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# TECHNICAL NOTES

## Fluid dynamics simulation as a tool for analysis of hospital inpatient climate control

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**Airflow rate and air distribution inside a hospital room are factors of great importance in the design of the air conditioning system, especially given today's requirements for environmental quality control. Regarding these issues, the current Italian regulations are rather dated, as they refer to Ministerial Circular 13011 of 1974, concerning only the physical-technical aspects of hospital facilities, which indicates a minimum fresh airflow rate of 2 vol/h, a value also confirmed by the recent specific decree on Minimum Environmental Criteria (CAM in Italian).**

The current design trend, also following requests from various health managements even before the recent pandemic, is oriented toward higher values of 3 vol/h (incidentally compatible with the requirements aimed at LEED certification) or even more. The US ASHRAE standard for hospital construction (ASHRAE Standard 170-2021) sets 2 vol/h as the minimum outside air renewal, and the very recent ASHRAE Standard 241-2023, related to airborne infection control, establishes about 100 m3/h per person as the minimum outside airflow in the area occupied by people (breathing zone).
DIN 1946-4:2018, a widely used reference in Europe, indicates 40 m3/h per person, with a minimum of 1.5 vol/h. In conclusion, the variability of the normative requirements and the fact that the volume of the room, as a reference for the determination of the airflow rate, implies different ventilation rates per capita for different sizes of the room itself, may give rise to uncertainties in the design choices.
In any case, the assumed renewal rate, together with the strong reduction in both summer and winter heat loads imposed by current legislation on the energy performance of buildings, makes it possible to consider adopting all-air outdoor systems, with local temperature control instead of the usual mixed primary air systems with room terminals normally consisting of radiant ceiling panels. This is an important innovation in the air conditioning of these hospital wards, involving a certain simplification of hydronic systems, but a greater complexity of aeraulic equipment, in terms of airflow rate controllers (for each single room or groups of homologous rooms), local post-heating coils, size of treatment plants and distribution networks, etc. This choice naturally implies particular attention in defining the way air is introduced, distributed, and taken out, to guarantee uniformity of temperature, an appropriate speed and acceptable overall quality.

A particularly useful tool for this purpose, which is increasingly being used in design practice, is fluid dynamics simulation (CFD: Computational Fluid Dynamics), which makes it possible to evaluate - and even visually represent effectively - temperature and air velocity distributions under a specific study condition. There are many simulations software for thermofluid dynamics available today, allowing such types of analyses.

These software programs use finite element or finite volume numerical methods to solve the equations governing fluid motion and heat transfer, considering multiple boundary conditions, such as heat transfer coefficients of the envelope elements, convective and radiative internal heat loads, and of course, the characteristics of the supplied and extracted airflows. Particular attention must be paid to application aspects, such as the choice of the turbulence model of fluid motion and the modelling of air diffusers. In addition, given the rather high velocities at the inlet, the discretization grid - called "mesh" - of the space considered must be denser there than in the rest of the environment, as in the example shown in Figure 1.

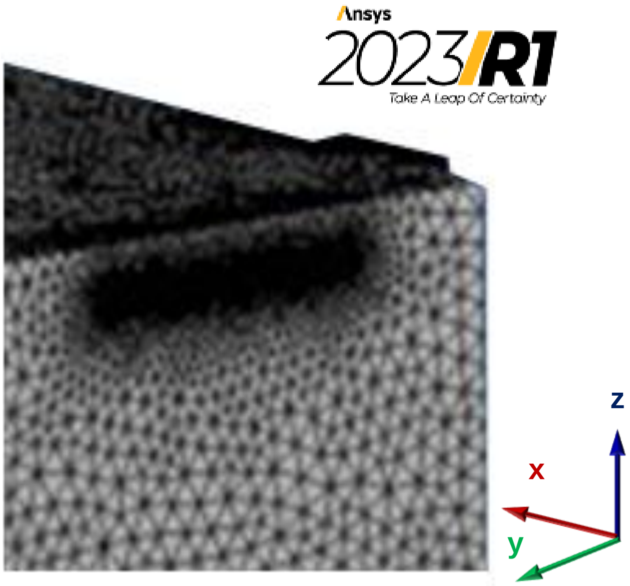


Fig. 1
The "mesh" of spatial discretization, densified in the most critical areas to increase the accuracy of numerical simulation

In a case recently considered, different types of air intake and extraction in a two-bed inpatient room were to be compared to a possible variation in the work in progress. Therefore, a digital model of the considered room was prepared using ANSYS Fluent software, as shown in Figure 2: the room has a floor area of about 29 m2 with a height of 3 m for a total volume of 88 m3. The input airflow rate is 300 m3/h, corresponding to more than 3 vol/h. The considered air conditioning system is of the all-air type, for the reasons previously stated.
In addition to the design solution, which involved linear ceiling diffusers throwing air vertically along the window (solution A in Figure 3) and air extraction partly from the toilet (to which the air comes through a slot under the door) and partly from the room itself at the ceiling lowering above the entrance, two other alternatives were considered. One (solution B) with supply through two diffusers placed on the longitudinal wall, high above the heads of the two beds, with throw tangent to the ceiling and with return air as in the design case. The other (solution C) with the introduction of air through a linear diffuser of the same type as in solution A, located on the uplift above the entrance to the room, with a horizontal throw tangent to the ceiling and with the same mode of extraction.
In all three cases, a modest portion of the injected air also transits to the corridor, through the gap under the front door, to maintain a slight overpressure in the room relative to the corridor.

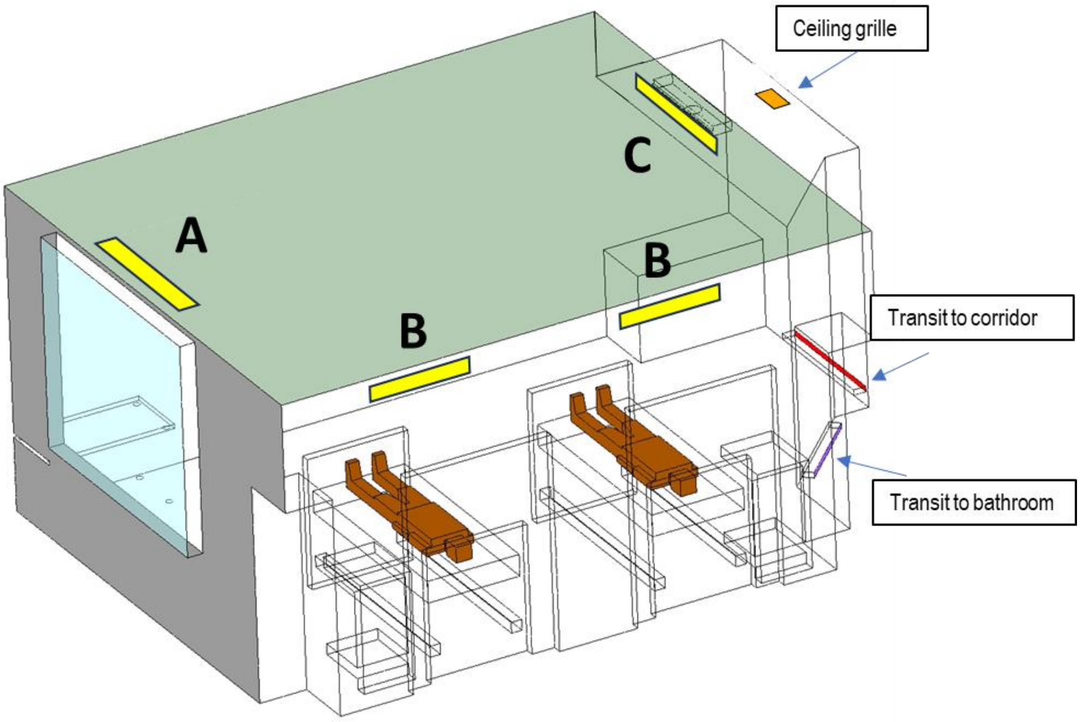


*Fig. 2*
*The digital model of the inpatient room*
*Alternative positions of supply diffusers:*
*A: at the ceiling, along the window*
*B: on the wall, above the bed headboards*
*C: on the ceiling uplift, at the entrance to the room*
*The supply air flow rate is 300 m³/h; extraction is through under-door transit to the corridor (30 m³/h), under-door transit to the bathroom (190 m³/h), and the ceiling grille above the entrance door (80 m³/h)*

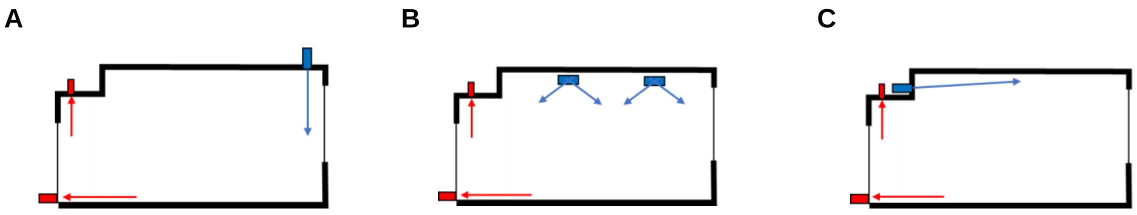


*Fig. 3*
*The different arrangements considered for the three types of air intake*

The simulations performed made it possible to determine and visualize the temperature and air velocity distributions in typical winter heating and summer cooling situations for the hypotheses considered. The most satisfactory solution was found to be C. Comparison with the others was made based on graphical representations of the trends in room temperature and air velocity.

Figure 4 shows the colour maps of temperature and air velocity distributions related to the adopted solution, which is also found to be the most cost-effective. The picture shows that temperature uniformity is very high, and the air velocity distribution is acceptable, given the required ventilation rate.

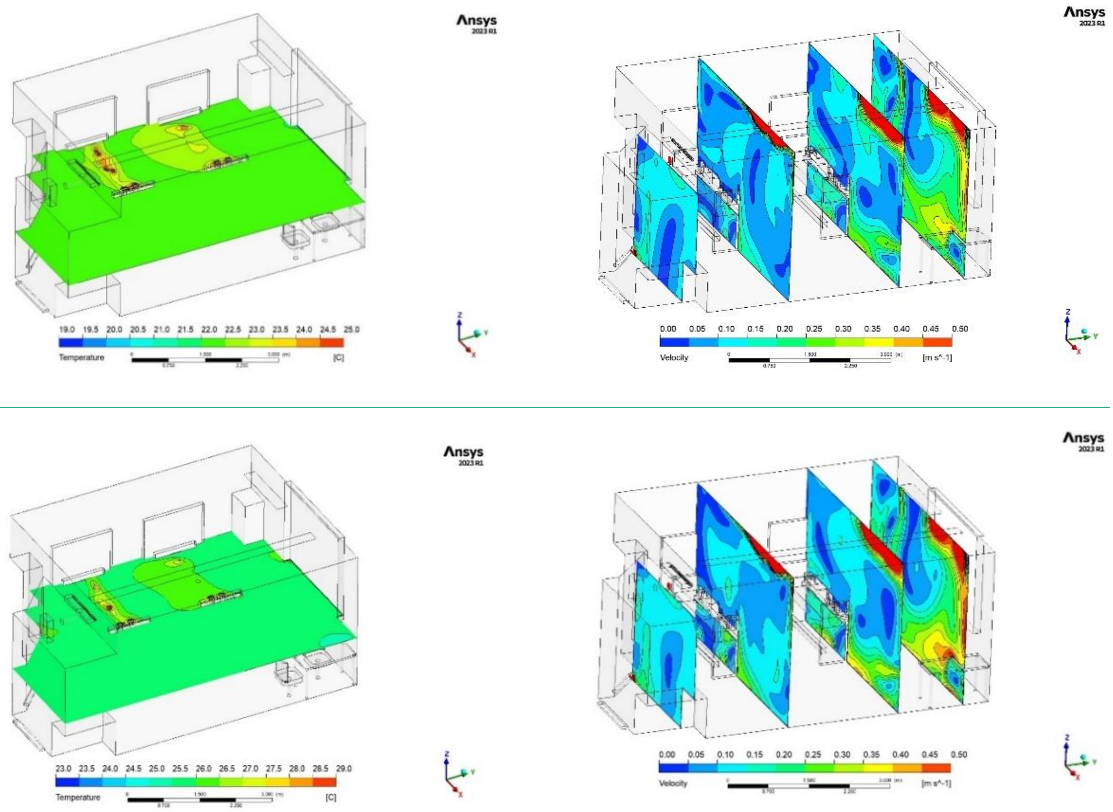


*Fig. 4*
*The distribution of temperatures at 1.1* m *height above the floor (left) and air velocities over significant vertical sections (right), in the case of air intake from the entrance area canopy, in the winter situation (above) and summer situation (below)*

Figure 5 shows the flow line pattern of the air distribution, which highlights how the higher velocity zones do not affect the area occupied by the inpatients' beds, while lapping, with positive effect, the large glass area.

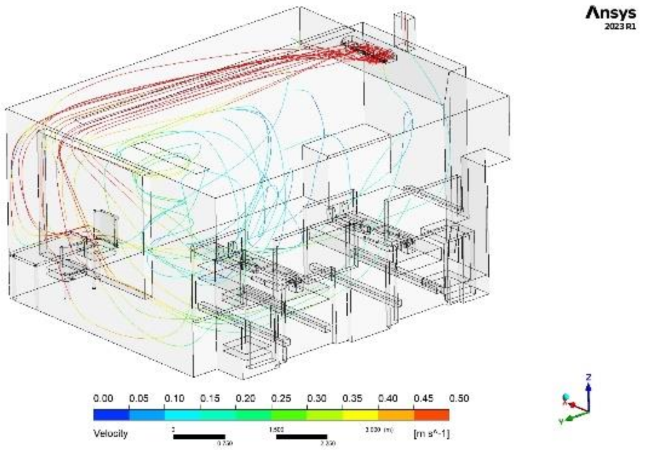


*Fig. 5*
*Trend of air flow lines with chromatic display of air speed*

Fluid dynamics simulation is a very helpful tool in the study of suitable solutions to meet current and future air conditioning and air quality needs in problematic environments, of which hospital ward rooms are just one example.
Moreover, the aspects to be considered when studying the air conditioning system of an inpatient ward are not just those exposed. Great attention must be paid to filtration systems (both as type and location within the air-handling units) and to heat recovery devices from the exhaust air, with particular reference to the positions of the supply and exhaust fans, in order to avoid, both under normal operating conditions and in the event of failure, any possibility of leakage of the exhaust air to the fresh air entering the air-handling unit. Then there is another issue to evaluate, namely the request, sometimes made by the health management, to further increase the air flow rate in case of emergency. In this regard, it should be noted that a renewal rate of 3 vol/h, now frequently adopted, corresponds, for this type of environment, to an air flow rate of more than 100 m3/h per person, a value therefore higher than those indicated in the aforementioned ASHRAE Standard 241-2023, specifically aimed at contrasting the spread of airborne infections.
If it is nevertheless intended to have the possibility of increasing air flow rates in emergency mode, the use of computational fluid dynamics makes it possible to assess the acceptability of the distribution of air in the room in the various situations, also in relation to the type of diffusers, which must be able to cope with said variations without compromising the performance of the air conditioning system in the occupied zone. In relation to this possible increase in flow rates in emergency situations, however, the specific aspects of sizing air handling units, distribution ducts and other system components should not be overlooked.
Finally, it should be noted that all the above must be considered as referring to standard units and non-specific hospitalizations, such as those for infectious or immunosuppressed, the requirements of which must otherwise be resolved also considering the control of relative pressures between rooms in and around the hospital.

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