How to ensure Thermal Comfort in buildings with CFD

Using CFD Simulations to analyze and improve HVAC Systems

WhitePaper

SIMSCALE

Simulation in your browser

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How to use CFD Simulations to Analyze and Improve HVAC Systems.

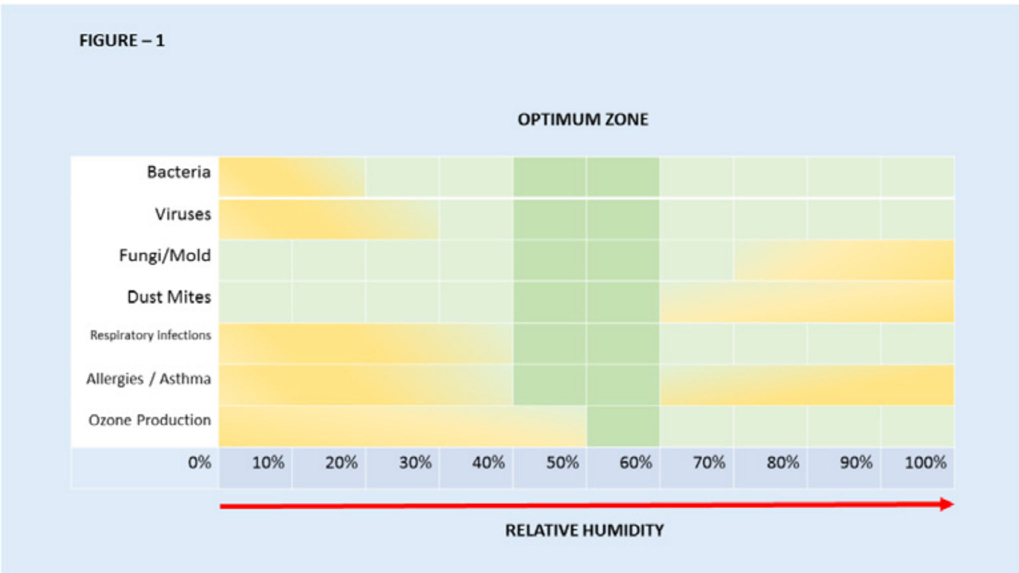
Thermal comfort is vital at home, in vehicles, within commercial buildings as well as in offices. Designing air conditioning systems for heating and cooling that provide optimal comfort at varying ambient conditions has always been a complex challenge for HVAC (Heating, Ventilating, and Air Conditioning) engineers. It is complex because air conditioning systems are designed for specifically defined loads, with a specific amount of refrigerant and a specific airflow through the cooling coils; however, these systems often fail to meet the comfort expectations of the users.

The quality of HVAC systems is affected by changes in the following five basic parameters:

1. Ambient temperature
2. Relative humidity (RH)
3. Air movement
4. Air quality
5. Mean radiant temperature

Ambient temperature and relative humidity (rh)

The first two parameters — ambient temperature and relative humidity — are the psychrometric processes of air for a particular climate, location, and altitude with seasonal and daily variations beyond human control. These two parameters combined indicate the heat content of air at any point in time – enthalpy. The first and foremost objective of the aircon is to reduce the enthalpy of the conditioned space. When the enthalpy of conditioned space is reduced, its air temperature and water content decrease. This results in the cooler air, coupled with evaporative cooling effect for human occupants. Human beings generally feel comfortable at an ambient temperature range of 294 degrees Kelvin (21o C) to 299 degrees Kelvin (26o C) when the RH value of the air is around 70% or less. For health and cleanliness reasons, the optimum zone for RH is 40% - 60%, as indicated in **Figure-1** below.



For **Cooling Load Calculations**, the air temperature value above the comfort range indicates the Sensible Cooling Load while the RH value of air above the optimum zone indicates the Latent Cooling Load of the conditioned space. At particular outside ambient conditions, both these loads may change with an increase in movement of fresh air into the conditioned space and increase in the occupancy (people as well as running equipment) of the conditioned space.

The calculation of both these cooling loads is the basic step of an iterative HVAC design process. It is important to highlight that over-sizing the equipment is not a solution for increasing thermal comfort. Over-sizing not only results in increased installation & operational costs but often causes short-cycling of the air conditioning system which results in under performance (the system may not run long enough to attain condensation temperatures at all cooling coils) and increased system wear due to increased start-stop cycles.

True thermal comfort created through air conditioning systems is achieved by giving additional consideration to the other three parameters responsible for the desired air conditioning quality: air movement, air quality, and mean radiant temperature. All three are discussed in the following sections.

Air Movement

Moving air gives a pleasant feeling. When air moves past our skin it enhances the evaporative cooling effect thus making us feel comfortable even at higher than comfort zone temperatures. Thus air movement creates a breeze like an effect in the conditioned space which adds to the human comfort.

On the other hand, air movement can be uncomfortable at lower temperatures similar to the *Wind Chill Factor*. Wind chill is the human feeling of a lower temperature than actual when cool air at 283 degrees Kelvin (10o C) flows past the exposed skin. A section of conditioned space which is exposed to direct air stream from cooling coil causes discomfort.

Studies performed to analyze and simulate study temperature distribution of a conditioned space using CFD (Computational Fluid Dynamics) tools, which are also equipped to perform thermodynamic calculations for CAE (Computer-aided Engineering), can help us identify high-temperature spaces where a forced air movement can improve human comfort. Such simulations can be rerun with changing parameters to investigate the best possible airflow with respect to identifying and eliminating uncomfortable zones in an otherwise comfortable air conditioned space.

Figure – 2

- A CFD simulation snapshot of air temperatures inside an office space with cooling vanes installed close to ceiling for air conditioning
- Red color sides indicate heat transfer through windows
- Walls and ceilings were treated as adiabatic
- Fresh air movement through two doors.

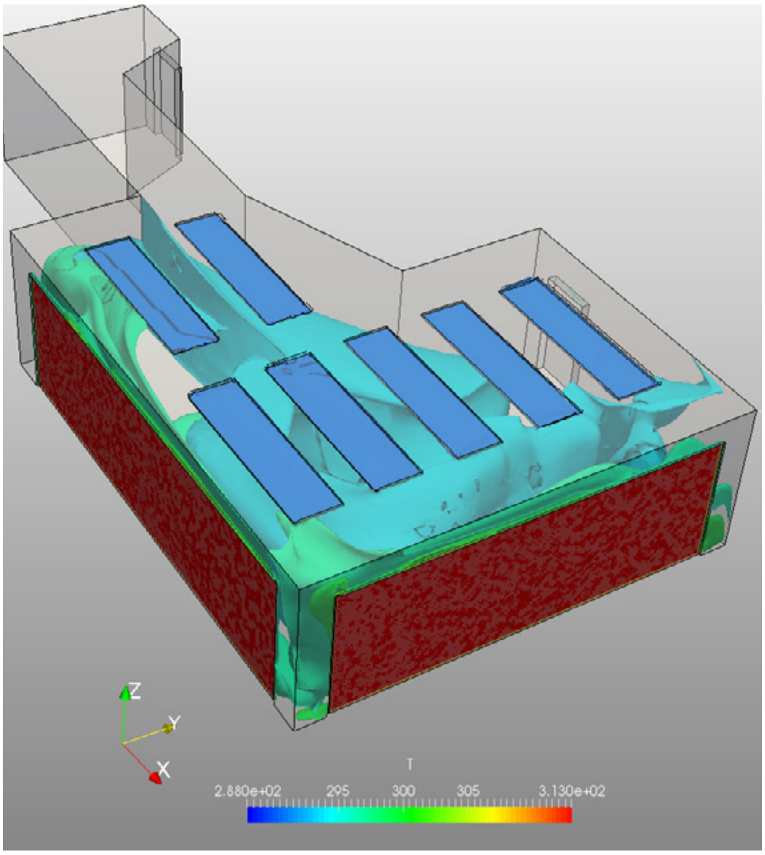


Figure – 2 is a snapshot of a steady state simulation carried out on the SimScale cloud-based simulation platform, showing 3-dimensional temperature distribution of the conditioned space. Blue represents the coolest zone and red/ orange — the hottest zone. The space near the windows has been identified as tending to be uncomfortable zone. This is important information; normally, people prefer to sit close to a window with blinds removed to enjoy the outside view and to have a feeling of openness. The simulation snapshot has identified the weakness of the HVAC system to create a comfort zone close to windows and this uncomfortable feeling will increase at high ambient conditions.

Figure – 3

- A CFD simulation snapshot of air temperatures inside an office space with cooling vanes for air conditioning
- Top view clearly identifies temperatures above the comfort zone
- Walls and ceilings were treated as adiabatic
- Fresh air movement through two doors.

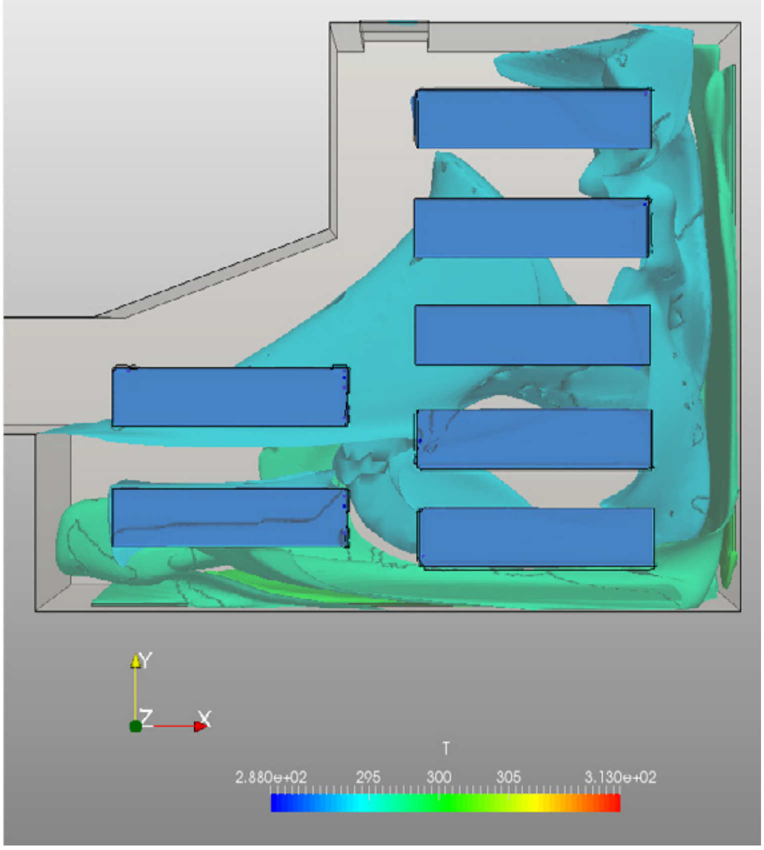


Figure – 3 is a plan-view snapshot of the same **steady state simulation** carried out on SimScale, showing temperature distribution along the length and breadth of the conditioned space, blue being the coolest zone and red/orange as the hottest zone. This top view has again highlighted the weakness of the HVAC system design to create comfortable air conditioning close to windows.

AIR QUALITY

Governmental agencies keep educating the public about deteriorating Air Quality Index (AQI) of various metropolitan areas – how polluted air is due to vehicular and industrial emissions. An increase in AQI means that the health of more people gets adversely affected. However, it is seldom emphasized that air quality of a conditioned space, especially homes, can be worse than the outside air quality if proper ventilation is not maintained. Various studies related to human exposure to pollutants done by Environmental Protection Agencies have indicated that indoor air quality can be many times worse than the outside air quality which causes building related discomfort and health issues for the occupants.

Use of activated carbon filters coupled with appropriate provisioning of fresh air improves the indoor air quality. An additional inside pollutant is noise, created in the conditioned space due to noisy fans and blowers. The noise factor is usually considered while designing air handling units for an HVAC system and outside air movements around a building can be studied to supplement AHUs and improve noise levels.

Mean Radiant Temperature

Various equipment (refrigerator, cold water dispenser, photocopier, printer, laptop, etc.) and structural components (heated rooftop, heated wall, window sill, window glass / grill) in addition to spreading heat through convection in the conditioned space, are also a source of hot body radiation. Likewise, cold walls and windows suck heat from the human body through radiation. This phenomenon is called mean radiant temperature effect. In simple words, a heated wall is radiating more energy towards the human body than the energy radiated by human body towards the wall, causing a heat source (which is uncomfortable during summer). A cold wall, in turn, is radiating less energy towards the human body than the energy radiated by human body towards the wall causing a heat sink (which is uncomfortable during winter).

How does this it affects thermal comfort in a building? Even if the temperature of the conditioned space is below 299 degrees Kelvin (26° C), people may feel uncomfortable as such heated surfaces keep blasting heat towards them. This phenomenon, which is applicable to both heating and cooling, is also manifested in Figure – 2 above, where the heated window panes are a constant source of heat radiations, in addition to convective heat input to the conditioned space.

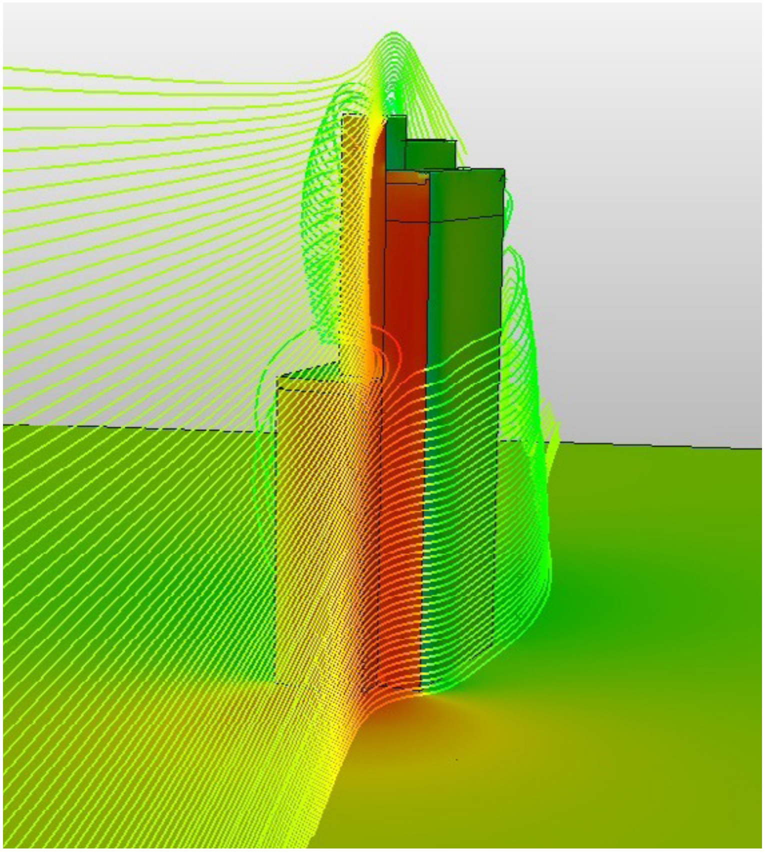
Simulating Air Movement

Air movement, air quality, and mean radiant temperature are interrelated issues in a conditioned space. Appropriately designed air movement coupled with necessary ventilation and insulation can adequately handle all the three issues. Knowledge of outside air movement, especially in high-rise buildings, also helps in utilizing outside air pressure and velocity in designing efficient air ventilation systems and ensuring inside air movement. **Figure – 4** below is the result of a CFD simulation done on SimScale – a Computer-Aided Engineering (CAE) solution.

The pressure velocity profile of air around a high-rise building, obtained through simulation, can help in efficiently designing *Outdoor Air Intake*, *Exhaust Air outlet*, and *Return Air route* through the HVAC system's ducts. This information also helps in optimizing noise levels inside the conditioned space.

Figure – 4

- A CFD simulation snapshot of wind velocities and pressure variations around a high rise building
- The information obtained through such a simulation can be used in improving air ventilation through HVAC systems
- Provides useful information about static pressure head for air circulation systems



HVAC systems are designed for human comfort. Engineering simulation and Computational Fluid Dynamics (CFD) in particular helps in anticipating, quantifying, and avoiding any uncomforted areas at the design stage. As a result, various components of HVAC systems perform in harmony, creating an efficient, durable and healthy conditioned space where people feel at home.

Conclusion

When it comes to designing modern air conditioning systems, thermal comfort along with energy efficiency and performance are crucial factors that need to be considered my HVAC designers and manufacturers in order to stay competitive.

Adopting new technologies can be the differentiator whether we talk about the IoT trend with smart HVAC products or engineering simulation technology and CFD tools in particular.

Engineers working in the HVAC industry can benefit from the emerging cloud-based CAE solutions like SimScale, incorporating simulation technology in their design process with minimum up-front investments and plenty of available resources for a fast adoption.

Author

Syed Kamran Ali is a professional engineer with more than 20 years of experience in the HVAC and Oil & Gas fields. He is working with CFD simulation of fluids in pipelines, be it a refrigerant piping, an oil / gas transmission line or any hydraulic measurement and control system with known fluid properties. Kamran is specialized in HVAC systems design based on Organic Rankine Cycle Turbines (heat recovery or solar applications) and Vapor Compression Cycle Heat Pumps. Possesses authoritative skills regarding fluid measurement systems for custody transfer applications