Presented at the COMSOL Conference 2008 Hannover

A Numerical Investigation on Active Chilled Beams for Indoor Air Conditioning

Cammarata G., Petrone G.

Department of Industrial and Mechanical Engineering
University of Catania (Italy)

Outlines

- Introduction to Active Chilled Beams in the framework of the HVAC systems
- Modelling of Active Chilled Beams by COMSOL Multiphysics
- Results & Discussion
- Conclusions

Outlines

- Introduction to Active Chilled Beams in the framework of the HVAC systems
- Modelling of Active Chilled Beams by COMSOL Multiphysics
- Results & Discussion
- Conclusions

Introduction to Active Chilled Beams

- In the modern society, people spend more than 90% of their time in an artificial environment, for instance inside buildings

- Air quality and thermal comfort for occupants inside conditioned environment are arguments of high interest

- HVAC (Heating, Ventilating, and Air Conditioning) systems are designed in order to supply comfort conditions for occupants

- Chilled Beams is one of the HVAC systems

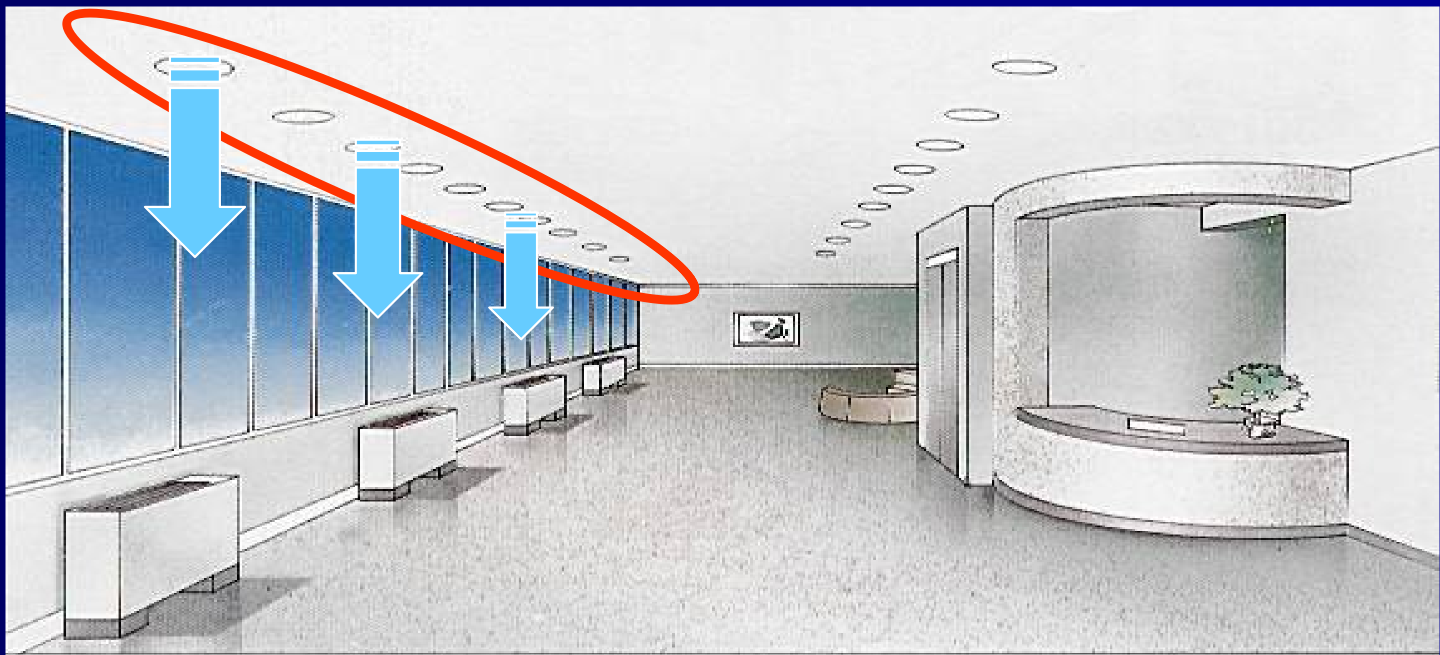
Introduction to Active Chilled Beams

In order to assure comfort conditions a HVAC system has to remove both sensible (dry) and latent (wet) heat. Many traditional HVAC systems are based on the following scheme:

Introduction to Active Chilled Beams

In order to assure comfort conditions a HVAC system has to remove both sensible (dry) and latent (wet) heat. Many traditional HVAC systems are based on the following scheme:

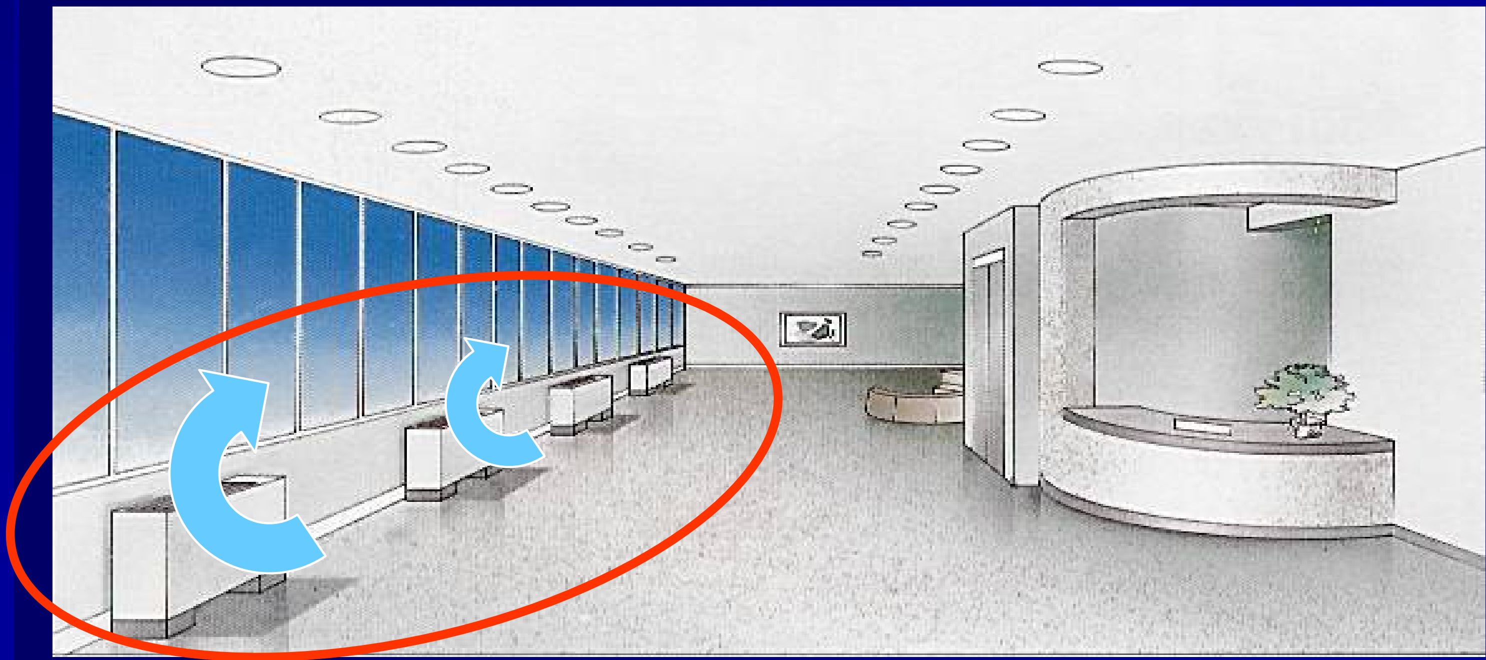
- External primary air is treated in a remote unit. It assures ventilation and takes care of the latent rate of heat



Introduction to Active Chilled Beams

In order to assure comfort conditions a HVAC system has to remove both sensible (dry) and latent (wet) heat. Many traditional HVAC systems are based on the following scheme:

- Secondary air is locally processed for removing the sensible rate of heat

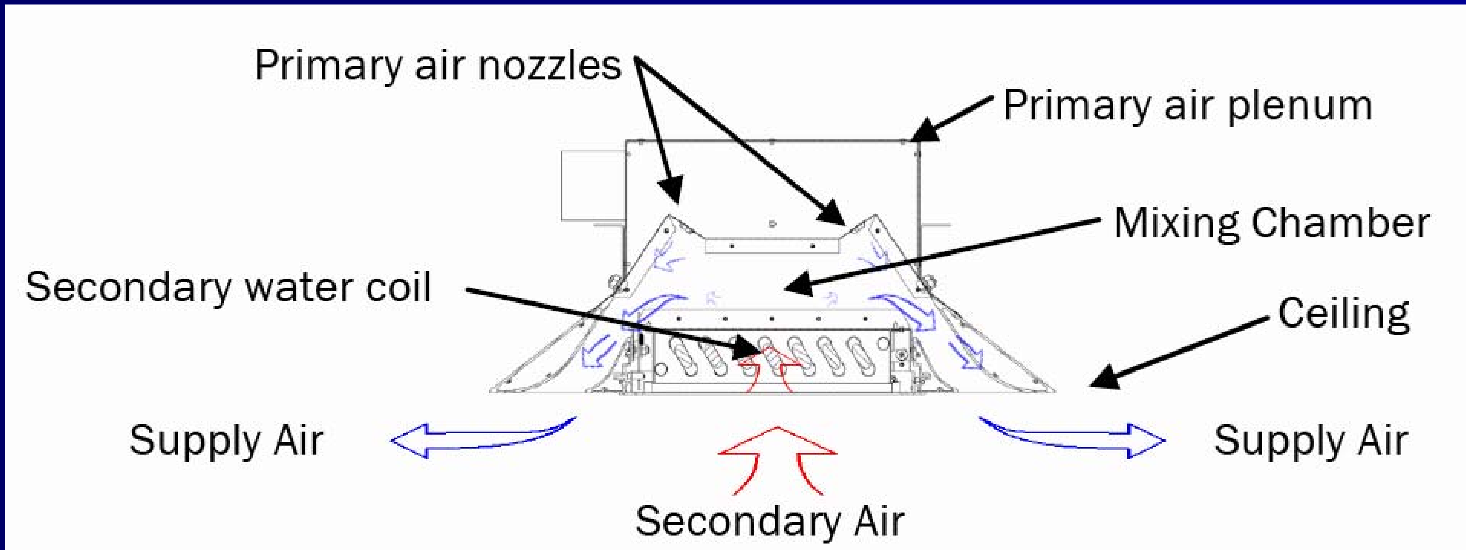


Introduction to Active Chilled Beams

Active Chilled beams combine ventilating fresh air supplying with local cooling or heating

Introduction to Active Chilled Beams

The functional principle consists in aspiration of air room inside the ceiling conditioning component by an high velocity jet supplying external fresh air.



Inducted air room is forced to flow through a water-air heat exchanger where it is cooled or heated. Then it is mixed with the fresh air introduced in the room from diffusing slots.

Introduction to Active Chilled Beams

The main advantages are related to the absence of moving part (fun) in the local terminal for secondary air treatment. It allows:

- Reduced overall electrical infrastructure in the building
- No regular maintenance as there are no moving parts
- Very low noise levels

But also related to the absence of the local unit:

- Space saving
- Improved architectural design of the room

Introduction to Active Chilled Beams

The purposes of this study are to numerically simulate those devices in order to investigate on:

- Technical performances (both in winter and in summer)

- The related comfort conditions (both from fluid-dynamical and thermal point of view)

Outlines

- Introduction to Active Chilled Beams in the framework of the HVAC systems
- Modelling of Active Chilled Beams by COMSOL Multiphysics
- Results & Discussion
- Conclusions

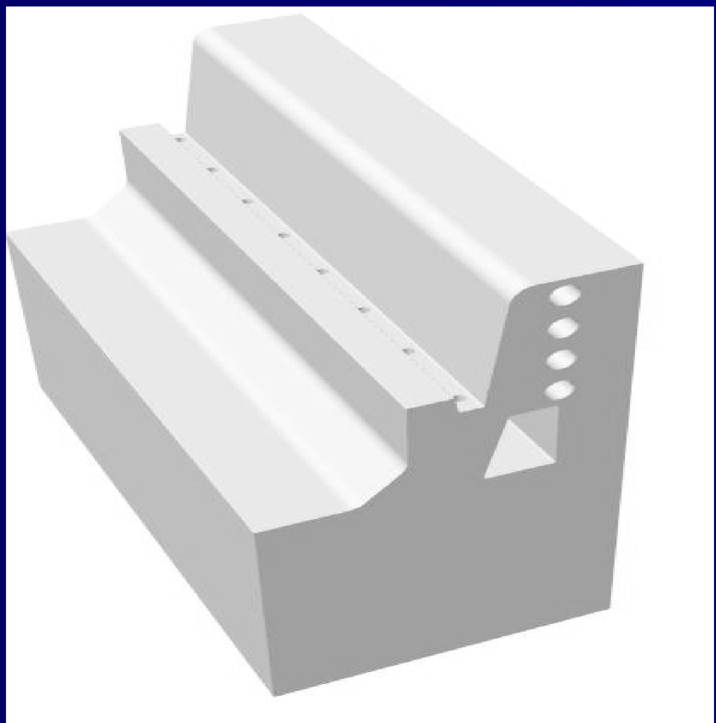
Modelling by COMSOL Multiphysics

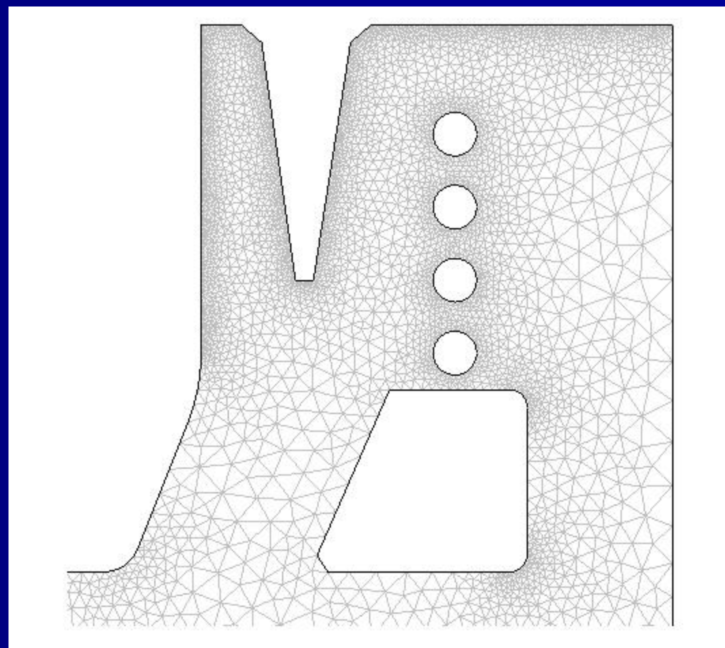
Three typologies of active chilled beams have been studied:

Modelling by COMSOL Multiphysics

Three typologies of active chilled beams have been studied:

- Vertical disposition both for nozzles of incoming fresh air and heat exchanger tubes

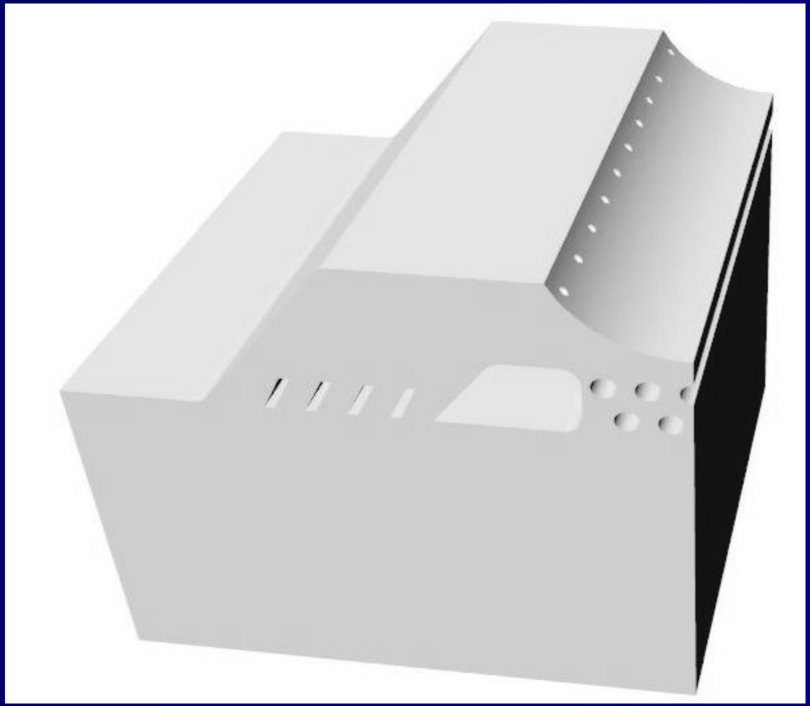


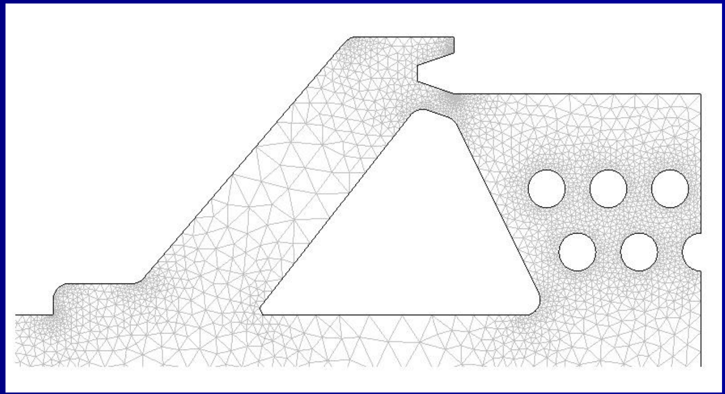


Modelling by COMSOL Multiphysics

Three typologies of active chilled beams have been studied:

➢ Horizontal disposition both for nozzles of incoming fresh air and heat exchanger tubes

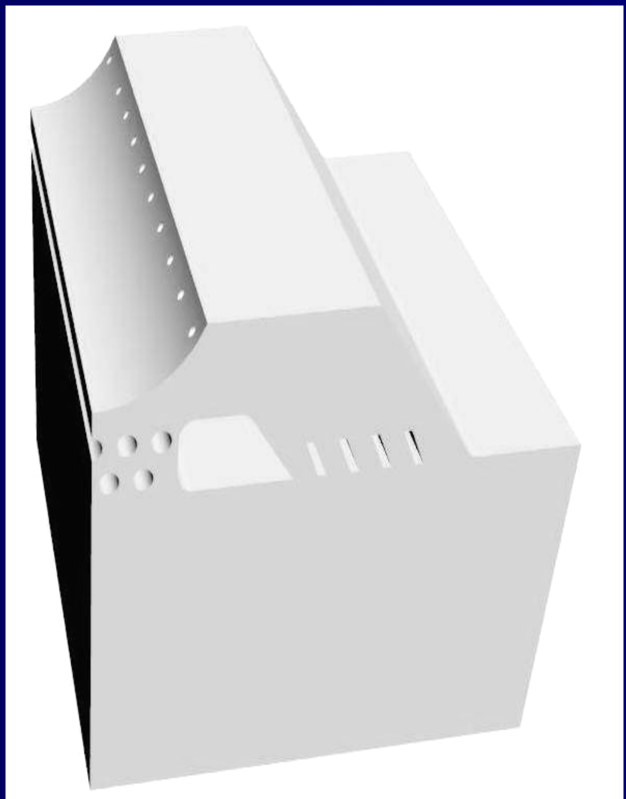


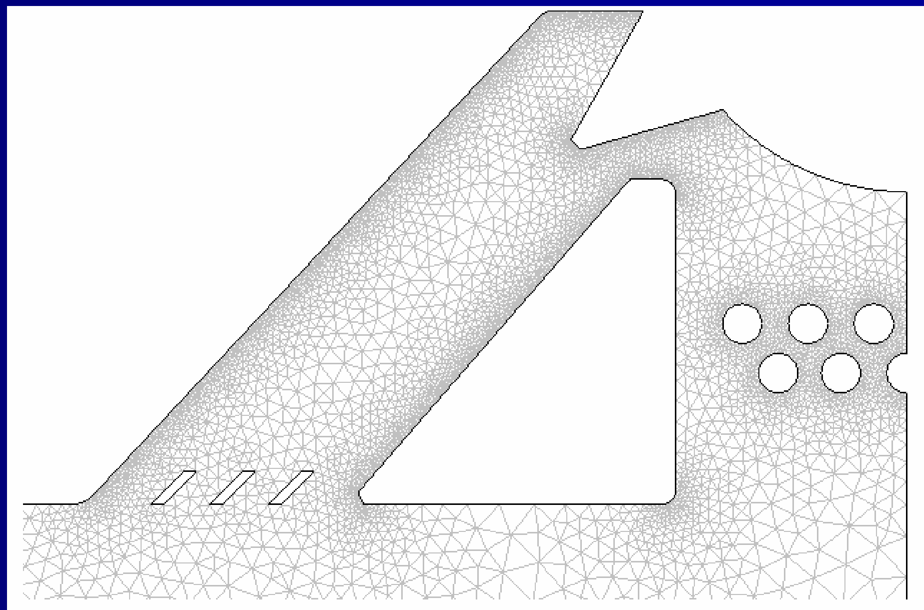


Modelling by COMSOL Multiphysics

Three typologies of active chilled beams have been studied:

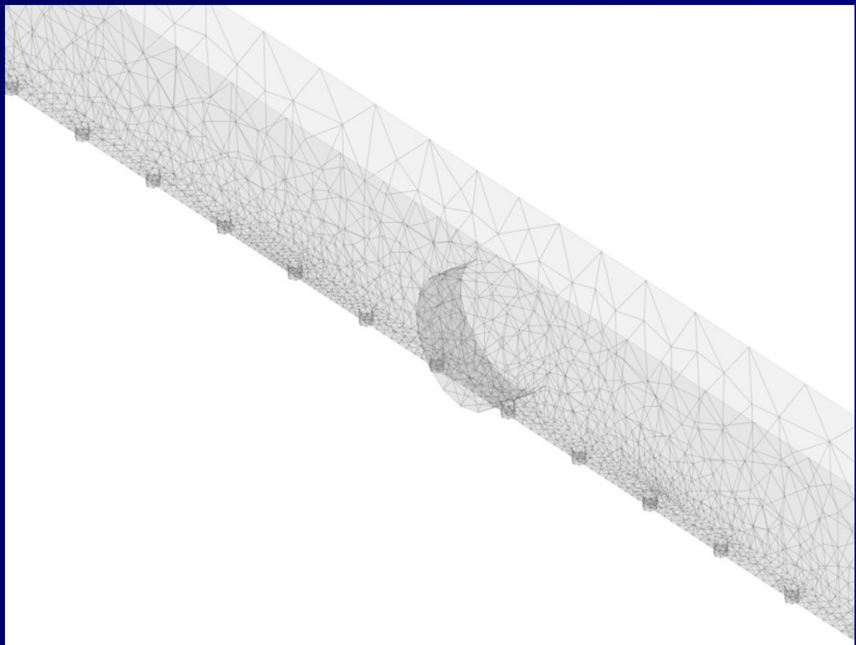
- Inclined (45°) disposition for nozzles of incoming fresh air and horizontal disposition for heat exchanger tubes

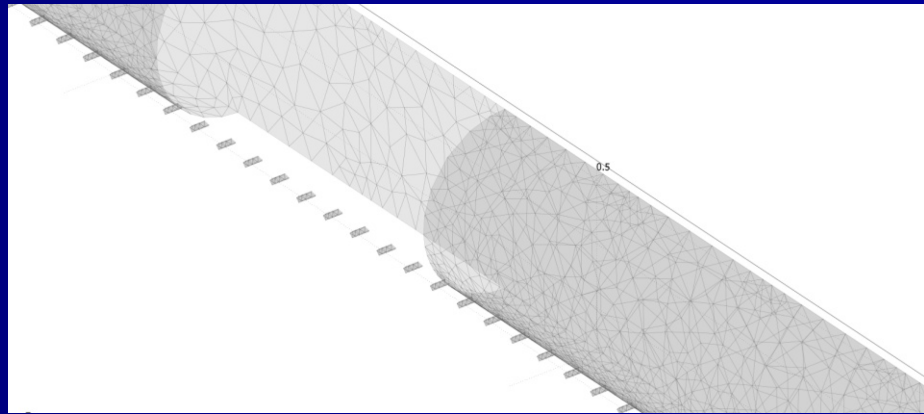




Modelling by COMSOL Multiphysics

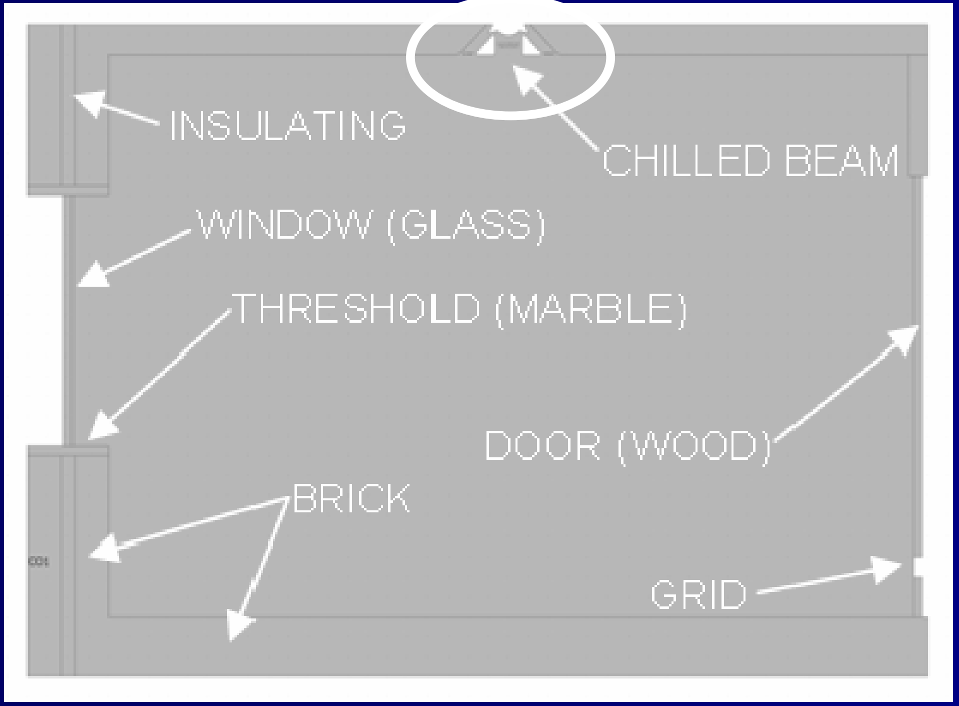
Distribution ducts have been also modelled in order to evaluate non uniform primary air supplying at nozzles terminal:





Modelling by COMSOL Multiphysics

Terminals have been integrated in a standard room geometry:



Air physical properties	
Density, ρ	1.19 [kg/m^3]
Dynamic viscosity, η	1.75 e-5 [Pa s]
Specific heat, C_p	1100 [J/(kg K)]
Thermal conductivity, λ	0.026 [W/(m K)]

Properties of solid materials			
Material	ρ [kg/m^3]	C_p [J/(kg K)]	λ [W/(m K)]
Brick	900	830	0.50
Marble	2700	800	2.80
Wood	420	2700	0.12
Insulating	30	1250	0.04
Glass	2500	840	1.00

Modelling by COMSOL Multiphysics

Turbulence (k-ε) Navier-Stokes and Energy equations have been solved with boundary conditions achieving both transient and steady solutions:

$$\rho\frac{\partial u}{\partial t}+\rho u\cdot\nabla u=\nabla\cdot\left[-pI+\left(\eta+\eta_T\right)\left(\nabla u+\left(\nabla u\right)\right)^T\right]+F$$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho u)=0$$

$$\rho\frac{\partial k}{\partial t}+\rho u\cdot\nabla k=\nabla\left[\left(\eta+\frac{\eta_T}{\sigma_k}\right)\nabla k\right]+\eta_T P\left(u\right)-\rho\varepsilon$$

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho u\cdot\nabla\varepsilon=\nabla\left[\left(\eta+\frac{\eta_T}{\sigma_\varepsilon}\right)\nabla\varepsilon\right]+\frac{C_{\varepsilon 1}\varepsilon\eta_T P\left(u\right)}{k}-\frac{C_{\varepsilon 2}\rho\varepsilon^2}{k}$$

$$\rho C_p\frac{\partial T}{\partial t}+\nabla\cdot\left(-k\nabla T\right)=Q-\rho C_p u\cdot\nabla T$$

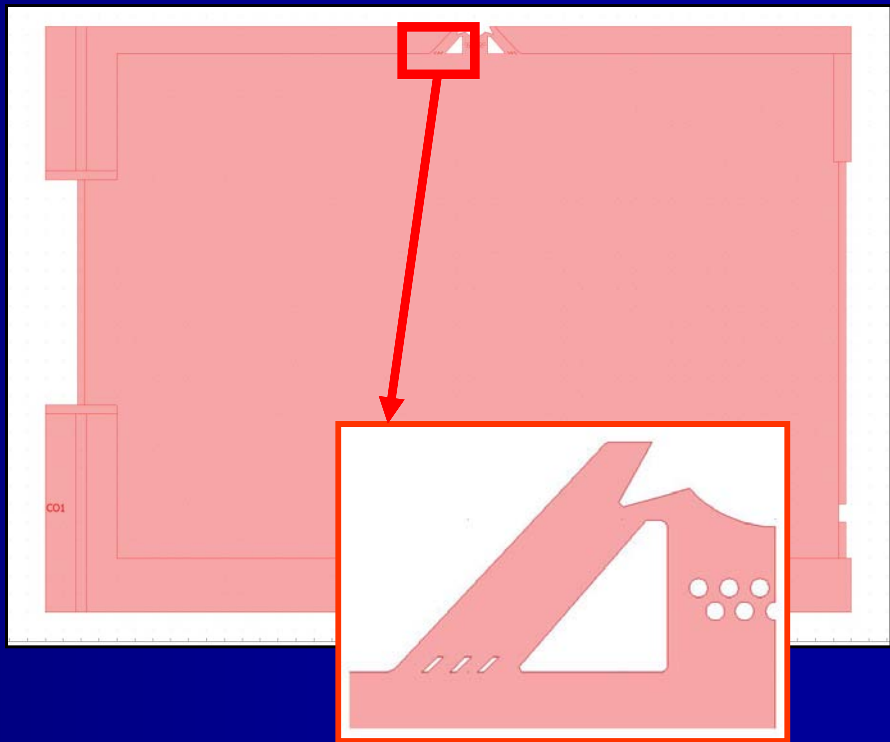
Outlines

- Introduction to Active Chilled Beams in the framework of the HVAC systems
- Modelling of Active Chilled Beams by COMSOL Multiphysics
- Results & Discussion
- Conclusions

Results

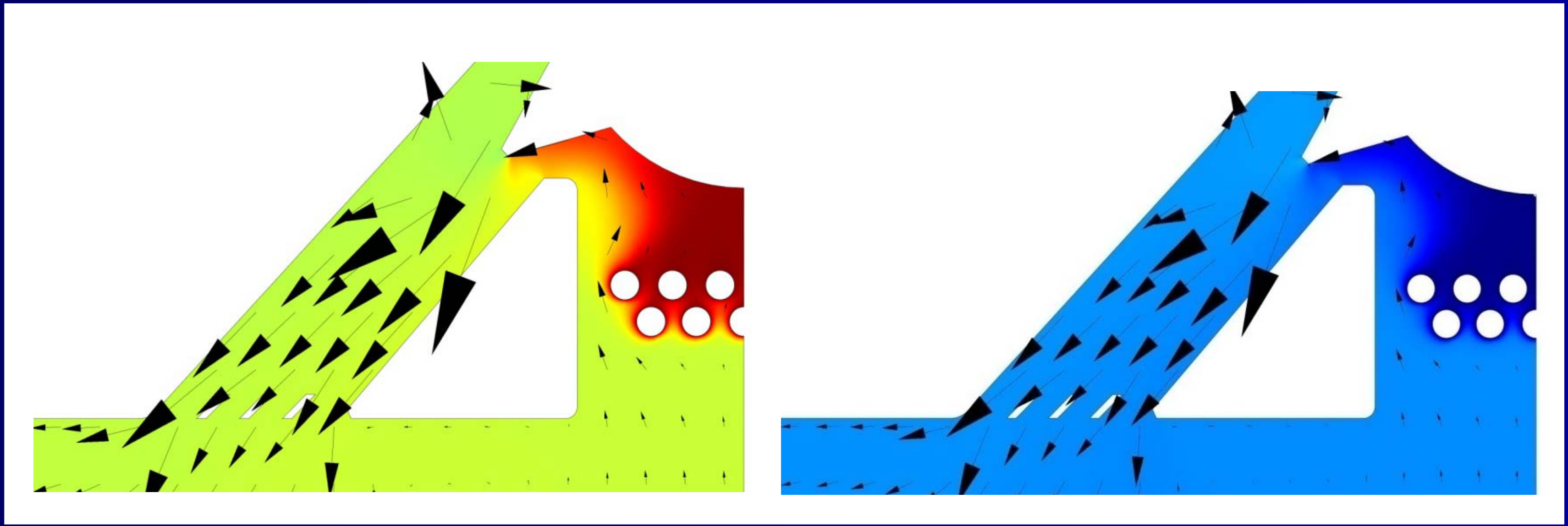
Results refer to parametric analysis of the studied systems (all geometrical configurations) both in winter and summer climatic conditions.

Parameter	winter	summer
T_{ext} [°C]	-5	35
h_{ext} [W/(m² K)]	25	25
T_{int} [°C]	8	28
h_{int} [W/(m² K)]	8	8
T_{batt} [°C]	40-45	16-21
u_{in} [m/s]	8-20	8-20
T_{air} [°C]	18-22	16-20



Results

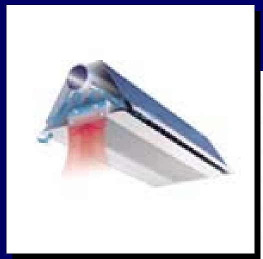
The active chilled beam functional principle has been verified:

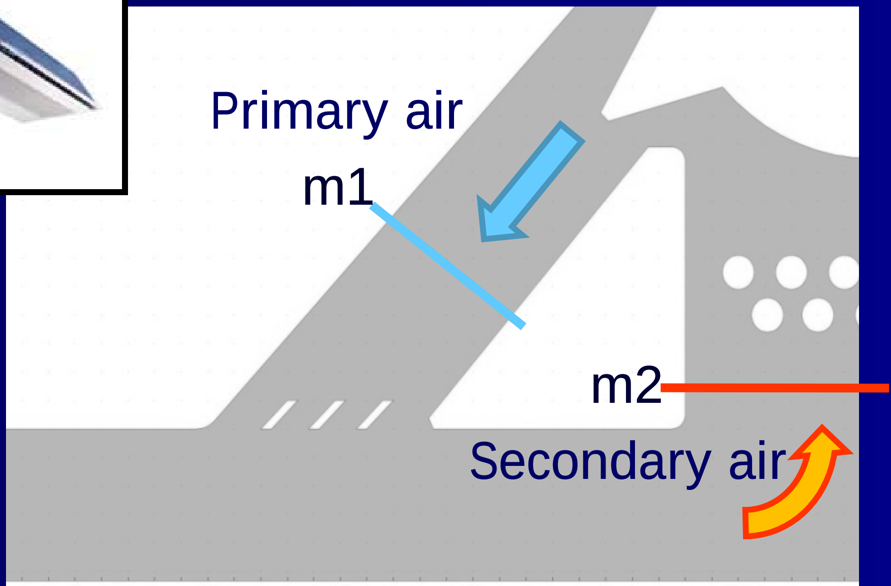


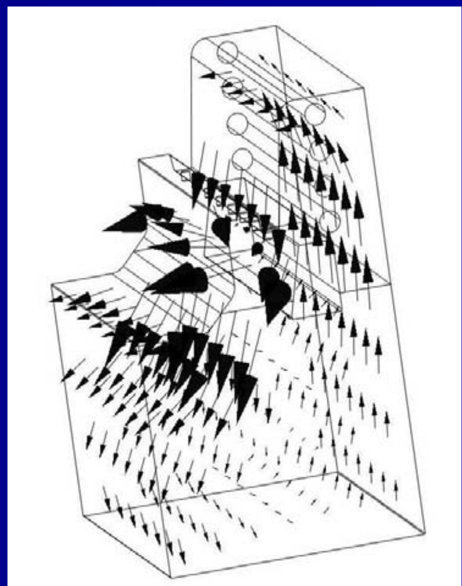
The inlet high velocity jet of fresh air produces a low pressure zone surrounding the nozzle, inducing indoor fluid to flow through the heat exchange battery.

Results

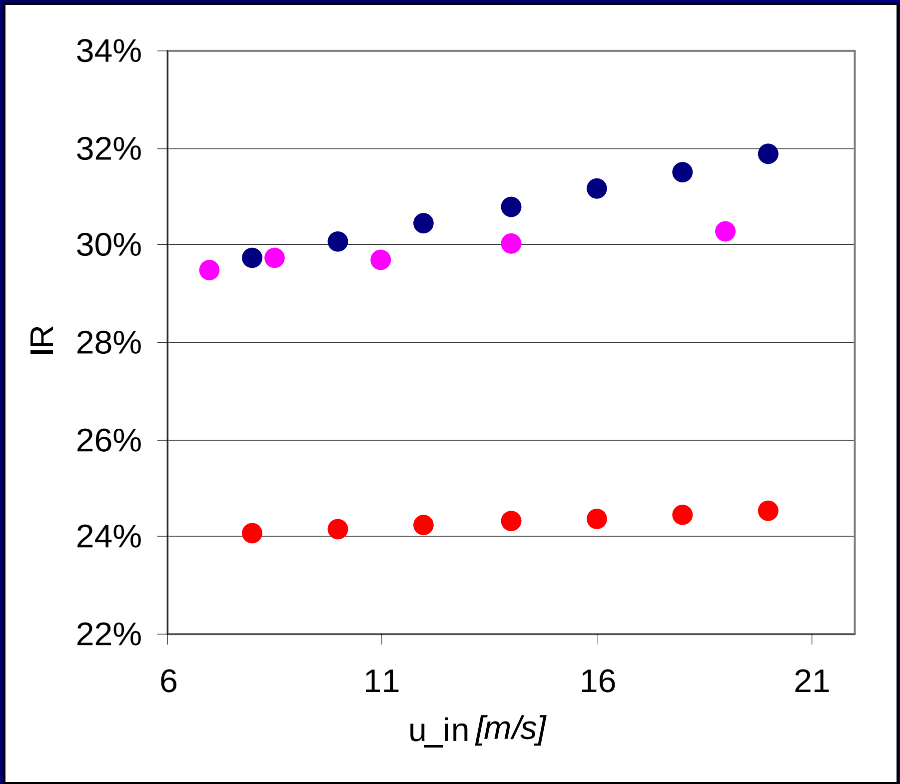
Induction Ratio (IR = m2/m1) between primary and secondary mass flow rate is evaluated in order to quantify the induction effect







Results



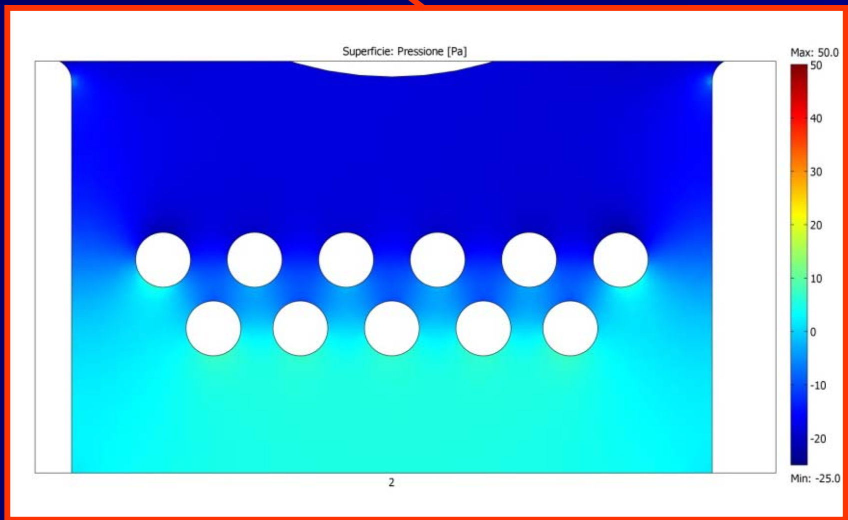
The IR values show a low sensitivity with respect to the inlet velocity of fresh air

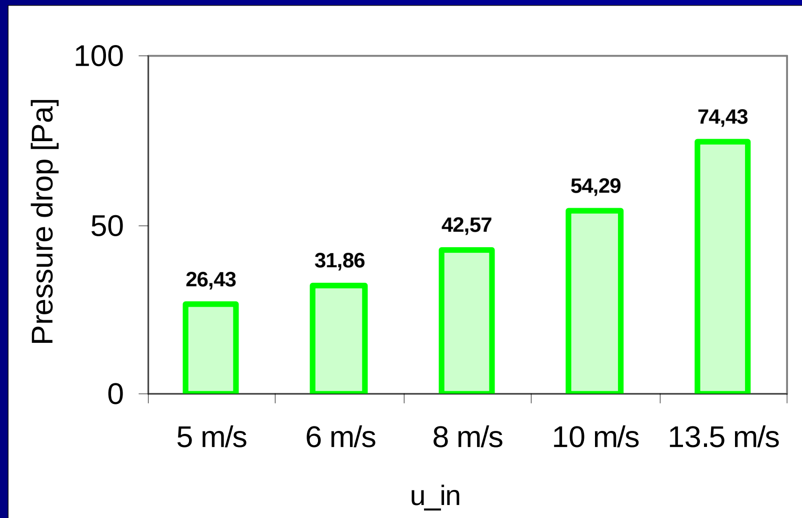
The range of variation (24-32%) well fits with technical data proposed by the leading constructors of those components.

- Vertical nozzles
- Inclined nozzles
- Horizontal nozzles

Results

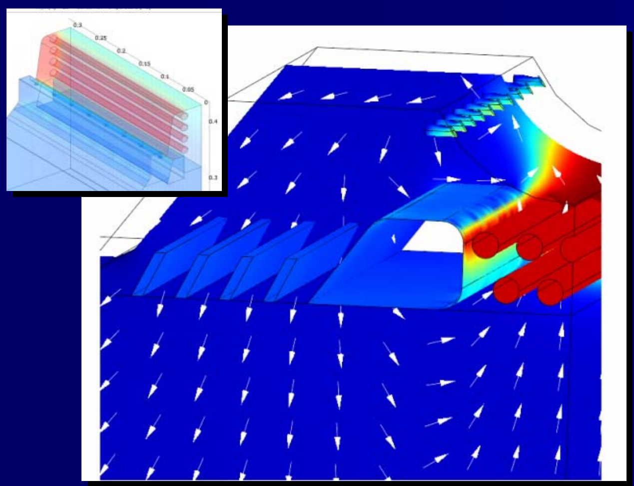
Pressure drops generated by heating/cooling batteries crossing has been also evaluated.





Results

From an applicative point of view, heating/cooling capacity represents the most important parameter. Heating/cooling capacity is computed from simulations by using the following expressions for the primary and secondary flows:



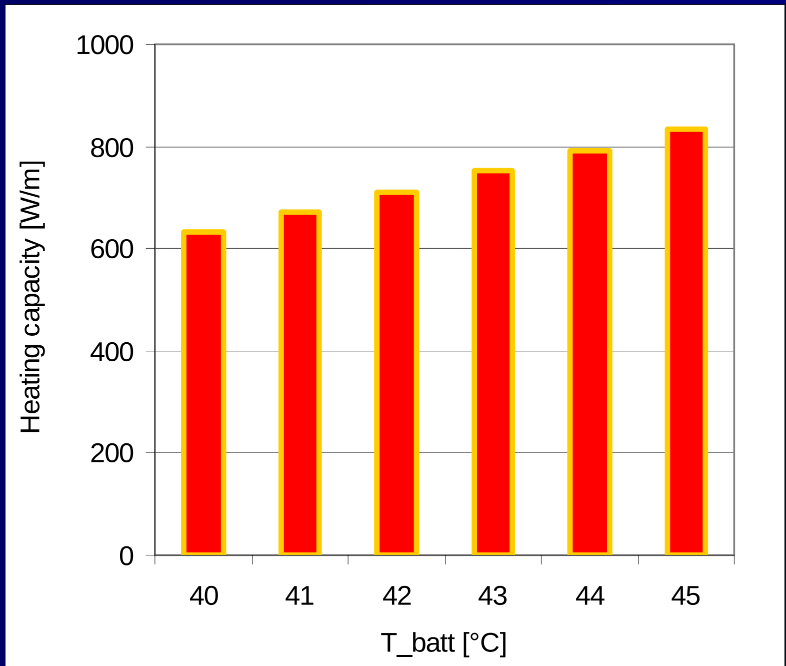
$$q = S_{nozzle}\ u_{in}\ \rho\ C_p\ (T_{air} - T_{amb})$$

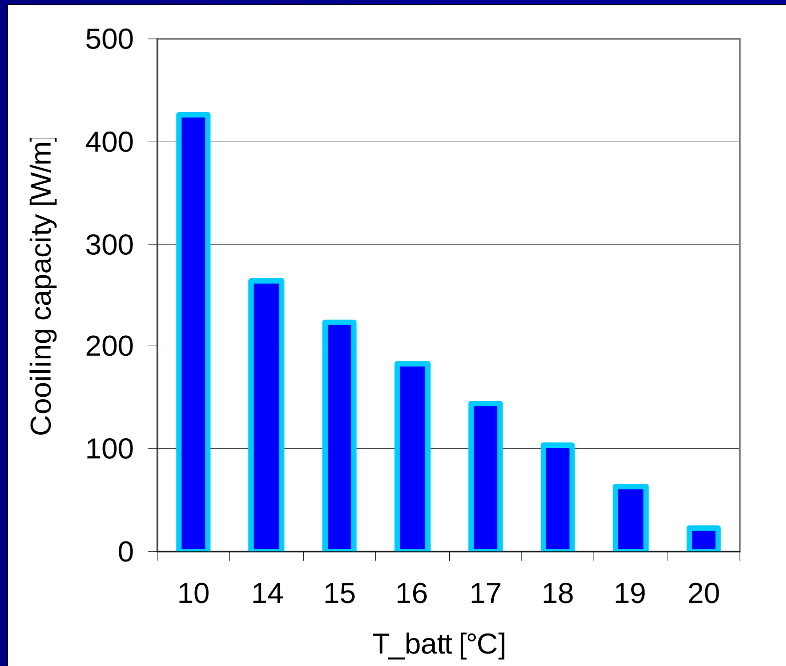
$$Q = S_{cross}\left(\frac{1}{W_{batt}}\int_{W_{batt}} u\ dx\right)\rho\ C_p\ (T_{batt} - T_{amb})$$

S_{nozzle} is the total inlet surface of fresh air for 1 [m] of length (60 nozzle per meter) and S_{cross} is the crossing section for fluid flowing through the battery (W_{batt} represents the battery width and ambient temperature T_{amb} is chosen 20 [°C])

Results

Values refer to the 45° inclined nozzles chilled beam that offers the lower thermal performance



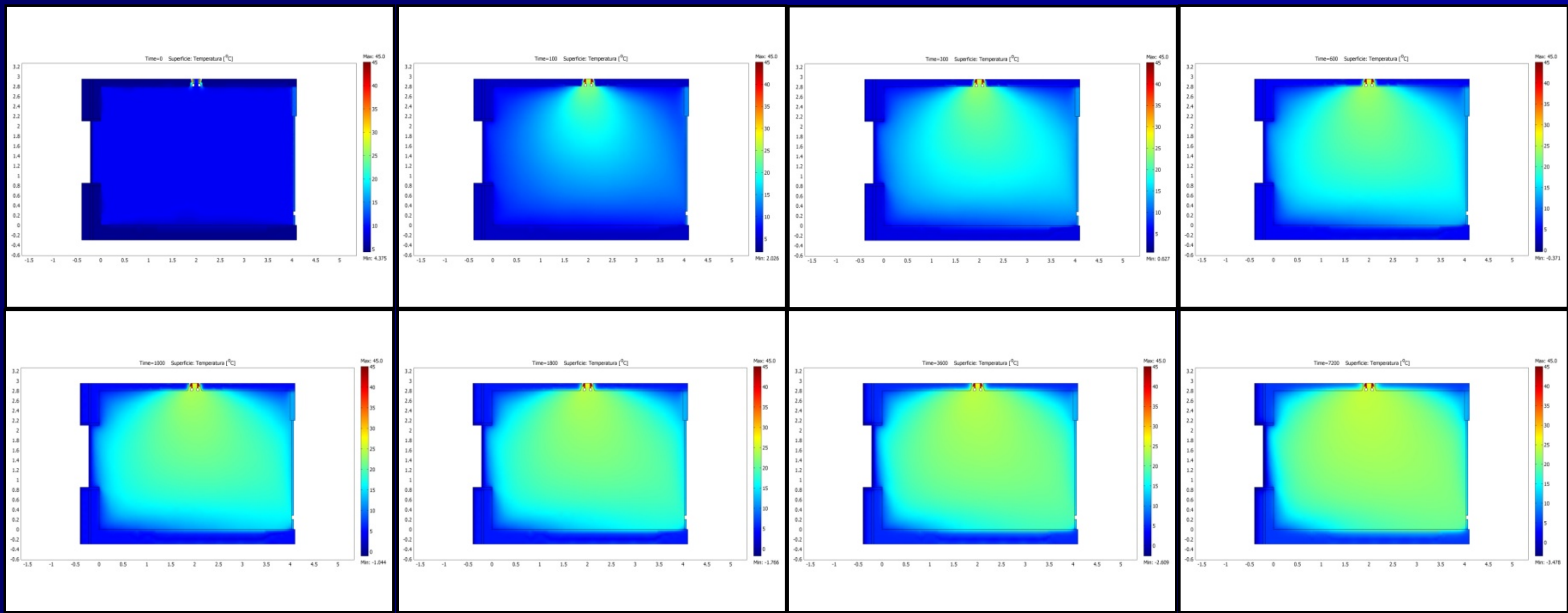


Results

Transient investigation allows to estimate thermal inertia of the system, due to the combination of walls (room structure) properties and air conditioning system.

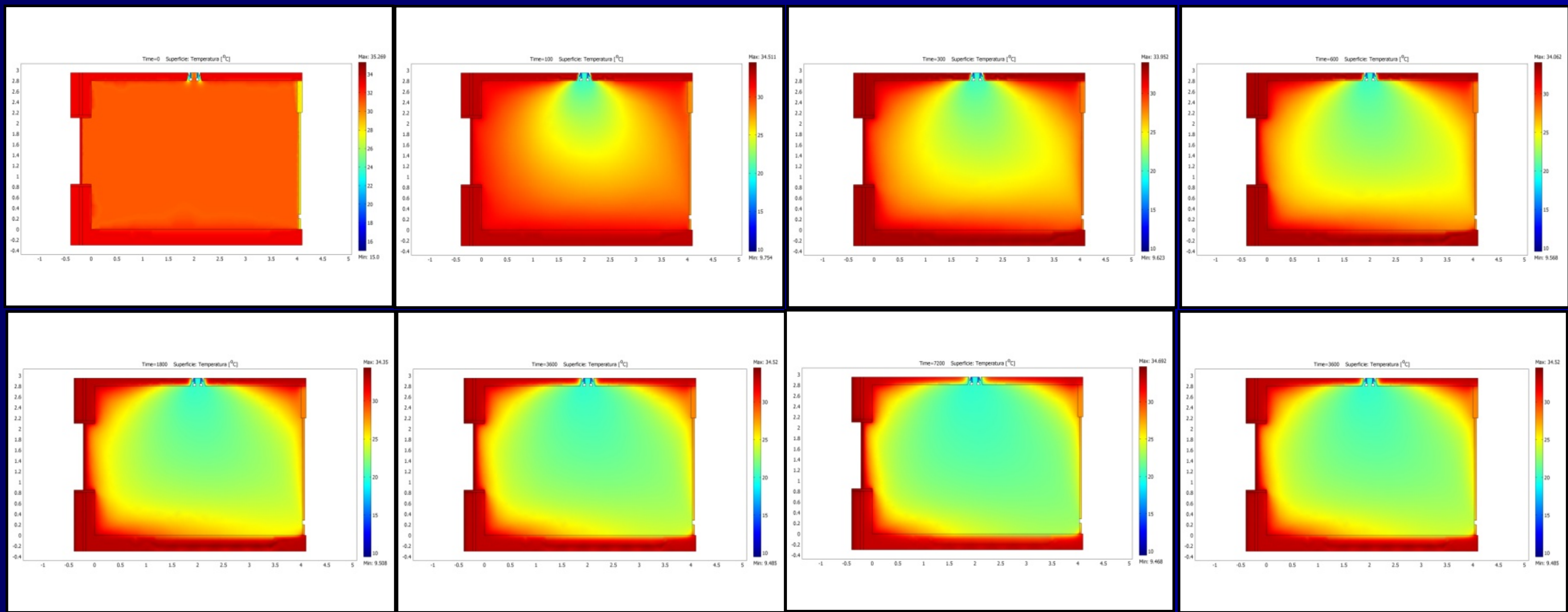
Results

Chilled beams systems are seen to achieve stationary conditions for air temperature in the occupied region of the room in about 30 minutes since initial time (hardest climatic conditions both in winter …



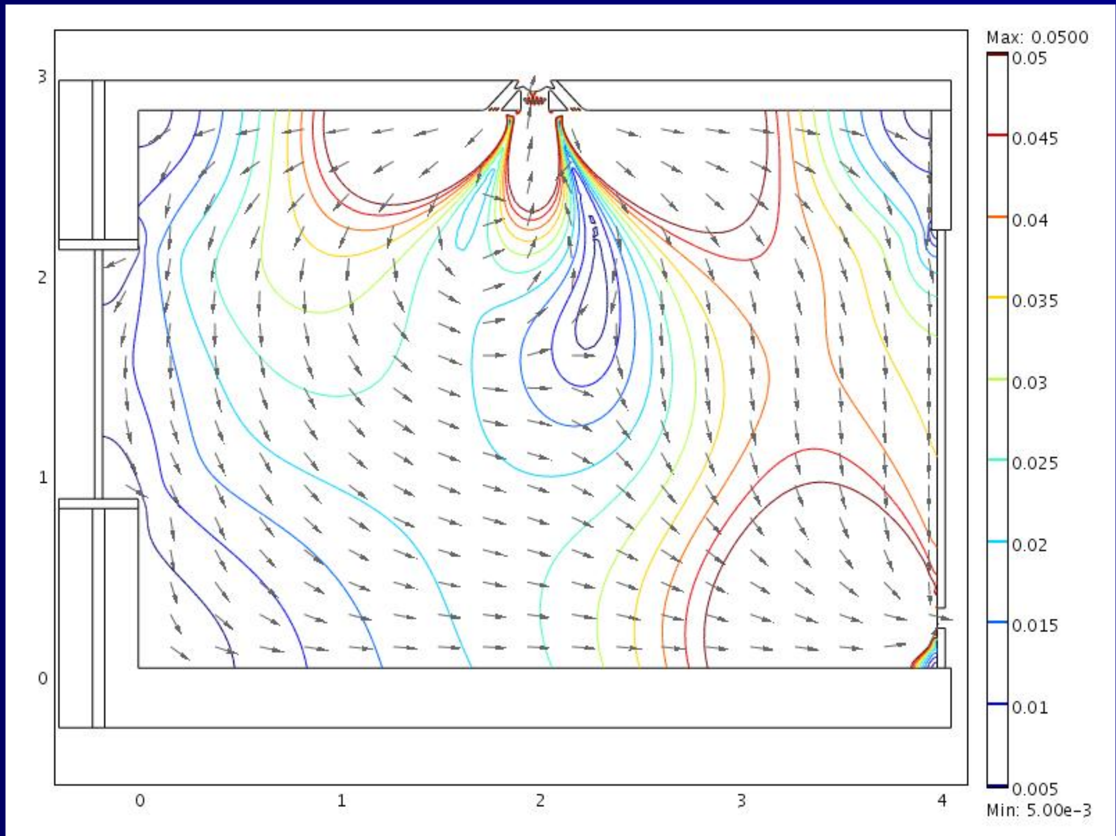
Results

Chilled beams systems are seen to achieve stationary conditions for air temperature in the occupied region of the room in about 30 minutes since initial time (hardest climatic conditions both in winter and in summer)



Results

Comfort conditions: fluid-dynamical aspects

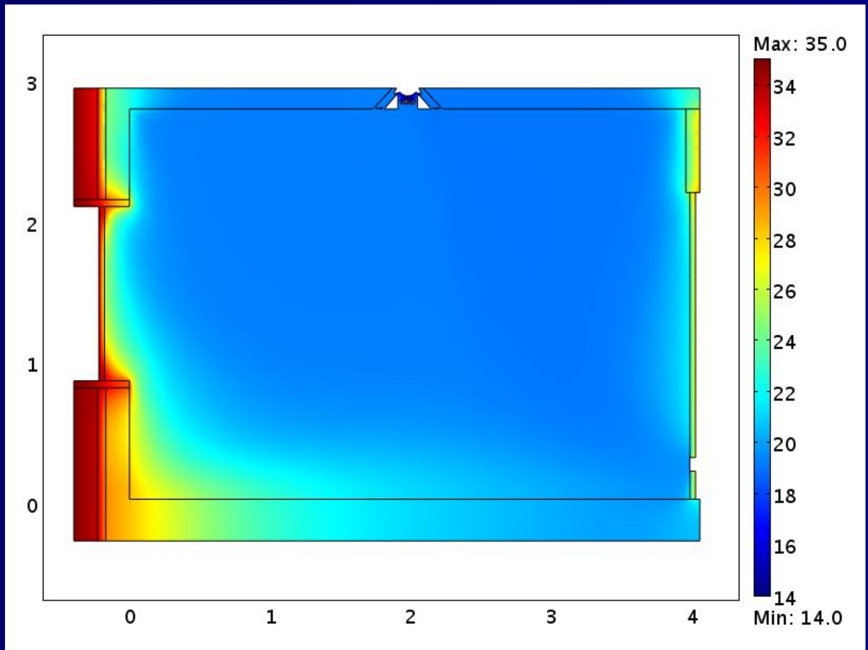


- ✓ velocity fields show an almost constant distribution in the occupied portion of room
- ✓ dynamical field is characterized by velocity values less then 0.1 [m/s]
- ✓ Varying inlet velocity, vectors quantitatively changes closed to the inlet components only

Results

Comfort conditions: thermal aspects

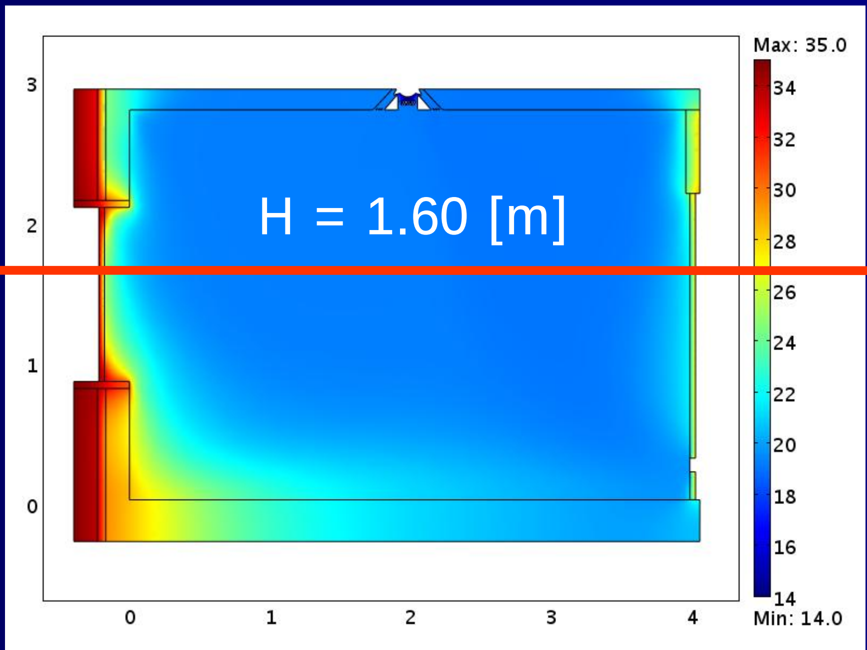
Vertical and horizontal temperature gradient, in the portion of the room where people stand, appear slight.

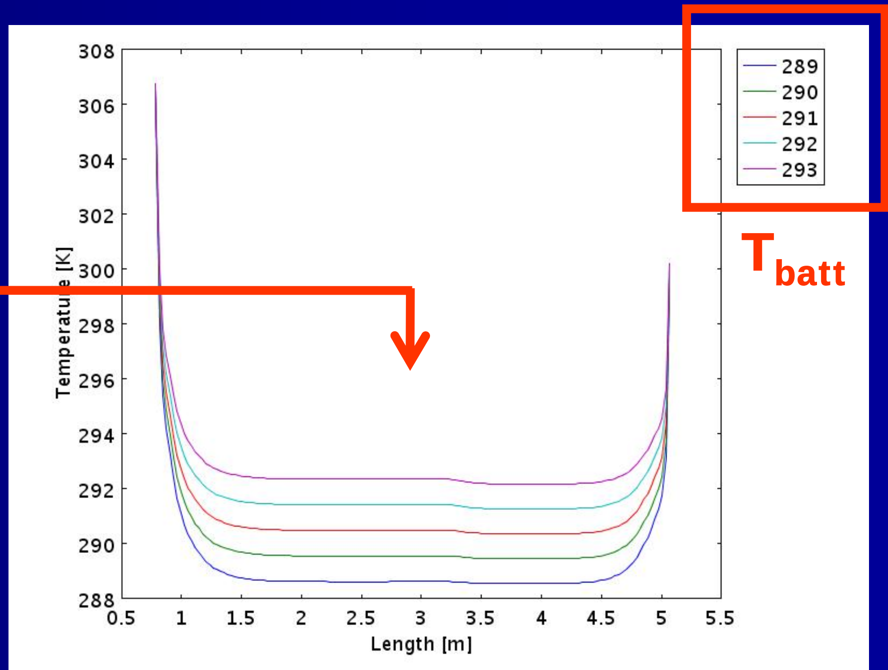


Results

Comfort conditions: thermal aspects

Vertical and horizontal temperature gradient, in the portion of the room where people stand, appear slight.





Outlines

- Introduction to Active Chilled Beams in the framework of the HVAC systems
- Modelling of Active Chilled Beams by COMSOL Multiphysics
- Results & Discussion
- Conclusions

Conclusions

A numerical study on active chilled beams has been conduced in COMSOL Multiphysics environment:

Models have been built for three typologies of the considered technological system. Computations were carried-out for steady and transient analysis, simulating both summer and winter functioning and varying some typical operating conditions

Two main parameters have been analysed for investigating on dynamical and thermal efficiency: the Induction Rate and the thermal capacity. Indoor comfort conditions were also investigated for a chosen standard room

Results show a good correspondence with indications supplied by technical sheets of leading constructors of this components

THANK YOU !!!

Department of Industrial and Mechanical Engineering
University of Catania

Authors contact

Address: D.I.I.M. – University of Catania
Viale Andrea Doria, 6 – 95125 CATANIA, ITALY

Phone: +39 095 738 2452
Fax: +39 095 738 2496

E-mail: gcamma@diim.unict.it
gpetrone@diim.unict.it

Web: http://www.ing.unict.it