Abstract
Autonomous HVAC CFD (AHC), an innovative tool built for HVAC designers solves the problem of designing buildings for occupant thermal comfort as well as indoor air quality, major factor being Carbon dioxide. Since there is a continuous supply of carbon dioxide due to breathing in a space, CO2 ppm is naturally increased and hence the air quality decreases drastically over time. The positioning and properties of space diffusers play an important role in determining the hazard and is a cause of concern for the HVAC designers. Autonomous HVAC CFD (AHC) provides HVAC designers the opportunity to simulate the CO2 ppm while designing the space.

Highlights
● CO2 modeling for Canteen with a different location of return air diffusers.
● Check the impact of the return air diffuser on CO2 air concentration at the breathing zone.
● Optimize HVAC design and indoor air quality by adjusting return diffuser location.

Introduction
Indoor Air Quality (IAQ) is the air quality inside buildings as represented by concentrations of air contaminants and thermal conditions that affect our health and comfort. Thermal comfort is an essential aspect of IAQ in representing human satisfaction, defined as “the condition of mind which expresses satisfaction with the thermal environment” – ASHRAE 55 (2013) (1). HVAC systems provide satisfactory indoor air quality, the aim of this study is to predict CO2 concentration inside the space at the early design stage and check the impact of return air diffuser location on indoor air quality.

Carbon dioxide (CO2) primarily released by human respiration is used in this study as an indicator of indoor air quality, as it is a common indoor air pollutant in offices, canteens, public spaces and schools. One way to reduce CO2 concentration is to regulate the HVAC system, but improper ventilation system design will lead to significant accumulation of CO2 and negative health effects. It is important to model the CO2 concentration inside the space at an early design stage to check the capability of the HVAC ventilation system. As Figure 1 shows, moderate increases in the indoor CO2 level between 1000 and 2000 ppm adversely affected the cognitive performance of people. When CO2 concentrations exceed 1000 ppm, discomfort symptoms such as nausea, dizziness, and fatigue occur. As such, it is necessary to model the CO2 concentrations at an early design stage.

Methodology
Indoor Air Quality Modeling Methodology
Indoor air quality (IAQ) modeling with the help of Autonomous HVAC CFD (AHC) involves simulating the CO2 concentration in supply, return, breathing zone air in an indoor location with little ventilation. Here are the basic stages involved in CO2 modeling with CFD:

Geometry Creation
In the BIM – Building stage, as shown in Figure 2, we create a model using a floor plan using sketching tools available to construct walls, place windows and doors on the walls. Different material properties can be assigned
from the library for walls, glass windows, roof/ceiling, and floor. The building site location and orientation are specified.

**HVAC Airside System**
The HVAC Airside System stage includes the creation of multiple air-side systems with different diffusers or A/C units and their supply/return positions to try different air distribution systems like overhead mixing, displacement ventilation or underfloor air distribution. Also, minimum ventilation requirement shall be considered as per ASHRAE 62.1 standard.

**Design Configuration and Scenario Stage**
In the design configuration stage, we are assigning the CAV/VAV based HVAC systems. In the Scenario stage, multiple simulation scenarios can be created such as full and half occupancies. Also, cooling and heating applications are simulated. For indoor air quality modeling, occupant density in each space and external weather conditions and CO2 concentration are specified.

**Meshing and Solving**
The next step is to divide the 3D geometry into small computational cells or “meshes”. This allows for the simulation of fluid flow and heat transfer in each individual cell. Once the boundary conditions are applied, the CFD software solves the mathematical equations governing fluid flow and heat transfer in each cell.

**Result Visualization and Analysis**
As shown in Figure 3 and Figure 4, HVAC engineers can visualize and analyze the results to gain insights into the behavior of the CO2 level in the space. This can include visualizing the CO2 concentration after a certain timeline, determining the concentration of CO2 at supply, return and breathing air, and identifying areas of high CO2 concentrations. It helps to ensure that CO2 ppm levels within the space are maintained within indoor acceptable levels or not.

**Optimization**
By analyzing the results, we can determine whether the earlier HVAC systems are able to maintain safe levels of CO2 concentration. If not, engineers can make design modifications or changes to the system to optimize its performance and reduce CO2 hazard by increasing the fresh air CFM.

**Test Case**
For modeling CO2 concentration, a canteen type space is created. The space size is 24 ft (W) x 48 ft (L) x 10 ft (H) and has a canteen type seating layout with 32 mannequins and outdoor location is Winter Haven, Florida, USA placed as shown in Figure 5. The space has glass windows which are placed on the South and West directions of the building and other walls are adiabatic. Ducted constant air volume (CAV) HVAC system to be considered with the supply air diffuser of 24’x24’ and return air grille of 18’x18’ placed at middle location. From the heat load calculation, 2100 CFM supplied to space and fresh air to be considered as per ASHRAE 62.1 which is coming to 229 CFM. The outside CO2 concentration is specified as 421 ppm.
Results
It is observed that CO2 concentrations are going beyond the acceptable indoor level after a 30-minute timeline for a particular area inside the space. As shown in Figure 7 and Figure 8, the green cloud shows the area where CO2 concentrations are within a range of 400 – 1000 ppm (Acceptable range). Mean age of air contour at a breathing zone plane at 1.10 m shows that there is some air which is settled in a large area for longer duration and maintaining ventilation effectiveness less than 1.

Optimizing the HVAC design
To maintain the indoor air quality within acceptable range, the return air diffuser location shall be changed and placed towards the North wall as shown in Figure 9.

Results and Discussions for Optimized Case
It is observed that the indoor air quality within space is improved after changing the location of return air diffusers and the CO2 concentrations are maintained within the acceptable range in maximum area. Mean age of air contour shows that there is some air which is settled in some area for longer duration and maintaining ventilation effectiveness greater than 1.

Future Work
Modeling indoor air quality for other parameters like VOCs, PM 2.5, will be added to the indoor air quality
modeling to completely predict the air quality at the design stage and make the HVAC modeling more effective. A report could be generated based on these standards to provide much more insights to the user and create effective design for a space with proper ventilation to achieve the best possible indoor air quality at the design stage itself.

**Conclusion**

Modeling indoor air quality at the early design stage can have significant benefits for building designers and occupants alike. By considering factors such as ventilation rates and occupant behavior, designers can make informed decisions that design ventilation systems capable of maintaining indoor air quality and improve overall building performance.

Indoor air quality modeling can also help to check ventilation effectiveness, identify potential issues at an early design stage. Overall, incorporating indoor air quality modeling into the design process can lead to more sustainable and comfortable buildings that support occupant health and well-being.

Autonomous HVAC CFD (AHC) application helps to model indoor air quality at an early design stage that is very useful for HVAC engineers to determine the quality of air and hazards that might follow. From the initial BIM stage to visualization of results, the cloud-based web application ensures designers have a solid tool to perform these simulations autonomously.

**References**