LOCAL VENTILATION SYSTEMS:
SOME INVESTIGATIONS ABOUT COMFORT LEVELS AND ENERGY DEMANDS

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Abstract. *Efficient ventilation of indoor environments shall guarantee not only a proper oxygen flow for human breathing, but also an effective removal of pollutants released by human metabolism and building materials. Usually, high ventilation rates are adopted to reach these two goals, with a consequent high energy consumption for buiding climatization. A good compromise between good indoor air quality and energy saving can be achieved by adopting local ventilation systems, such as the so called "task ventilation". Local ventilation has turned out to be a very effective way to respond to specific personal requirements and therefore also to improve satisfaction and productivity in working places.*
In this paper some local ventilation systems are analysed and compared with the traditional "well-mixed ventilation". A small movie theatre is simulated as a test case by using a CFD computer model: this way, local comfort indices as well as energy demands, have been determined for the different ventilation systems, in order to optimize the ventilation strategy.

Keywords: *Local ventilation, Thermal comfort, Energy demand, CFD*

1. INTRODUCTION

In building physics ventilation with outside air is responsible not only of providing proper quantities of oxygen to the indoor environment, but also of suitably removing pollutants emitted by materials, furniture and by occupants themselves. Recent research evidences suggest that occupant satisfaction and productivity can be significantly increased by improving indoor air quality (Croome 1989), (Fanger 2001), (Gohara 2001).
Contaminants concentration and distribution depend on the pollutant generation rate, on the geometry of the enclosure and on the efficiency and design of the ventilation system.
Three approaches to improve indoor air quality can be adopted. The first action consists of avoiding contaminants sources inside the building, but unfortunately this is often difficult to carry out, or even impossible (e.g., for human bioeffluents). Secondly, pollutants can be locally removed, but technical means are available only for same of them (e.g. moisture or dust particles). Finally, the easiest way to improve air quality is to supply outdoor air, poor in contaminants and rich in oxygen. However, this strategy significantly affects building's energy demands and the amount of outside air shall be kept as low as possible.

A proper positioning of ventilation diffusers is fundamental to provide comfort conditions for the occupants using low flow rates and in this regard, task ventilation systems play an important role especially in the tertiary sector. Derived from industry, the basic idea is the use of the air inflow just to ventilate the occupied zone, without modifying elsewhere both thermal conditions and pollutants concentrations. In fact, task ventilation permits to define different selective zones within the environment, with different microclimate for each specific requirement.

In the present paper some different ventilation systems are compared referring to a small movie theatre. By the use of CFD simulations, providing temperature and velocity fields and consequently allowing to calculate various comfort indexes, advantages and limits of different solutions are analyzed and discussed.

2. LOCAL VENTILATION SYSTEMS

Usually only 1% of the supplied air is inhalated by occupants, because primary air is extensively diluted by room air before coming in the occupied zone. So it is convenient to supply low flow rates of high quality primary air directly in defined zones close to people.

In these systems there are lots of inflow and extract devices placed in the proximity of occupied zone, but sometimes exhaust air outlets are located in the ceiling like in displacement ventilation systems, to take advantage of buoyancy forces caused by thermal loads. In any case, inlet air temperatures are quite close to comfort conditions, when compared with ceiling-level suppliers (Bauman 1998) (Bauman 2004).

In theatres or conference rooms local ventilation usually means that the supply of the air comes from diffusers situated at the top of the seat back or at the base of the seat; grilles and perforated plates on the floor or on the steps of the amphitheatre can also been used. In the cases of seat diffusers the air is discharged at a small angle towards the next rear seat, approximately 0-20° from the vertical. In classrooms or in open space offices the air can be supplied from linear diffusers placed along the front edge of the desk. In this way a jet envelope in front of the seated person is produced and the head is not directly in the path of the jet but within its entrainment zone (Tanabe 1995). An induction air system can be used to mix induced room air with primary air just to form the supply air. The discharge velocity for a personal diffuser is usually 1.5-2.5 m/s (ASHRAE 2001).

3. A TEST CASE

For the comparison of different ventilation strategies, a little movie theater (16 m long, 4 m high and 10 m wide) has been studied as a test case (Fig. 1).

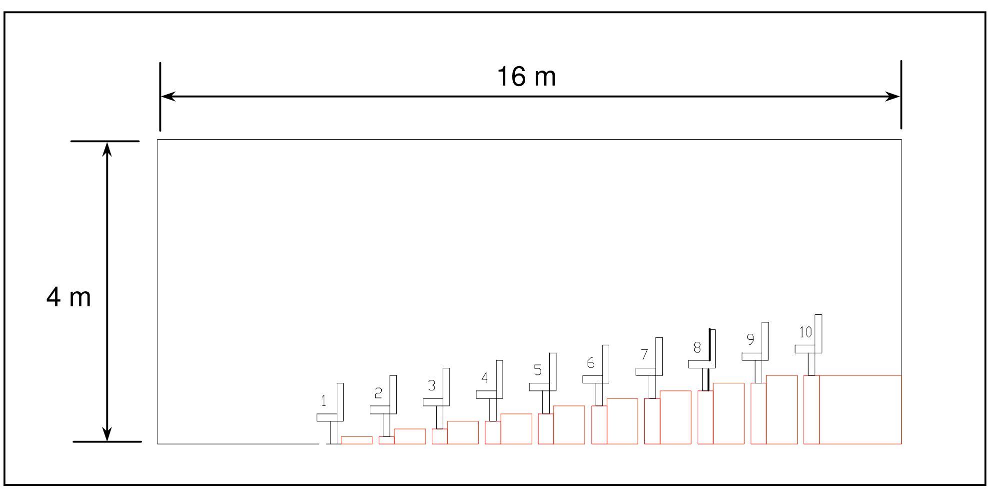


Figure 1. Scheme of the movie theater used as case study in numerical simulations.

The different systems performances have been simulated by resorting to the well known CHAM computer code "Phoenics" (Spalding 1987) (Sohn 2000). Since attention has been focused on energy consumptions and on thermal comfort, pollutant concentrations were not considered and steady simulations were performed with uniform temperatures of the walls (representing the boundaries of the CFD simulation domain). These temperature were kept at 18 °C in winter cases and at 30 °C in summer cases (for all surfaces except floor, seats, and lateral walls with respect to seated people, assumed to be adiabatic).

As a very high number of cells was needed to have a good description of temperature and velocity fields, two-dimensional simulations were performed to decrease computational time. Comparison of some two-dimensional simulations with three-dimensional ones showed the reliability of results.

4. RESULTS

A large number of simulations has been carried out with different positions of air inlets and outlets, with different characteristics of the jets and with different inlet temperatures. For each of them, the comfort conditions in the occupied zone has been assessed.

As well-known, the most reliable approach for thermal comfort was proposed by Fanger, now coded also by UNI-EN-ISO 7730 and based on the "Predicted Mean Vote" (PMV):

$$PMV = f\,(M, \eta_t, R_c, f_c, t_a, \phi_a, u_a, t_r) \quad (1)$$

expressed in a suitable scale (ranging from -3 to +3) and function of activity (methabolic rate M and mechanical efficiency η_t), clothing characteristics clothing resistance R_c and clothing factor f_c), air conditions (temperature t_a, relative humidity ϕ_a and the velocity u_a) and radiant field (mean radiant temperature t_r). The previous index is also related to the "Predicted Percentage of Dissatisfied" which represents the percentage of the people complaining about the thermal environment (Fanger 1972):

$$PPD = f\,(PMV) \quad (2)$$

Additionally, it is very important to remind that some particular discomfort causes have to be considered and some of them are very important for a right design of task ventilation system. In fact, serious draught complaints can often occur at high air speeds and/or high turbulence intensity and also the consequent percentage of dissatisfied, termed Draft Risk (DR) can be predicted (Fanger 1988). The empirical expression of DR take into consideration air temperature t_a, mean air speed u_a and turbulence intensity I :

$$DR = (34 - t_a)(v_a - 0.05)^{0,6223}(0,3693\ v_a\ I + 3,143) \quad (3)$$

From the velocity and temperature fields obtained by CFD simulations, PMV and PPD indexes, as well as draft risk DR were calculated. For all cases, metabolic rate was 1 met (sedentary activity), relative humidity was 50%, clothing resistance was 1 clo in winter and 0.5 clo in summer, turbulence intensity was 0,4.

Among the various considered situations, four cases have been selected since they presented satisfactory and comparable values of comfort indices in the occupied area. These cases are summarized in Tab. 1 where air inlet locations, velocities and temperatures are given. As for inlet temperature, this variable has been kept at 23 °C in winter and 24 °C in summer and the resulting values of the comfort indexes are reported in Tab. 2 (winter case) and in Tab. 3 (summer case).

For these cases the results obtained by means of CFD simulations are graphically shown in Figures 2 and 3. It easy to observe that cases A and B represent local ventilation strategies: the jet spread is slightly different, but in both cases comfort is quite confined around the occupied zone (both in winter and in summer). In case C, instead, can be defined as a “semi localized” ventilation system with air inlet on chair back and outlet on a vertical wall. Finally, case D is the traditional solution, represented by the “well mixed” ventilation strategy: air must be delivered at higher velocities and spread angles in order to uniformly reach the occupied zone.

Table 1. Ventilation strategies investigated in the simulations

	Inlet location	**Outlet location**	**Jet spread**	**Air Velocity**	**ventilation rate**
A	chair back	under chair	jet spread 10°	0.3 m/s	108 m^3/h
B	chair back	under chair	jet spread 20°	0.3 m/s	108 m^3/h
C	chair back	on wall	jet spread 20°	0.3 m/s	108 m^3/h
D	ceiling	under chair	jet spread 25°	0.5 m/s	180 m^3/h

Table 3. PMV, PPD and DR values in cooling mode (wall surface temperatures 30 °C).

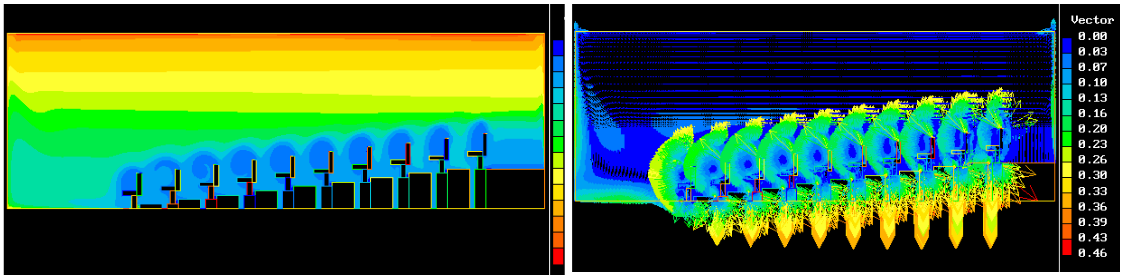
		case A		case B		case C		case D	
		seat 1	seat 5	seat 1	seat 5	seat 1	seat 5	seat 1	seat 5
Air Velocity v_a	[m/s]	0.16	0.18	0.17	0.11	0.11	0.10	0.19	0.13
Air Temperature t_{air}	[°C]	24.3	24	24.2	24	24.2	24	25	24.3
PMV	[-]	0.30	0.17	0.25	0.45	0.49	0.48	0.34	0.41
PPD	[-]	7	6	6	9	10	10	7	9
DR	[%]	7.79	8.86	8.29	5.68	5.44	4.79	8.25	6.43

Table 4. PMV, PPD and DR values in heating mode (wall surface temperatures 18 °C).

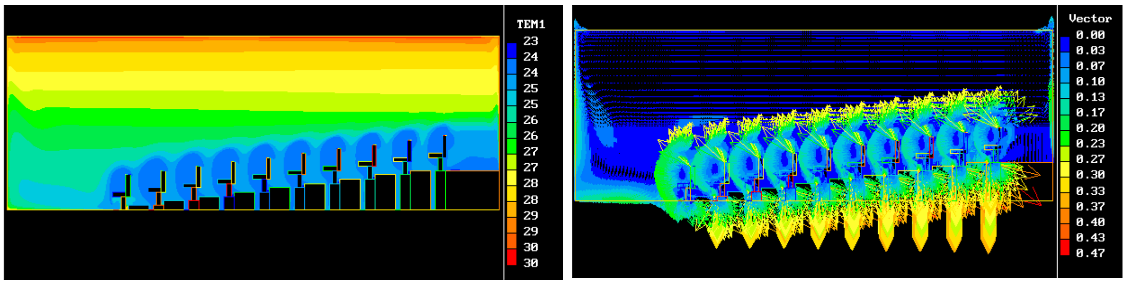
		case A		case B		case C		case D	
		seat 1	seat 5	seat 1	seat 5	seat 1	seat 5	seat 1	seat 5
Air Velocity v_a	[m/s]	0.10	0.09	0.06	0.05	0.09	0.11	0.08	0.07
Air Temperature t_{air}	[°C]	22.2	23.01	21.7	22.50	22.87	23.02	22.19	22.70
PMV	[-]	-0.49	-0.37	-0.50	-0.50	-0.39	-0.40	-0.45	-0.37
PPD	[-]	14	8	10	8	8	8	9	8
DR	[%]	8.82	4.99	1.86	1.12	4.74	6.25	4.35	3.36

In Fig. 2 and Fig. 3 the effect of increasing the seat supply angle is quite clear, since the head of the individual is within the fresh air zone. In the overhead system simulations (case D) ventilation cause a short cut between diffusers and outlet devices especially in cooling conditions: the whole enclosure is interested by air flows and no thermal stratification is evident. Intermediate conditions are presented for case C with chair inlet and wall outlet: air flows from inlet to outlet generating a controlled bubble on occupied zone, but its dimensions are larger than in cases with local discharge and outlet. On the other hand a certain thermal stratification is still present both in winter and in summer conditions.

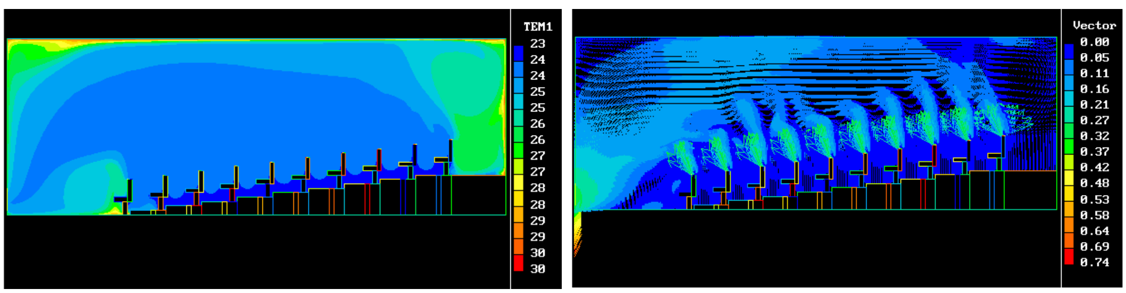
Case A: seat diffusers, under-seat extract openings, supply angle 10°



Case B: seat diffusers, under-seat extract openings, supply angle 20°



Case C: seat diffusers, wall extract openings, supply angle 20°



Case D: ceiling diffusers, under-seat extract openings, supply angle 25°

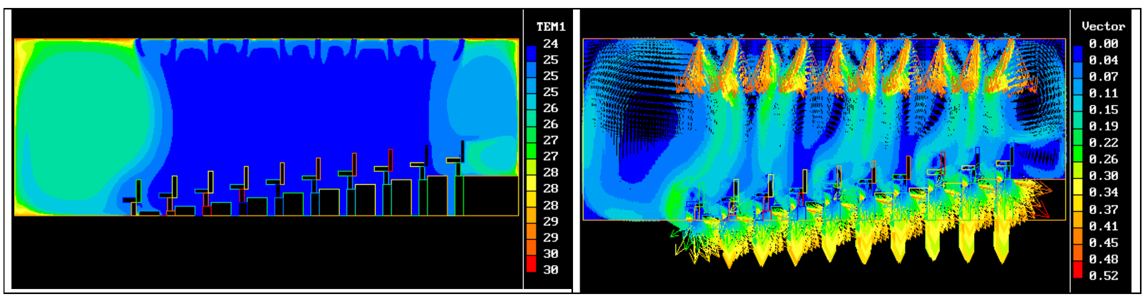
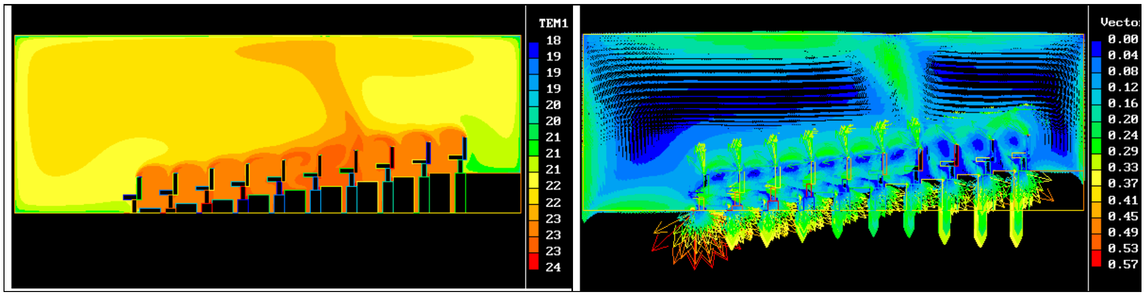
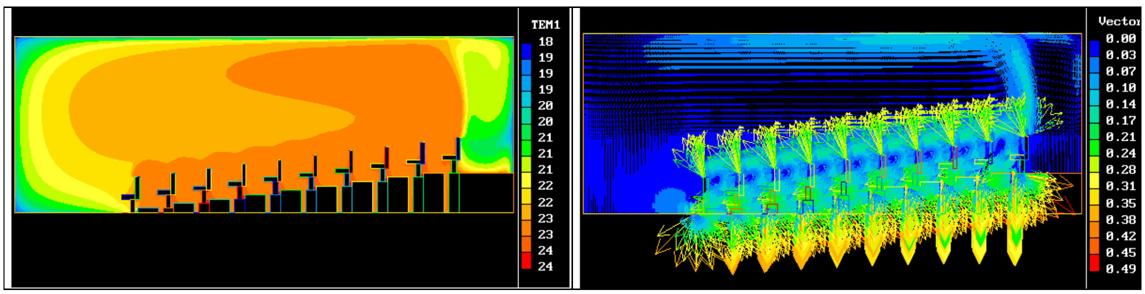


Figure 2. Temperature (left column) and velocity fields (right column) for the different systems in cooling mode.

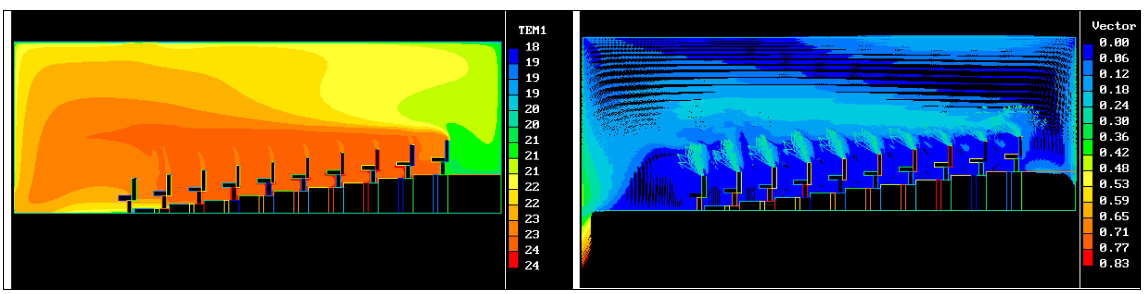
Case A: seat diffusers, under-seat extract openings, supply angle 10°



Case B: seat diffusers, under-seat extract openings, supply angle 20°



Case C: seat diffusers, wall extract openings, supply angle 20°



Case D: ceiling diffusers, under-seat extract openings, supply angle 25°

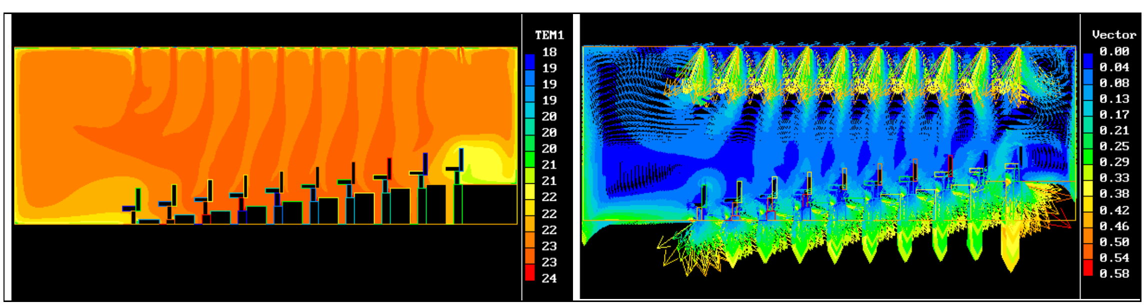


Figure 3. Temperature (left line) and velocity fields (right line) for the different systems in heating mode.

After air flow patterns have been obtained, the four ventilation strategies have been compared from the energy point of view. Being t_L and t_I the air temperature at the outlets and inlets the system heating/cooling loads will be:

$$q_c = G_a c_p (t_L - t_I) \qquad (4)$$

where G_a is the overall air flows for mechanical ventilation. This quantity has been calculated for the various cases and the results are shown in Fig. 4 (cooling mode) and Fig. 5 (heating mode).

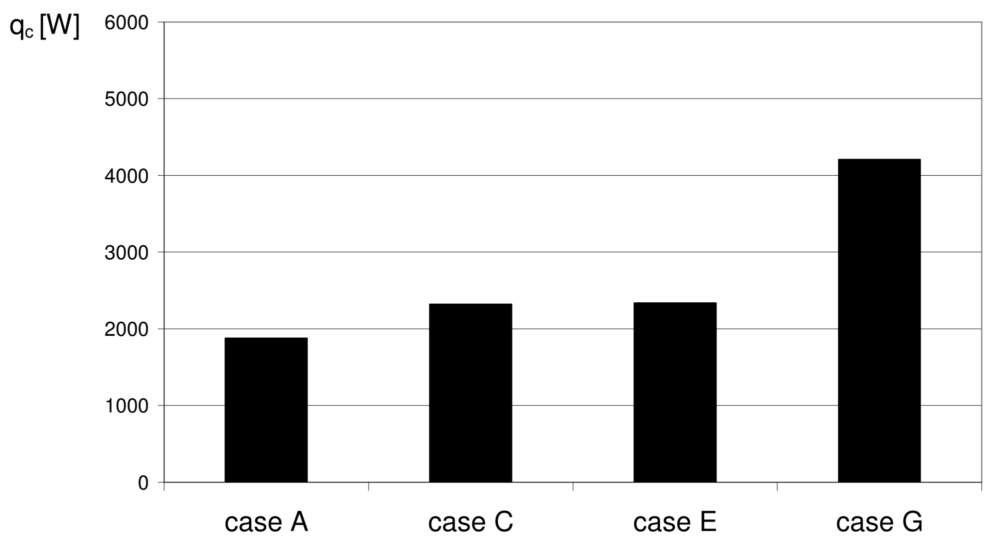


Figure 4. Cooling for the ventilation strategies in summer conditions.

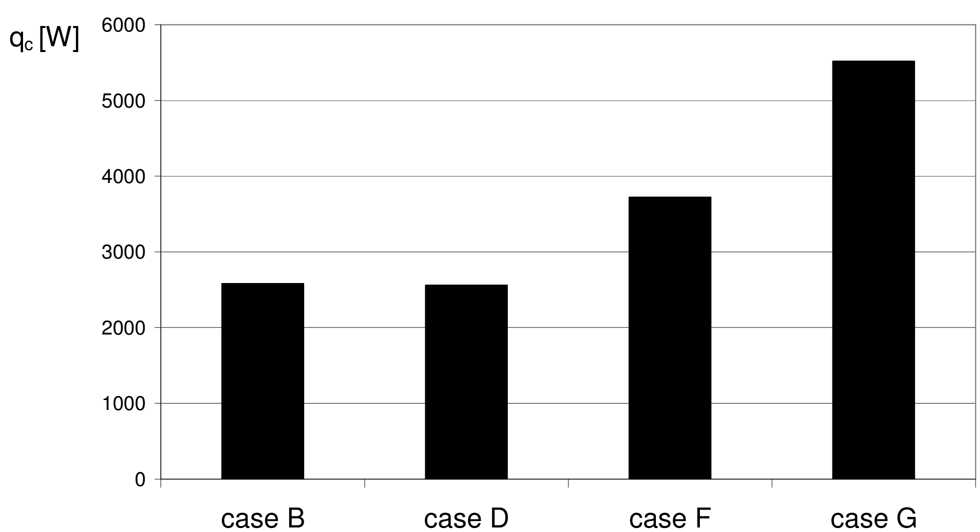


Figure 5. Heating loads for the ventilation strategies in winter conditions.

In cooling mode local ventilation strategies (cases A, B and to some extent also C) can save a considerable amount of energy in comparison to the ceiling air inlet (case D). In

particular, about 55% of energy can be saved with the air inlet on the chair back and the outlet under the chair (case A). Moreover, also the influence or inlet spread can be pointed out by comparing cases A and B: since the variation of inlet angle does not affect the air mixing volume in the room, there is little difference in the cooling demand.
In heating conditions the differences between the systems are still emphasized. Cases A and B are slightly different and have the lowest heating demand; case F, instead, shows a remarkable increase in heating demand, but it is still lower than the “well mixed” ventilation.

5. CONCLUSIONS

Computational fluid dynamics was used to investigate the performances of several local ventilation strategies in a movie theatre. Global comfort and local discomfort indices were computed and an energy consumption assessment was carried out.

The comparison of results pointed out that all systems can achieve a good comfort level: on the other hand interesting energy saving could be reached using air inlets on the chair back and outlets under the chair both in heating and cooling conditions. This result can be explained by the limited air volume involved in the mixing induced by ventilation flows: therefore, task ventilation systems effectively produce a layer in correspondence of the occupied zone where the air conditions are controlled.

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