

A view of the project site at Jay Precision Pharmaceuticals, Vasai



Energy Efficiency and Air Quality Achieved with Displacement Ventilation System in a Cleanroom

By **B. Gautham Baliga** Opal HVAC Engineers Pvt. Ltd., Design & Build Contractors, Mumbai

Preamble

The layout of the plant and the air-conditioning system was designed with a specific brief to achieve the best cleanroom air quality, temperature, humidity and operator comfort with minimum energy consumption. The conditioned space admeasures 12,500 sq. ft. with a false ceiling at 12 feet, and houses 14 injection molding machines dissipating around 82kW heat.

A conventional air-conditioning system to achieve Class 100,000 (ISO 14644 Grade 8) with supply air from the ceiling would require a system having 3 x 18,000 CFM air handling units (AHUs) with 99 TR of refrigeration capacity, consuming 162.72 kW peak energy depending on the season.

Considering a different type of system, called a displacement ventilation system, with air being supplied from low level instead of from the false ceiling, it was possible to achieve the same parameters of Class 100,000 using a system having 3 x 7,000 CFM AHUs with 80 TR of refrigeration capacity, consuming 91.3 kW peak energy depending on the season. This represents a 43% saving in peak loads.

In addition, as a feature, it was decided to go in for Class 10,000 (ISO Grade 7) cubicles, one for each injection molding room, for conducting the packing activities. Each of the cubicles, when in use, would consume 2.38 TR of refrigeration and 3.75 kW of energy. The idea was to provide an even better environment with the flexibility to use it only when necessary.

About the Author

Gautham Baliga is a graduate mechanical engineer from IIT Kharagpur and has been in the HVAC profession for the last 38 years. After his initial 8 years with Voltas Ltd., he has been director with Opal HVAC Engineers Pvt. Ltd. – a company engaged in specialised HVAC projects related to healthcare, pharmaceutical, industrial and comfort sectors. He is a Past President of ISHRAE Mumbai Chapter and an ISHRAE Distinguished Lecturer.

How Conventional Air-conditioning Works

The conventional air-conditioning adopted for Class 100,000 cleanrooms is based on the mixing (dilution) ventilation system concept, in which air is supplied in a manner such that the entire room volume is fully mixed. The cool supply air exits the outlet at a high velocity, inducing room air to provide mixing and temperature equalization. Since the entire room is fully mixed, temperature variations throughout the space are small, *while contaminant concentration* is uniform throughout the zone.

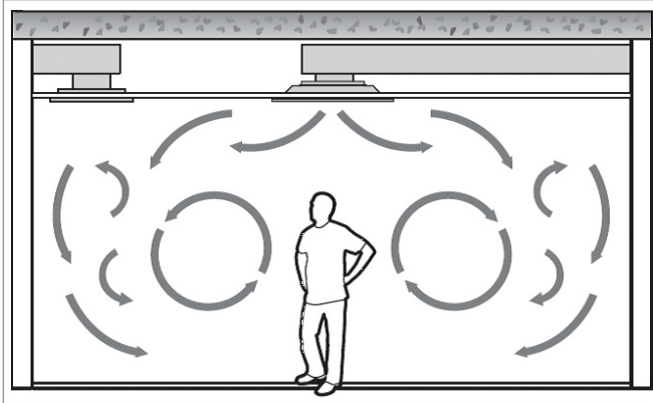


Figure 1: Conventional air-conditioning using the mixing (dilution) ventilation system

How Displacement Ventilation System Works

Displacement ventilation systems introduce air into the space at low velocities, which cause minimal induction and mixing. Displacement outlets are traditionally located at or near floor level. The system utilizes buoyancy forces in a room generated by heat sources such as people, lighting, computers, electrical equipment, etc. to remove contaminants and heat from the occupied zone. This results in the *air quality in the occupied zone being generally superior to that achieved with mixing ventilation.*

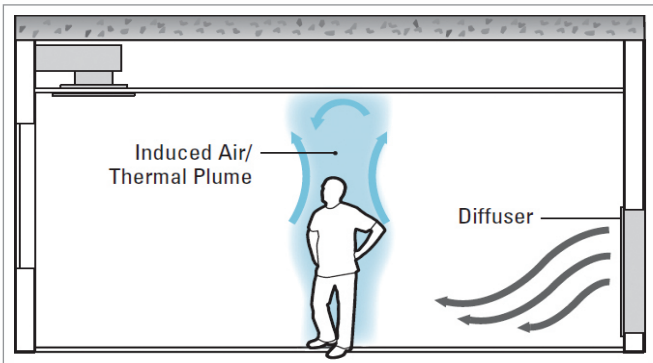


Figure 2: Air-conditioning using displacement ventilation

Air Flow Penetration

A displacement system supplying cool air through a diffuser will deliver air along the floor in a thin layer typically less than 8 in. (0.20 m) in height. The supply air spreads across the floor in a manner similar to water flowing out of a tap, filling the

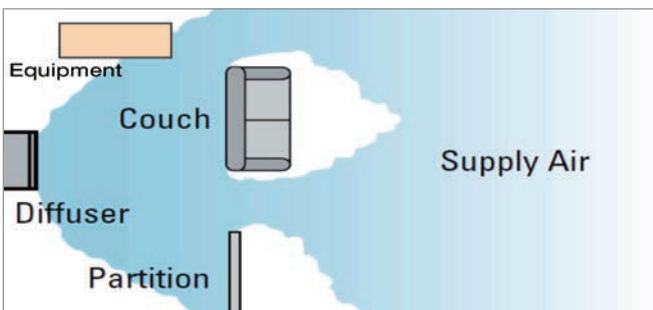


Figure 3: Obstruction

entire space. If obstructions such as equipment or partitions are encountered, the air will flow around and beyond the obstruction, as illustrated in *Figure 3.*

Even rooms with irregular geometries, as illustrated in *Figure 4,* can be uniformly supplied with air.

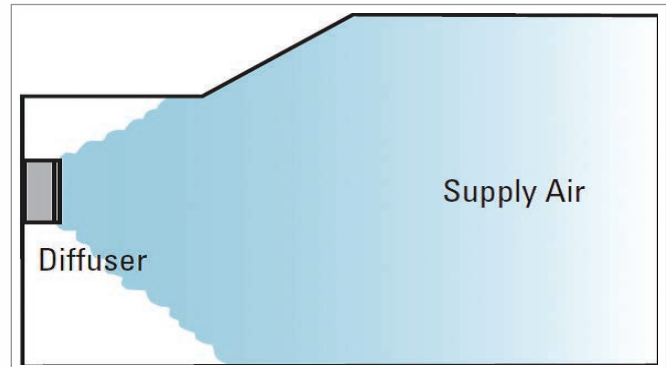


Figure 4: Irregular room geometry

Contaminant Distribution

Contaminant distribution is influenced by several factors such as supply air method, contaminant source type, location within the space, heat sources and space height. Displacement ventilation improves occupant air quality by reducing the contaminants in the lower portion of the room. The general upward motion of air causes contaminants to concentrate within the upper zone (*Figure 5.*)

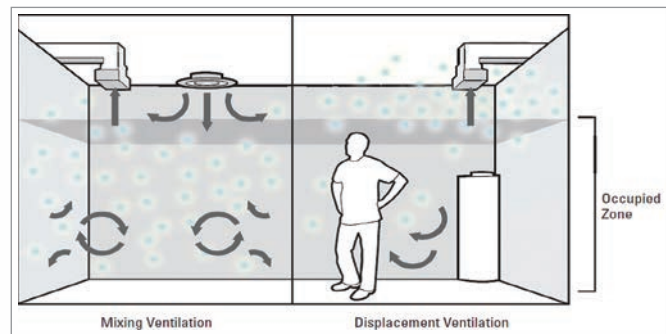


Figure 5: Contaminant distribution

With mixing ventilation, contaminants are diluted with supply air and are distributed evenly throughout the space. *Figure 5* represents contamination distribution in a room supplied with mixing and displacement ventilation for a typical case where the contaminant source is warm (a person, for example).

With displacement ventilation, because the upward convection around a person brings clean air from lower level to the breathing zone, the air in the breathing zone is cleaner than the room air at the same height. Contaminants that are heavier than air need to be extracted at a lower level through a second return if they present a safety concern.

Temperature Distribution

Controlling stratification in the occupied zone is critical to maintaining occupant comfort. The temperatures are comfortable in the occupied zone at 25° to 26°C (77° to 78.8°F).

The air temperatures above the occupied zone will steadily rise, depending on other loads. In this installation, considering high equipment loads, it rises to 40°C (104°F).

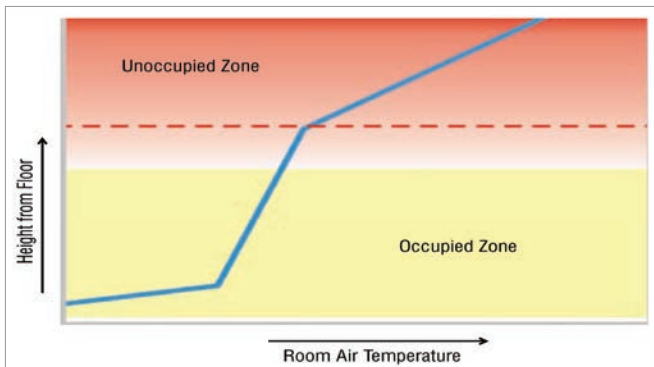


Figure 6: Temperature distribution

Based on CFD analysis, the following room temperature profile was expected in the production area:

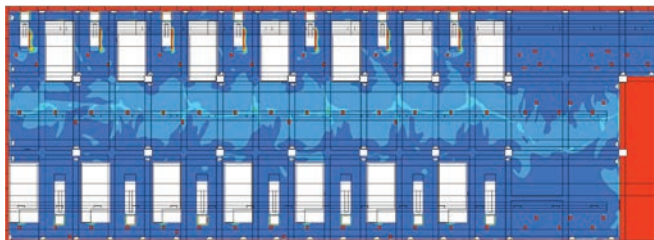


Figure 7: Temperature contour at 0.5M (20 inches) from floor

Remarks: Cool at near floor level around 18.5°C (65.3°F)

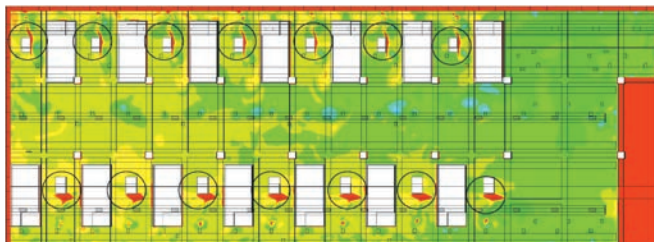


Figure 8: Temperature contour at 1.8M (6 feet) from floor

Remarks: Comfortable at occupied level around 26°C (78.8°F)

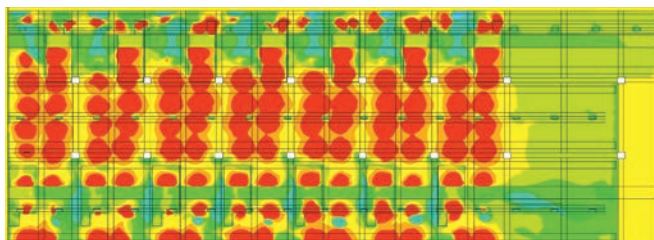


Figure 9: Temperature contour at false ceiling level, 3.6M (12 feet) from floor

Remarks: Hot at false ceiling level, at 40°C (104°F)



18C 25 40C
Legend for Temperature

Measures taken for Air Quality, Operator Comfort and Energy Savings

Air Quality

- HEPA filtered air supplied into the open areas at low level to achieve best air cleanliness class (Class 100,000) at the operating level.
- Each injection molding machine has a packing area adjacent to it. The packing area comprises of an air lock and a packing room, which are maintained at Class 10,000 cleanliness.
- Product exposure in the molding machine and the traverse by the robot to the packing room conveyor are maintained at Class 100 cleanliness.
- The cleanliness of packing room and airlock outside production areas are preserved by maintaining a pressure gradient with the clean to the dirty axis.

Thus air quality is maintained best where it matters most. This makes the cleanliness levels affordable and easier to maintain.

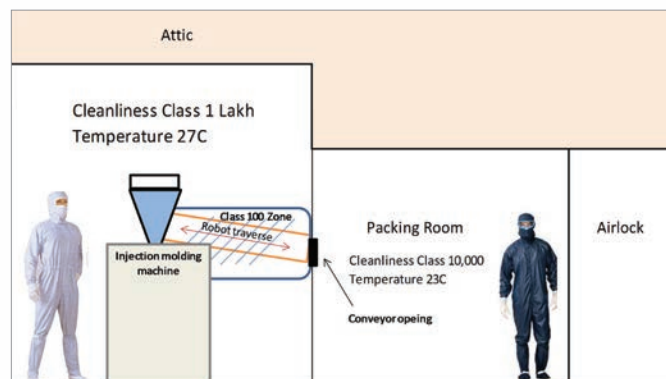


Figure 10: Air cleanliness and temperature scheme in and outside the production area

Operator Comfort

- As described earlier, displacement ventilation provides uniform comfort at 27°C (80.6°F) in the occupied zone of the open production area. There are no air drafts. Since the packing rooms maintained at Class 10,000 require elaborate cleanroom gowning, these rooms are maintained at a lower temperature of 23°C (73.4°F) for operator comfort.
- The high return air temperature at false ceiling level posed a peculiar problem of creating operator discomfort due to radiant heat from the false ceiling. Radiant heat can result in higher load on the air-conditioning system. Radiant heat was minimized by providing low emissivity anodized aluminum false ceiling material. *Low emissivity results in transferring maximum heat through the false ceiling into the attic space and reflecting back minimal heat into the conditioned space*
- Due to maximum radiation getting into the attic space, heat would build up there and would result in a hot floor on the floor above. This would make the operators in the floor above uncomfortable. To obviate this, the underdeck of the main ceiling was insulated with *low emissivity insulation* and the heat build-up in the attic was drained by providing ventilation

in the attic space with ambient, filtered air. It may be noted that both the low emissivity false ceiling material and the low emissivity insulation are quite economical. Please refer *Figure 11* for the low emissivity scheme.

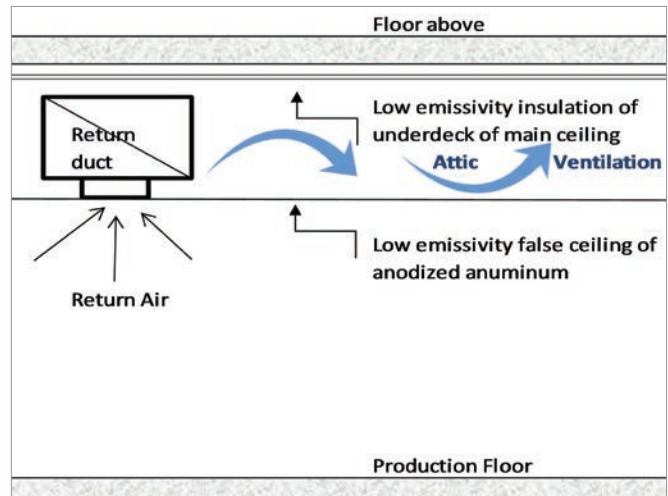


Figure 11: Low emissivity scheme

Energy Saving Measures

- The main production area is air-conditioned based on displacement ventilation. The supply air temperature into the area is around 18.3°C (65°F) as against 13.3°C (56°F) used in normal mixing ventilation air-conditioning system. The input energy required to obtain the higher temperature is one main source of energy savings.
- The air re-circulation required in normal mixing ventilation air-conditioning systems to obtain Class 100,000 cleanliness class is around 20 air changes per hour. As against this, since the release of supply air in displacement ventilation system is at the operating level, around 10 air changes per hour air circulation has been used. This has effectively reduced the air handling unit fan energy requirement by half to achieve the same cleanliness.
- Further energy savings are obtained by using free cooling of return air. The air returning to the air-handling units is at 40°C (104°F). The ambient temperature is around 35°C (95°F) in summer and lower during night-time and in mild seasons. By incorporating heat pipes, ambient air is used to cool the return air before feeding into the AHUs. This way, around 10.2 TR of air-conditioning is recovered.

Acknowledgements

Grateful thanks are due to Mr. Xerxes Rao, Managing Director, Jay Precision Pharmaceuticals Pvt. Ltd. for reposing confidence in us to carry out this path-breaking project, which came with its associated entrepreneurial risks. Thanks are also due for his guidance on the design aspects from his immense fund of knowledge, to look at things from the basics, which helped us in our own perspectives.

The author acknowledges that *Figure 1 to 6* are sourced from the literature of Price Industries, USA on displacement ventilation systems. ❖