CFD Study Investigating Optimal Methods for Supplying Preheated Fresh Air to Kitchens with Gas Stoves

The purpose of the study was to identify optimal solutions to mitigate, in winter conditions, the flow of cold air ventilation air entering through ventilation holes of research center's kitchen.

At a Glance

- Study carried out for the internationally renowned SISSA (International School for Advanced Studies) research center.
- Solution for ventilation problem common for all commercial kitchens with gas stoves.
- Use of DesignBuilder CFD simulation and validation with smoke-test results

Project details

Project description: The work was carried out in the SISSA research center's kitchens and focused on the ventilation holes for gas cooker, placed over the windows.

Performance criteria: Preheat outside inlet air, which enters the room at high flow rates due to fume extractor fan that strongly depressurizes room, without obstructing the holes or heating coils.

Location: Via Bonomea 265 – Trieste, Italy

Project status: Realized in 2013 and validated

Introduction

Fire prevention rules impose high ventilation rates for kitchens fitted with stoves fueled by natural gas. This requirement can involve significant discomfort for occupants because while the cooker extractor fan operates, large volumes of cold air enter the kitchen during the winter. It can cause extreme environmental conditions and staff illness.

The obstruction of air inlet holes with any heating batteries is not permitted so SISSA managers have requested a solution to pre-heat supply air, in line with fire prevention rules.

Approach and analysis

The working strategy

The 3-D model was structured with a narrow portion of kitchen space to simulate the behaviour of the air stream to make it easier to simulate each different HVAC solution. The study of air flows inside the room, from each simulation outputs, were evaluated and all possible corrections for improvement were applied to reach the objective. In this way, it was possible to identify the solution best able to meet the needs of the client. After the best solution had been identified, further, more detailed, simulations were carried out to test different diffuser options.

The purpose of the analysis was to identify the best configuration of the air supply terminals to give the most comfortable conditions for the indoor environment. DesignBuilder CFD was used for this work.

The façade and model construction

The study was carried on one of the three ventilation supply grills present in the kitchen (see Figure 1). The model had realistic and validated thermo-physical characteristics and air boundary conditions based on data measured during kitchen working periods.

The kitchen geometry and the air speed were measured carefully to help estimate the supply air flow rate entering through the vents.

The model reproduced a significant portion of the volume of the kitchen (see illustration), including the ventilation grill, the niche of the window, the walls, the ceiling and the floor. The plan dimensions was 5 x 5 m. From the wall at the opposite side of the window air was ventilated uniformly over the entire surface, the volume of air taken by the extractor fan was the same to that of each single external hole.

Figure 1 External view of window and ventilation vent

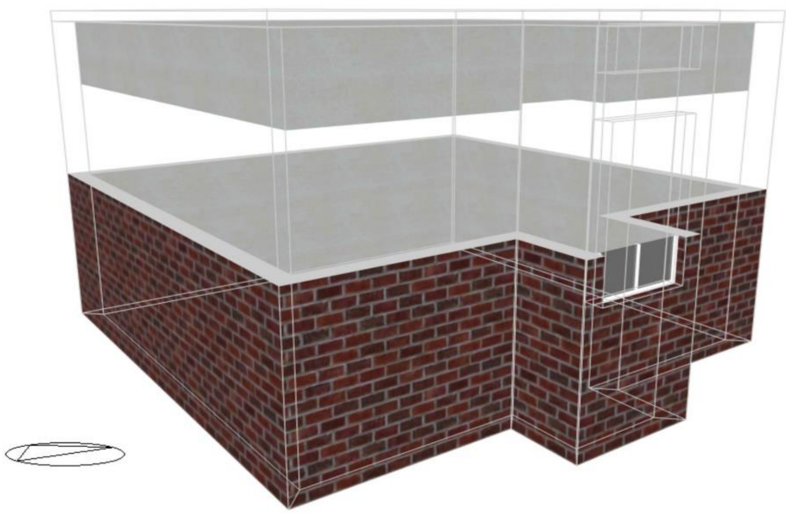
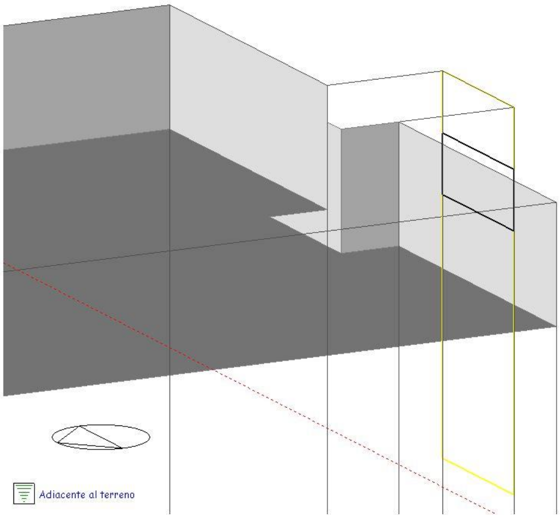


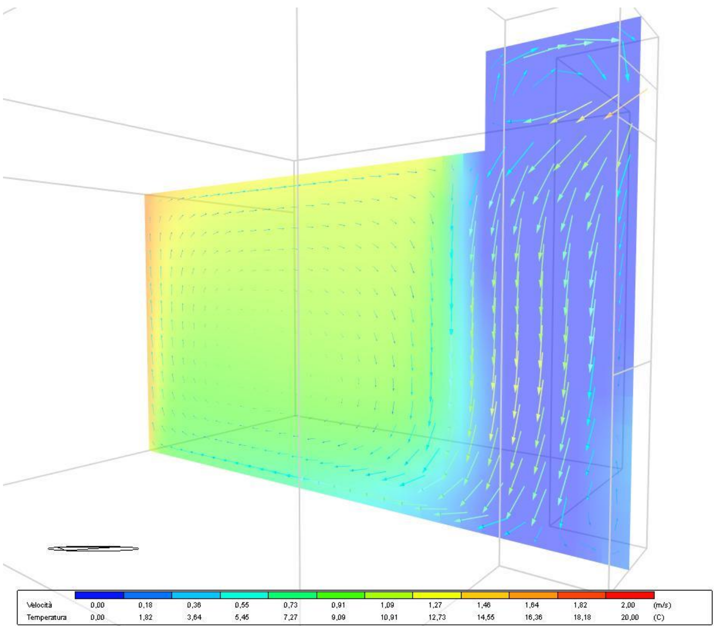
Figure 2 3-D view of the simulation model

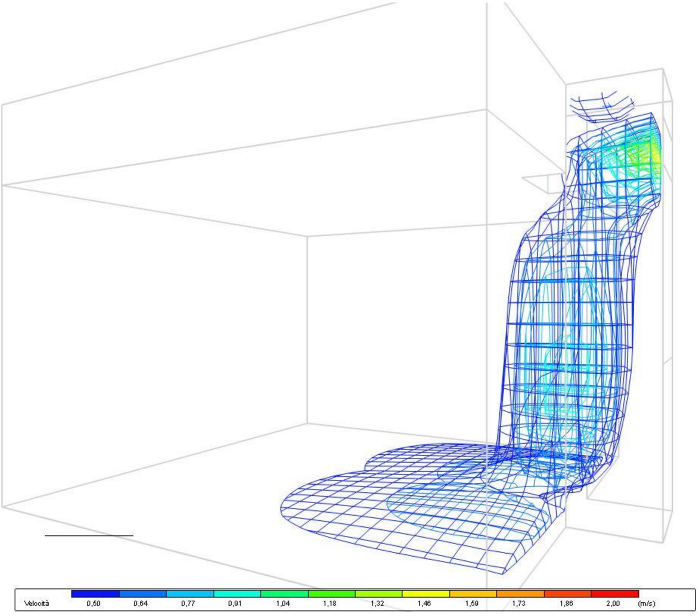
Validation of the Initial Model

The initial model without any HVAC solution is the starting point. It is therefore a model corresponding to the current state with internal air initially at 20°C and inlet air from the outside at -5°C. This configuration reflects the most critical condition during the season, so it is expected this model will give the worst case internal comfort results.

In the images below you can see a) the geometric configuration, b) a vertical section represented with the variables related to air speed and temperature and c) 3-D contours of the zones with air velocity greater than 0.5 m/s.





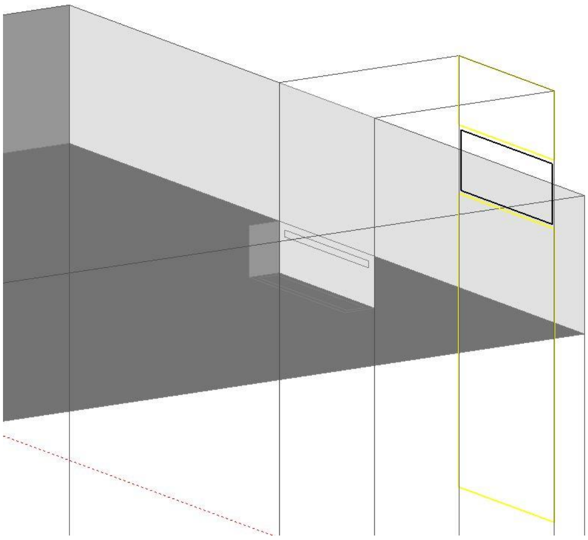


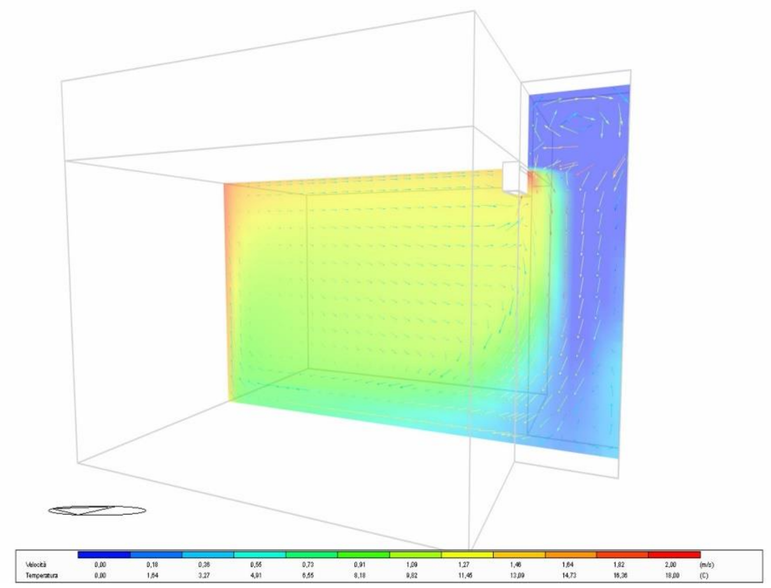
Simulation of Design Assumptions

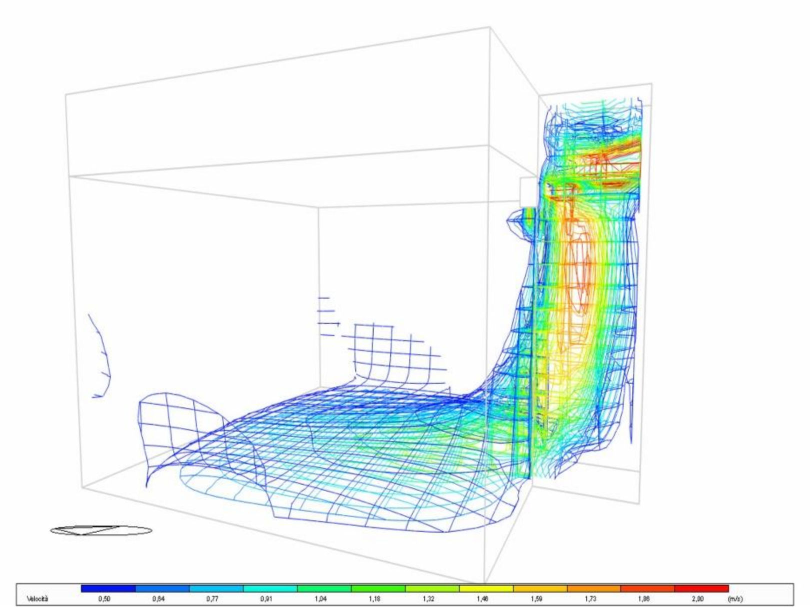
The first configuration simulated investigates the application of an Air Knife placed horizontally at the opposite side of the hole, where the air is driven towards the hole and taken from below.

The following images show the results obtained. The evaluation is qualitative and the results do not meet our needs. The Air Knife is not, in fact, able to mix the cold air inlet and, because of the vacuum present in the environment. It spreads down a cold and faster air column that causes cooling of the zones below the hole.

In the images below you can see a) the geometric configuration, b) a vertical section represented with the variables related to air speed and temperature and c) 3-D contours of the zones with air velocity greater than 0.5 m/s.





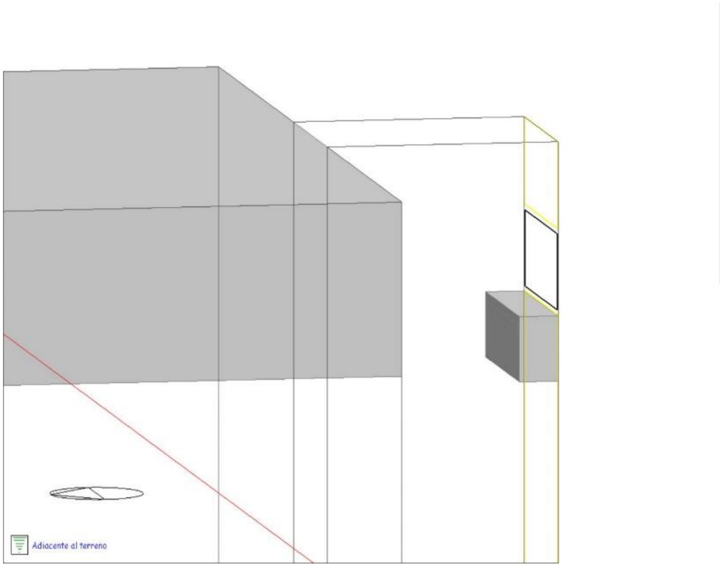


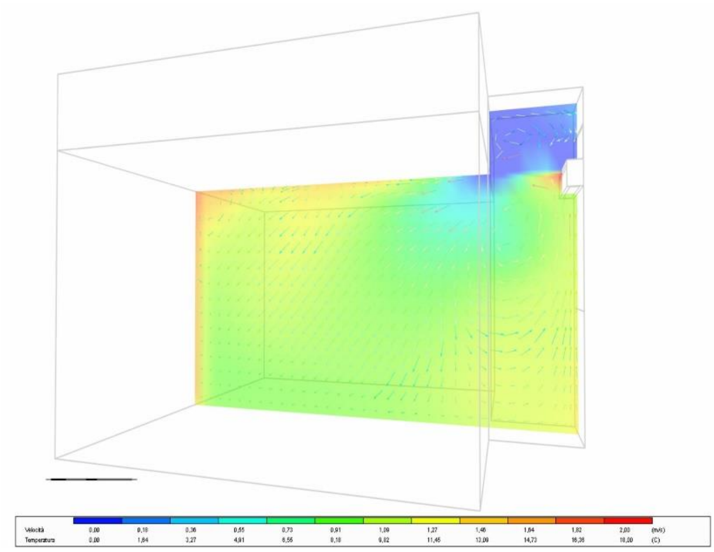
Search for the Best Solution and Validation

Based on the results obtained, without carrying out any on-site work and at no added costs for the customer, we have made changes and enhancements to the solution. After several attempts (see below for some examples), we realized that the Air Knife was not the right choice because the incoming air is cold and dense and is drawn in by the vacuum.

For this reason, we exploited the false ceiling to install a fan-coil with suction air in front of the external hole and the outlet heated air at the bottom, forming a cushion of warm air. The air flow of the fan-coil has been calibrated on the air flow incoming from the external holes so that 100% of cold outside air was heated and input again from below.

Solution “B”


Adiacente al terreno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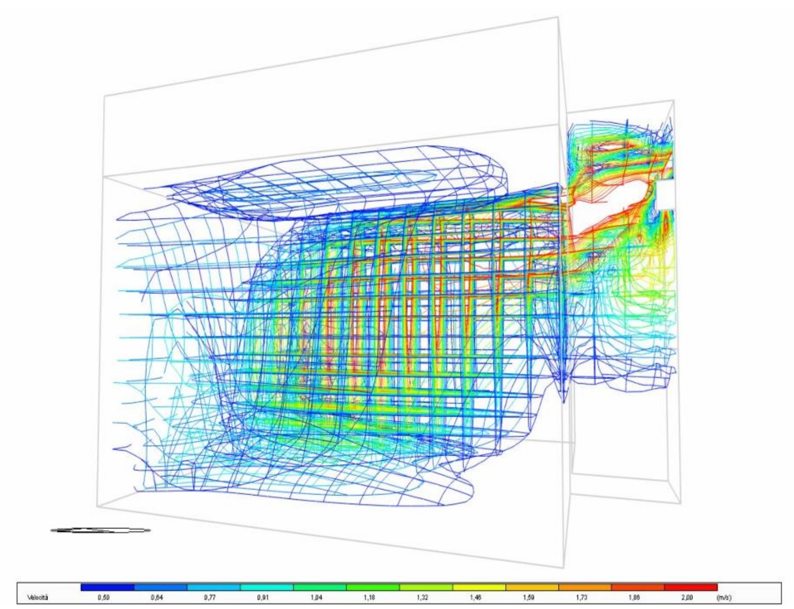
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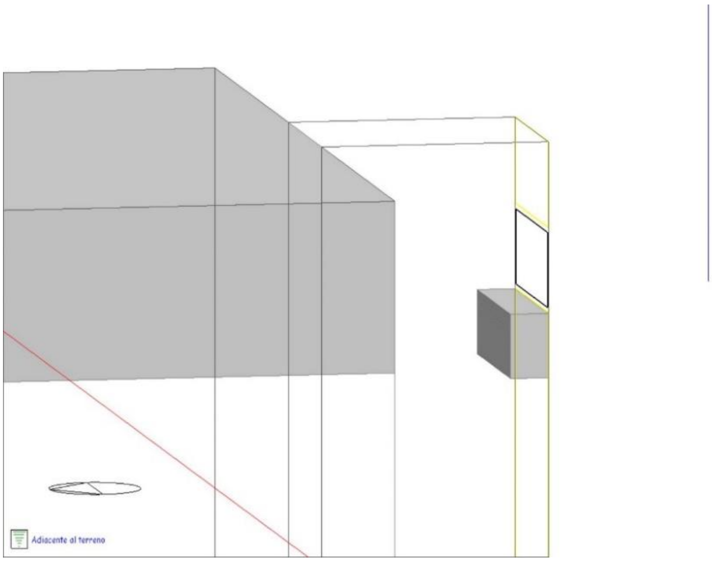
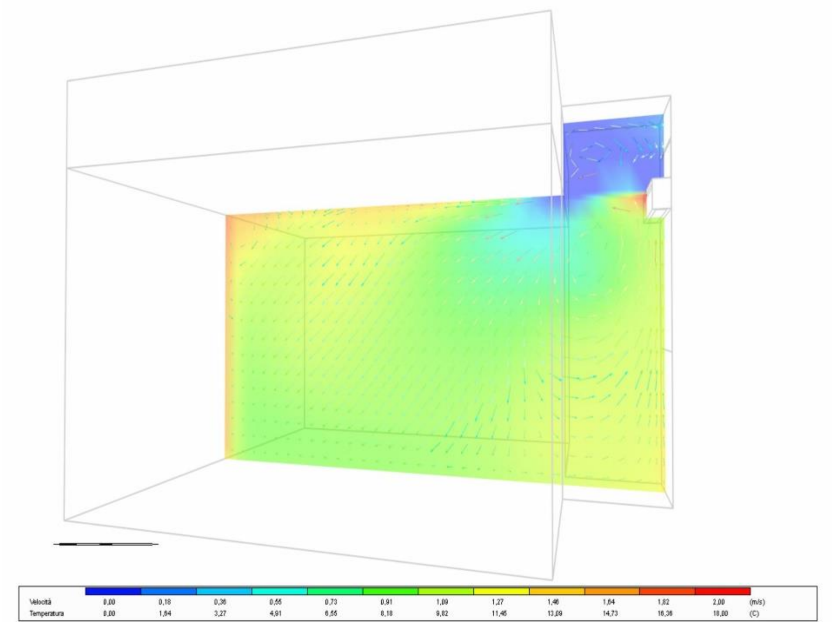
Solution “C”


Adiacente al terreno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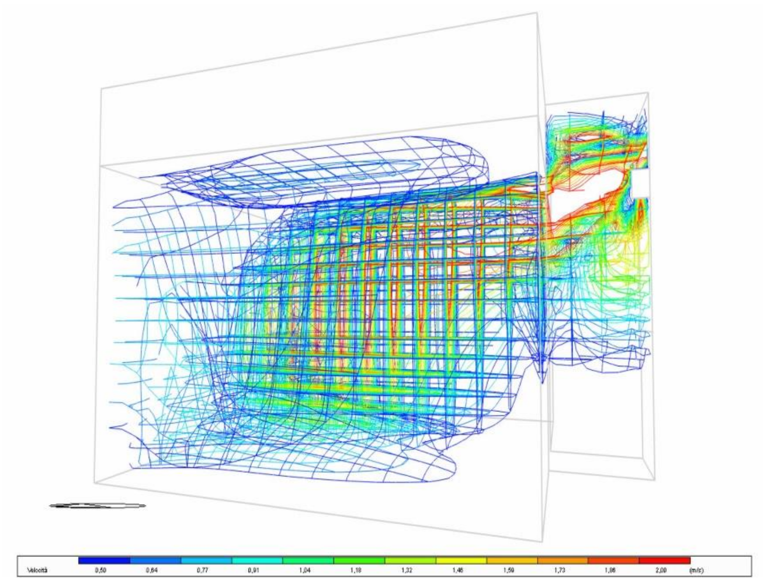
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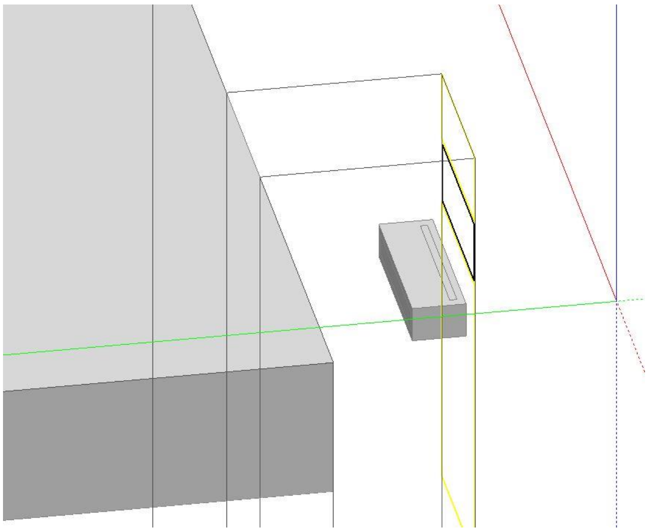
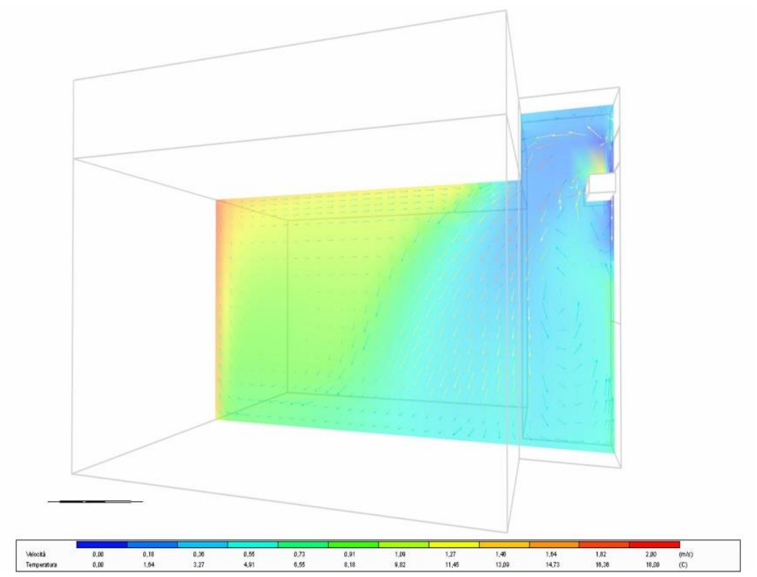
Solution D

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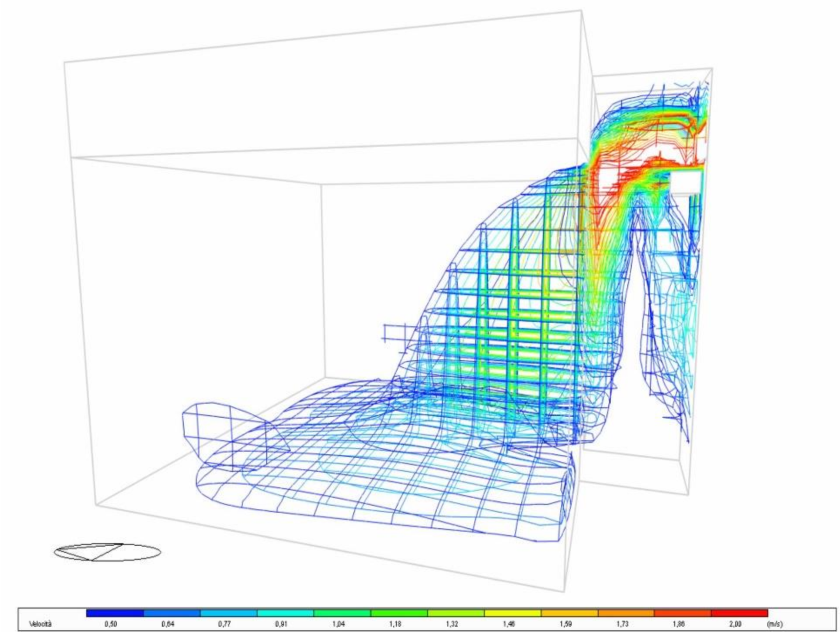
Temperatura 0,00 1,64 3,27 4,91 6,55 8,18 9,82 11,45 13,09 14,73 16,36 18,00 (C)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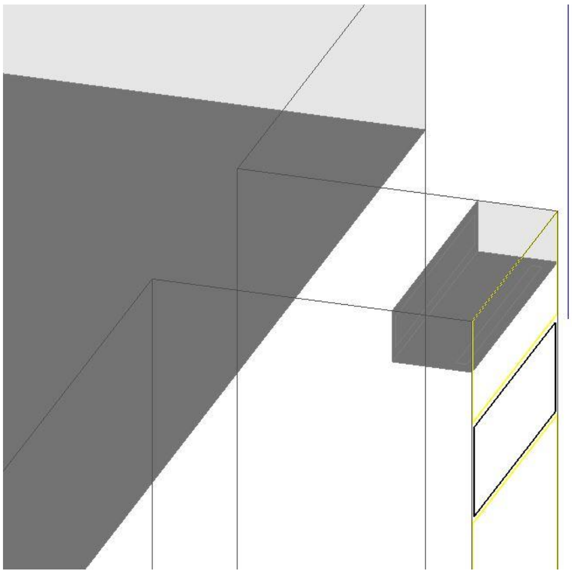
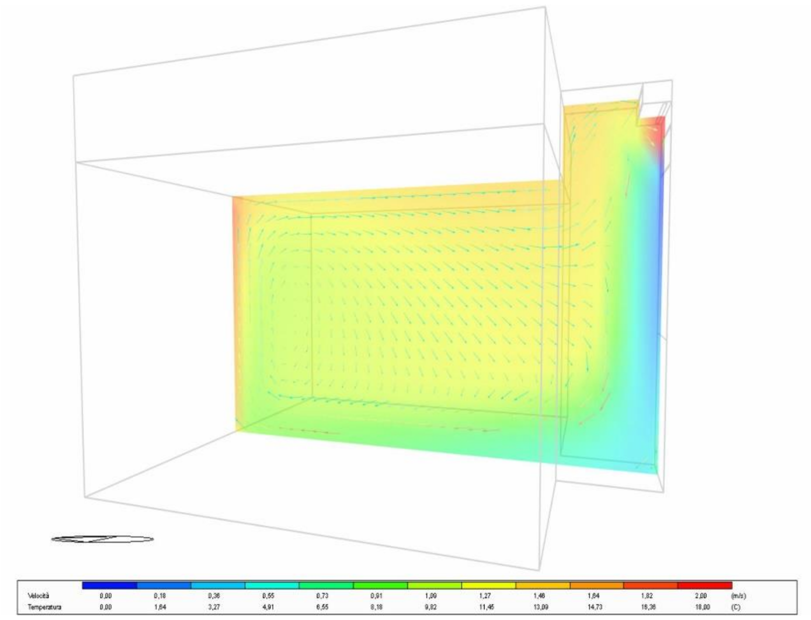
Solution E

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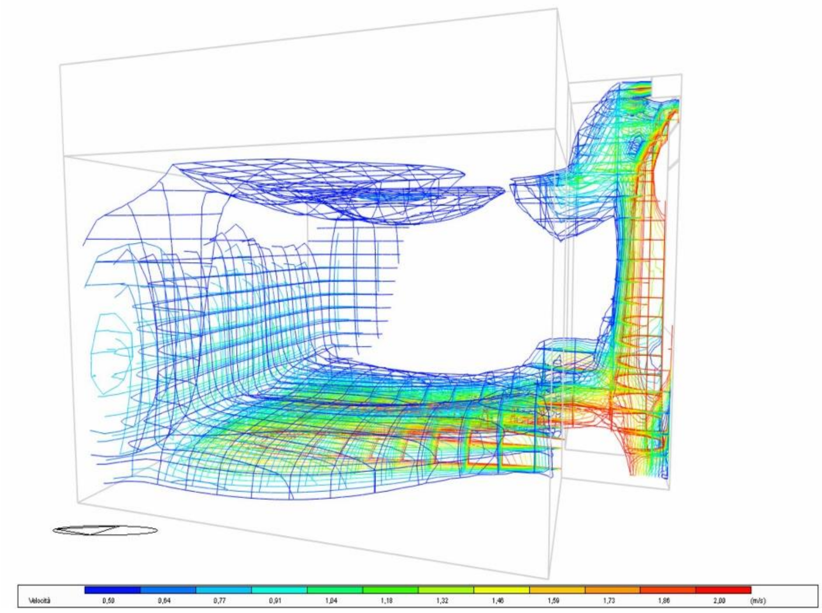
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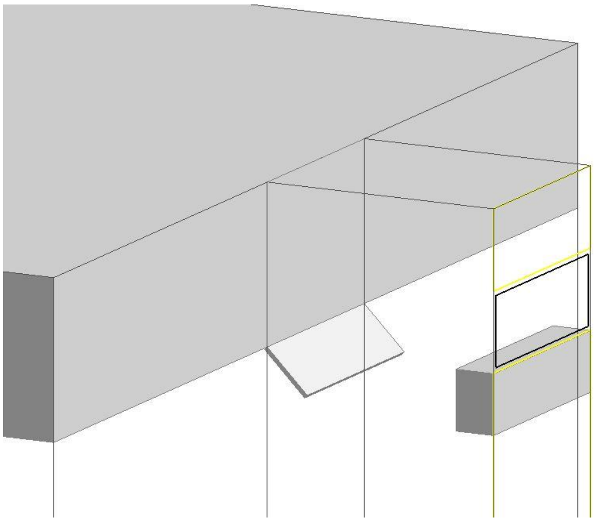
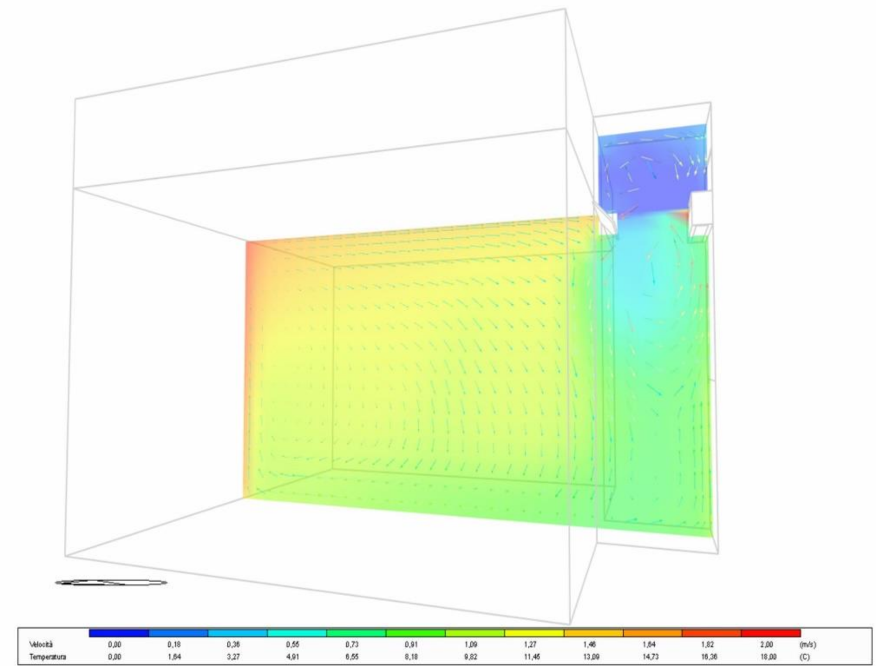
Solution "F"

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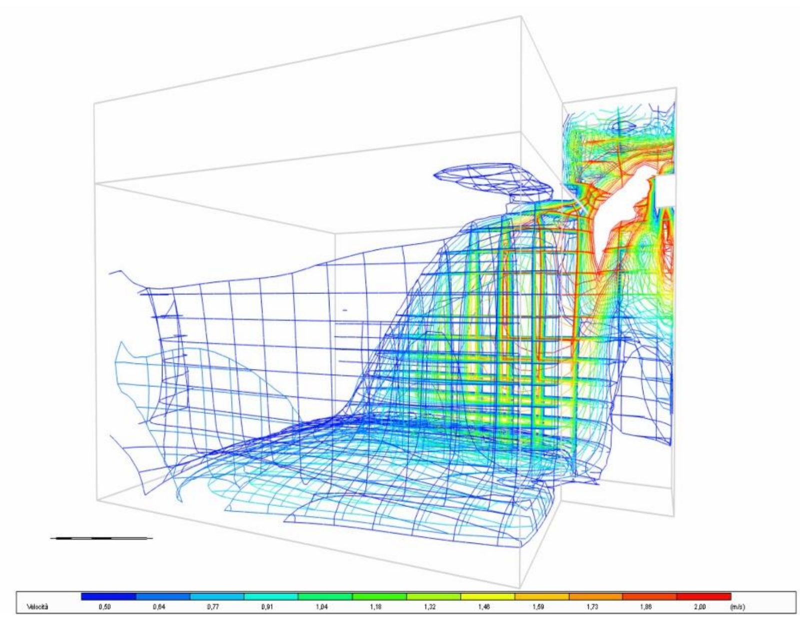
Temperatura 0,00 1,64 3,27 4,91 6,55 8,18 9,82 11,45 13,09 14,73 16,36 18,00 (C)


Velocità 0,50 0,64 0,77 0,91 1,04 1,18 1,32 1,46 1,59 1,73 1,86 2,00 (m/s)

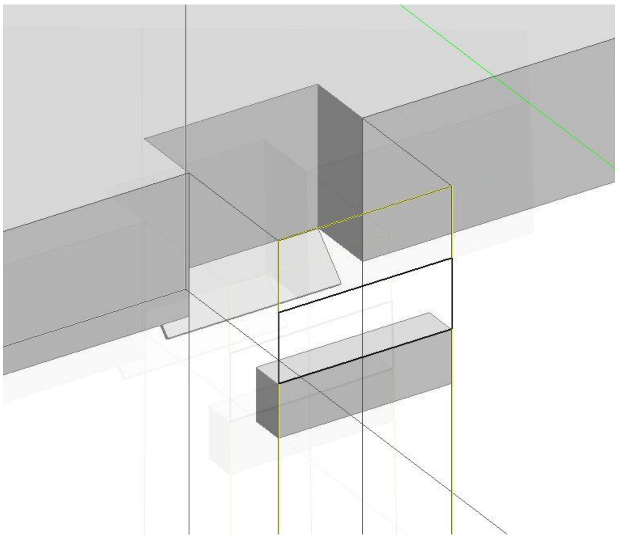
The Best Air Knife solution

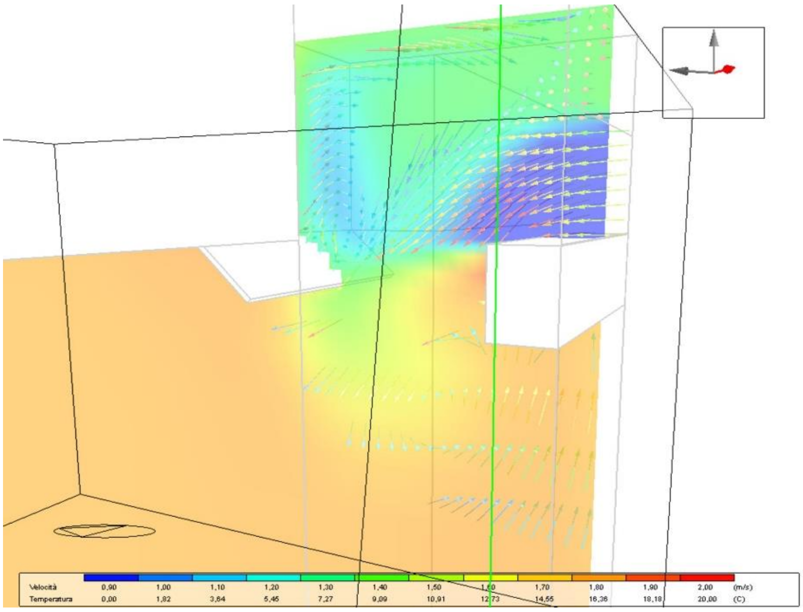
Based on the preliminary simulations we found that the best Air Knife solution is configuration F. Before changing the strategy and moving to the other solution (the fan-coil in to the false ceiling), we investigated optimising the model through a more detailed analysis of the Air Knife system.

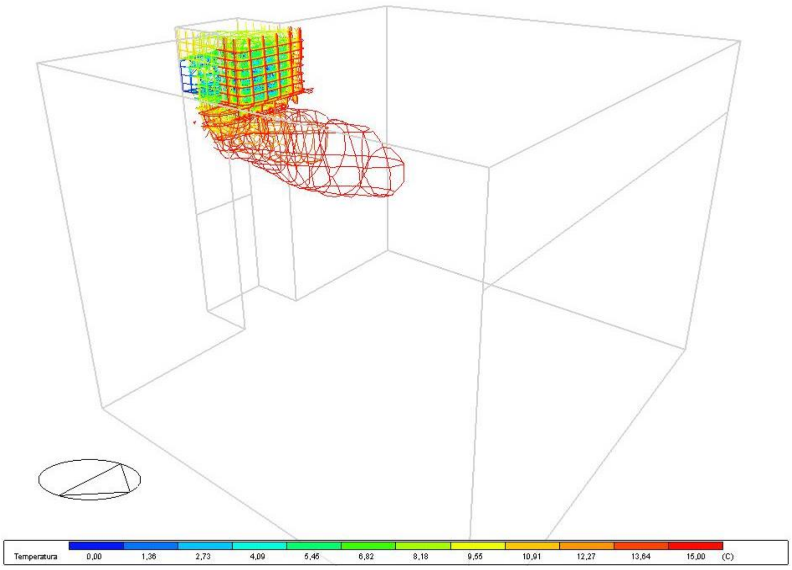
The simulation results are shown below. They showed the design team that the temperature gradient and air velocities within the volume are generally within the required range. Note that, in the most critical area, near the hole of ventilation, temperatures reach levels of comfort before reaching the occupied areas.

This evidence is also visible in the 3-D grid outputs which show the contours of the zones only at a temperature below 15°C. Very low temperatures remain confined to the area overlooking the ventilation hole and the ceiling.

However, the results, even when optimized were not considered to be satisfactory and for this reason, we decided to change the system, switching to a fan-coil embedded in the ceiling, as described previously.





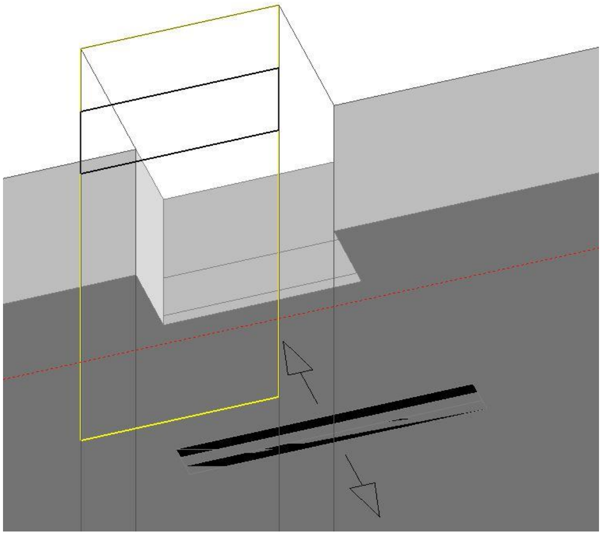


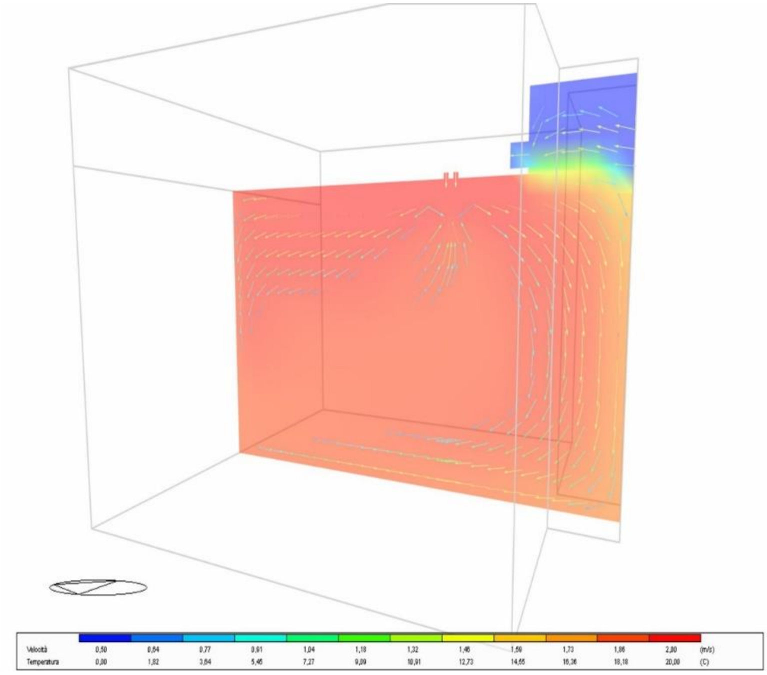
Regions where air temperature is less than 15°C

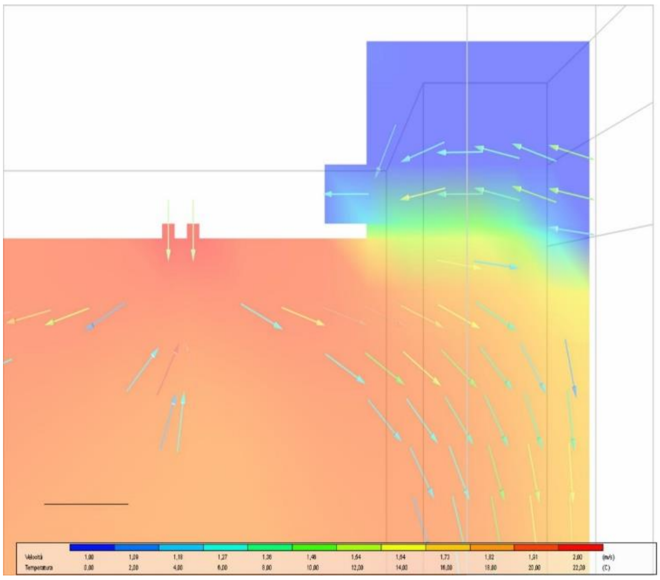
OPTIMAL FAN-COIL CONFIGURATION

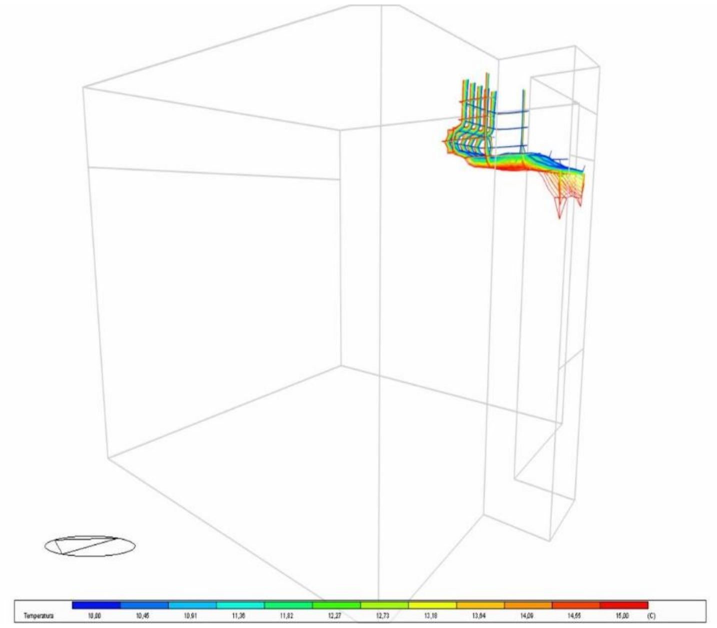
After various tests the fan-coil solution was shown to provide best results and the next step was to compare various diffuser geometry configurations for this option. The simulation results can be seen in the following pictures.

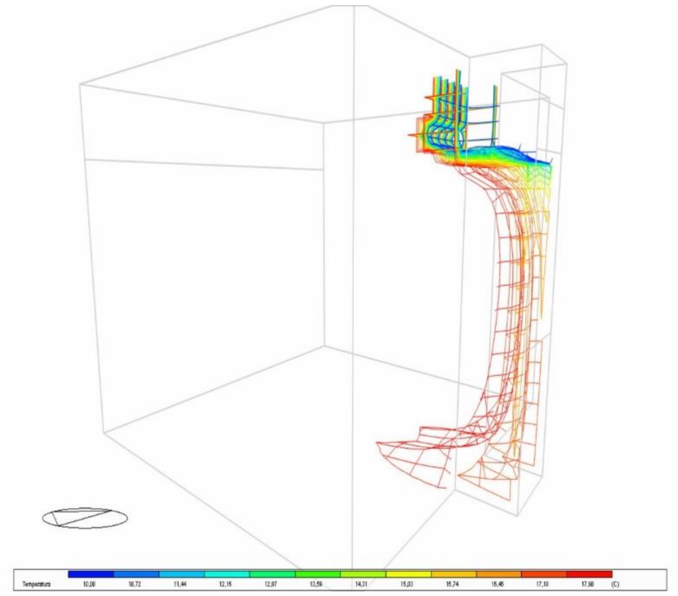
Correct operation of the system can be checked both from the point of view of the temperature gradients air velocity profiles. Analyzing the details, it was possible to detect good comfort temperatures in the occupied areas. Very low temperatures remain confined in the area overlooking the external ventilation hole, while the limit for acceptable temperatures are reached only near the window, whose surface temperature was about 8°C.

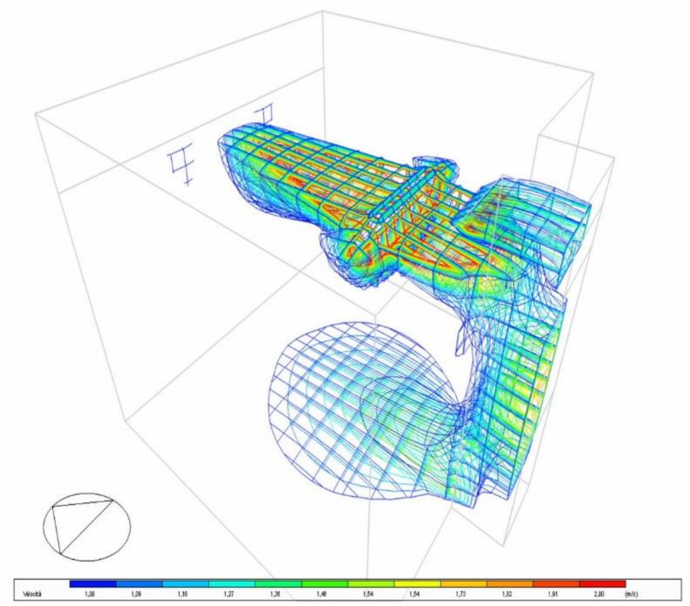



Velocità 0,50 0,64 0,77 0,91 1,04 1,18 1,32 1,46 1,59 1,73 1,86 2,00 (m/s)
Temperatura 0,00 1,82 3,64 5,45 7,27 9,09 10,91 12,73 14,55 16,36 18,18 20,00 (C)


Velocità 1,00 1,09 1,18 1,27 1,36 1,46 1,54 1,64 1,73 1,82 1,91 2,00 (m/s)
Temperatura 0,00 2,00 4,00 6,00 8,00 10,00 12,00 14,00 16,00 18,00 20,00 22,00 (C)


Temperatura
10,00
10,45
10,91
11,36
11,82
12,27
12,73
13,18
13,64
14,09
14,55
15,00
(C)


Temperatura
10,00
10,72
11,44
12,15
12,87
13,59
14,31
15,03
15,74
16,46
17,18
17,90
(C)


Velocità
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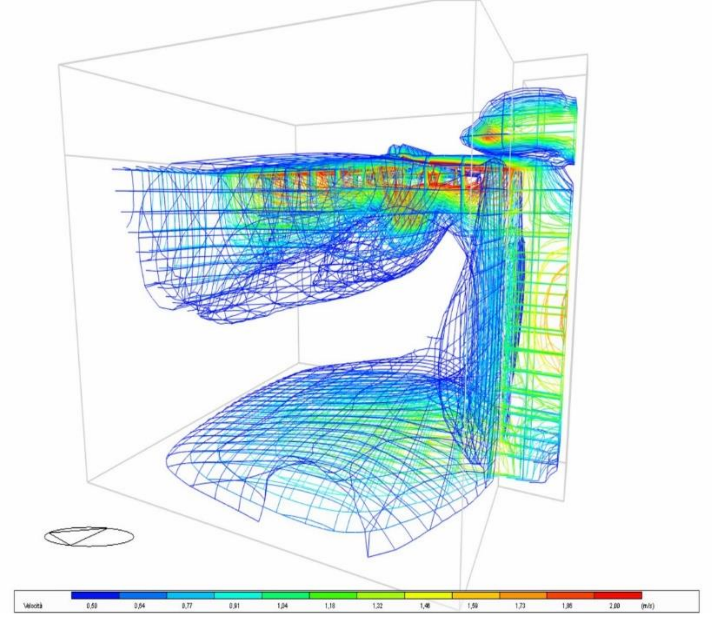

Conclusion

A series of CFD simulations identified the two solutions that could best meet the customer's requirements.

The study on the Air Knife was carried out to check for excessive air movements in the room. It was decided to include a deflector that dissipates flow energy before it reaches the occupied zone. With this solution, the speed of the air within the environment was found to be much lower and with better mixing between the cold air inlet and hot air.

The second solution, using the fan coil, allows the overall capacity of the HVAC systems to be minimised and ensures excellent mixing of the air.

The power and flowrate of the HVAC plant was sized based on the flow of outside air measured during the inspection to cover the heat load.

The final choice between the two solutions, both of which are technically correct, will be taken based on economic and availability of space in the ceiling considerations.

The simulations have been useful to help identify the most cost-effective solution as well as helping to detect possible problems and avoiding the installation of a poorly performing system.

To verify the accuracy of DesignBuilder CFD simulations a smoke test was carried out and the videos confirmed the accuracy of the simulated airflow paths.

SGM Architecture

SGM Architecture specialises in the use of advanced building energy simulation tools to support designers to find the best solutions for energy saving and occupant comfort. They also offer dedicated services for fluid dynamics, natural lighting, design optimization and acoustic analysis.