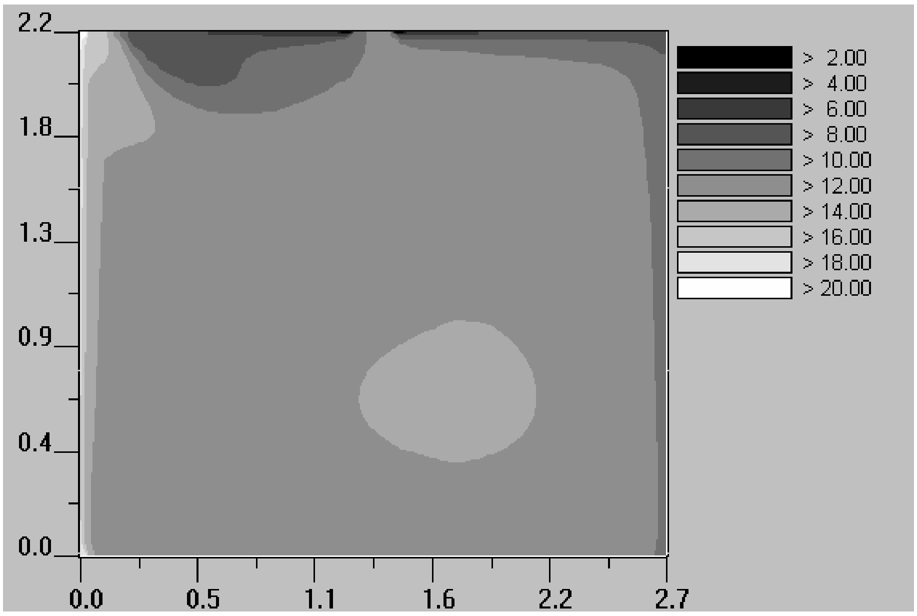
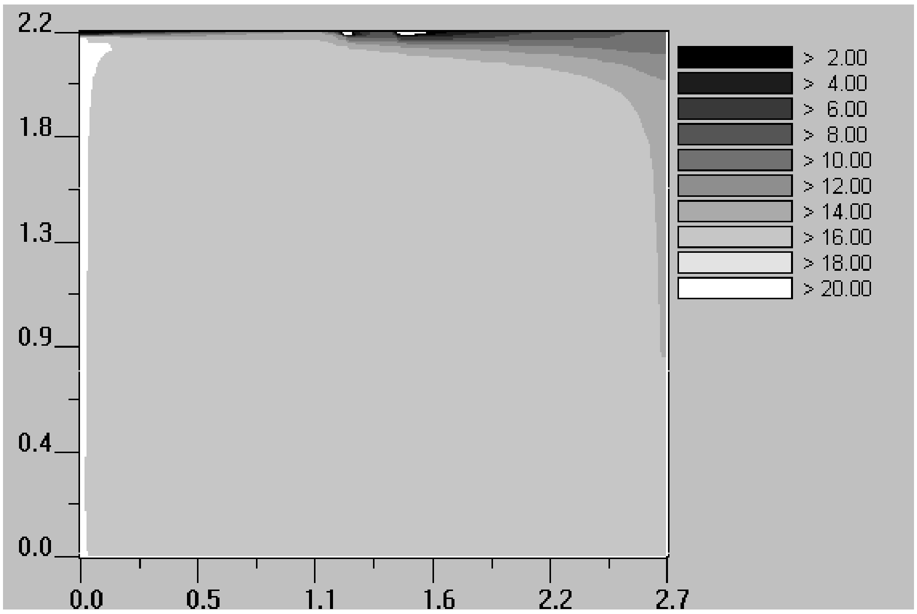
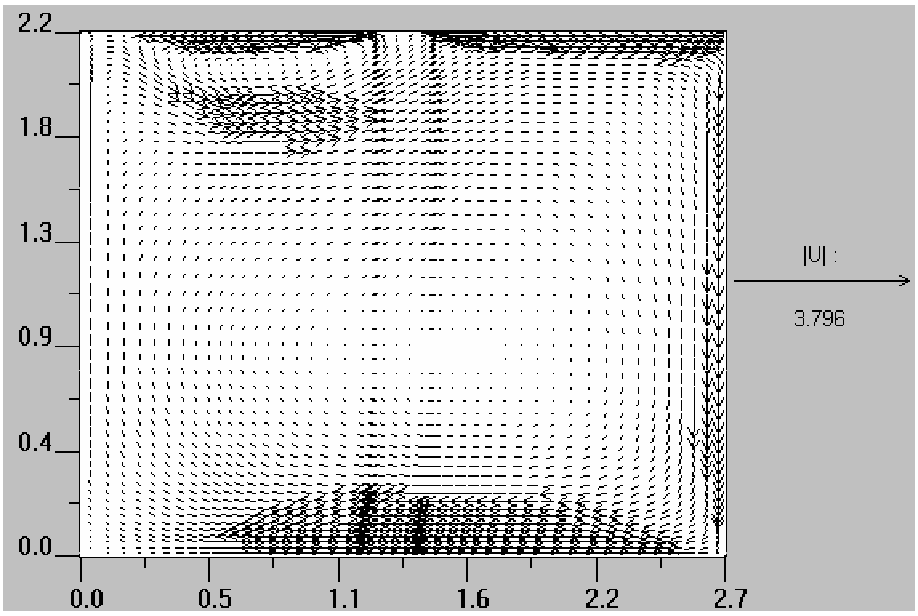


A - case #1 Active ventilated cooled beam
Average air temperature in the occupied zone is 28.5°C

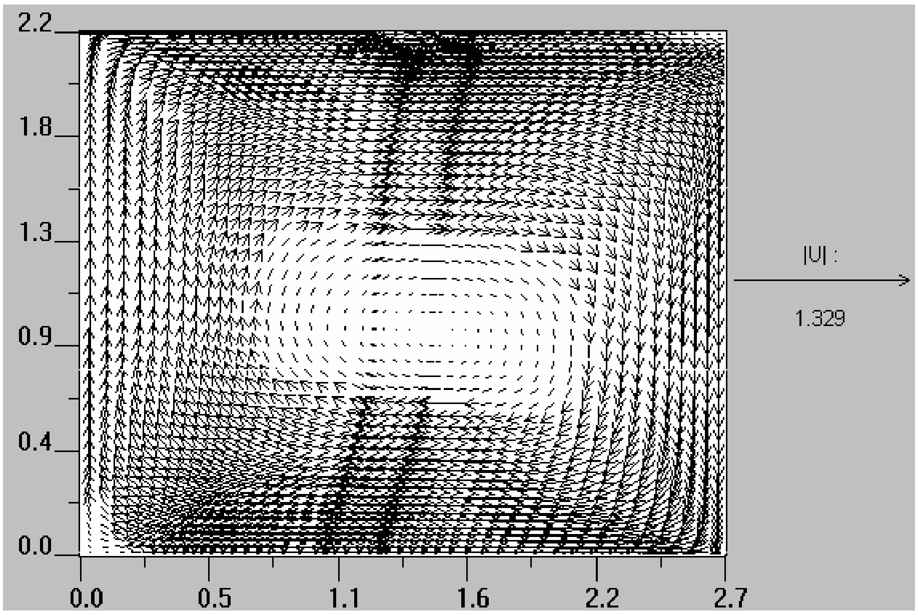


B - case #2 Static beam + ceiling diffuser
Average air temperature in the occupied zone is 33.4 °C

Fig. 4 Temperature distribution in the characteristic cross-sectional view, reference temperature is 15°C

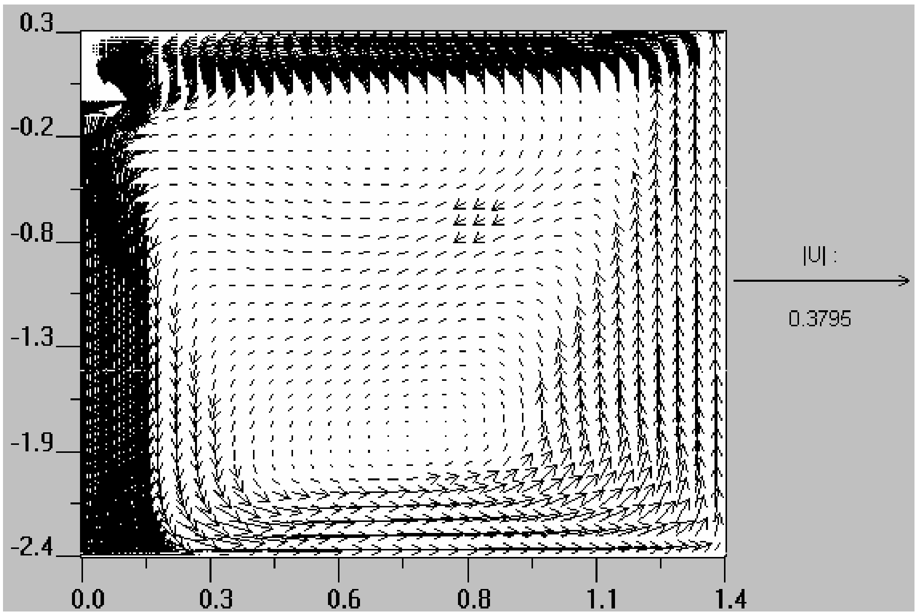


A - case #1, average and maximum velocities in the occupied zone: Uavr= 0.15 m/s; Umax= 0.41 m/s

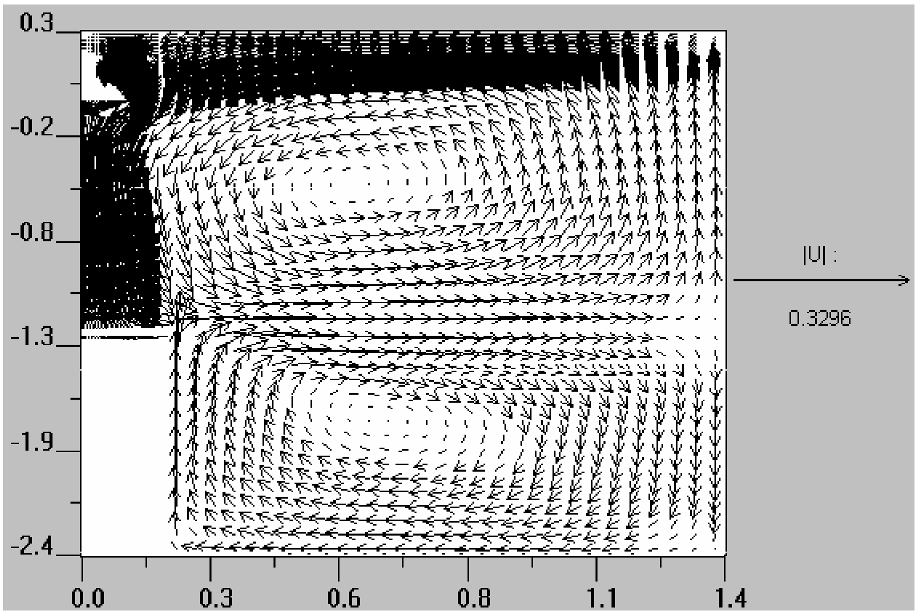


B - case #2, average and maximum velocities in the occupied zone: Uavr= 0.16 m/s; Umax= 0.4 m/s

Fig. 5 Diagram of velocity vectors in characteristic cross-sectional view



A - case #3.1 Average air temperature at height 1.1 m is 20.2°C



B - case #4.1 Average air temperature at height 1.1 m is 21.7°C

Fig. 8 Diagram of velocity vectors in the characteristic cross-sectional view.