Council on Tall Buildings and Urban Habitat Korea

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
March 2022, Vol 11, No 1, 69-74
https://doi.org/10.21022/IJHRB.2022.11.1.69

Furniture Layout and Design for Better Indoor Air Quality in Office Buildings

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Abstract
- COVID -19 taught us a lot about how to protect our tall buildings from infectious diseases. This paper captures the lessons learned about airflow in indoor spaces when considering furniture and its placement. By applying them we move towards future proofing our buildings both in normal and pandemic times.

Keywords Post-pandemic design, CFD, Indoor Air Quality, COVID-19

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1. Introduction

The Covid-19 pandemic has highlighted the importance of indoor air quality and HVAC systems as it relates to our health and wellbeing. The ASHRAE Epidemic Task Force has Core Recommendations[1] that guide the HVAC system design; however, the focus is at the spatial level. Methodologies such as the Wells Riley equation address the overall space average but not the specific local air flow conditions. Recent research, such as at a Korean restaurant cluster[2] indicated specific local airflow matters, and in the study it contributed to infection that is 6.5 m away from the indexed person infected. While much of the focus has been on increased HVAC filtration systems and overall average risk of a space, this collaboration between SOM and Steelcase was to investigate how furniture design and configuration impact the local airflow conditions and indoor air quality in a typical leased office space.

2. Physical Assumptions

We based our model on a common large-scale office floor plan measuring approximately 40 feet from the core to the outside perimeter wall (also known as the lease span), with 10-foot ceilings.

The HVAC is assumed to be conventional variable air volume (VAV). The space is divided into 2 zones, the exterior zone is 15' from the window and the rest is the interior zone. The space is assumed operating in the summer with 75°F setpoint and 50% relative humidity. It is an open office layout. The exterior zone is assumed at 2 cfm/sf slot diffusers and the interior zone is assumed at 0.7 cfm/sf with ceiling diffusers. The supply air diffusers are indicated in blue in Figure 1. Return air is designed to be return grilles in the interior zone. The return air diffusers are indicated in bright red in Figure 1. The total number of diffusers and lights was also constant between each layout. There were a total of two return diffusers, and two interior supply diffusers, which each supplied 575 CFM. Additionally, there were five linear diffusers along the South wall that supplied 345 CFM each. The ceiling, floors, and walls were all set to a fixed setpoint temperature of 75°F, and the six lights were modeled with a power density of 7 W/sm of floor area and a light density of 52 W/sm of simulated light. The lights are indicated in dark red in Figure 1.

The occupants in the space were modeled at 75 W each. Each laptop in the space was also accounted for and assumed to have a power density of 35 W.

3. Model Assumptions and Metrics

We used Computational Fluid Dynamics (CFD) to test two common office furniture layouts as designed pre-COVID-19 and compared them to a "Post-COVID" layout

[1]https://www.ashrae.org/file%20library/technical%20resources/covid-19/core-recommendations-for-reducing-airborne-infectious-aerosol-exposure.pdf
[2]https://pubmed.ncbi.nlm.nih.gov/33258335/

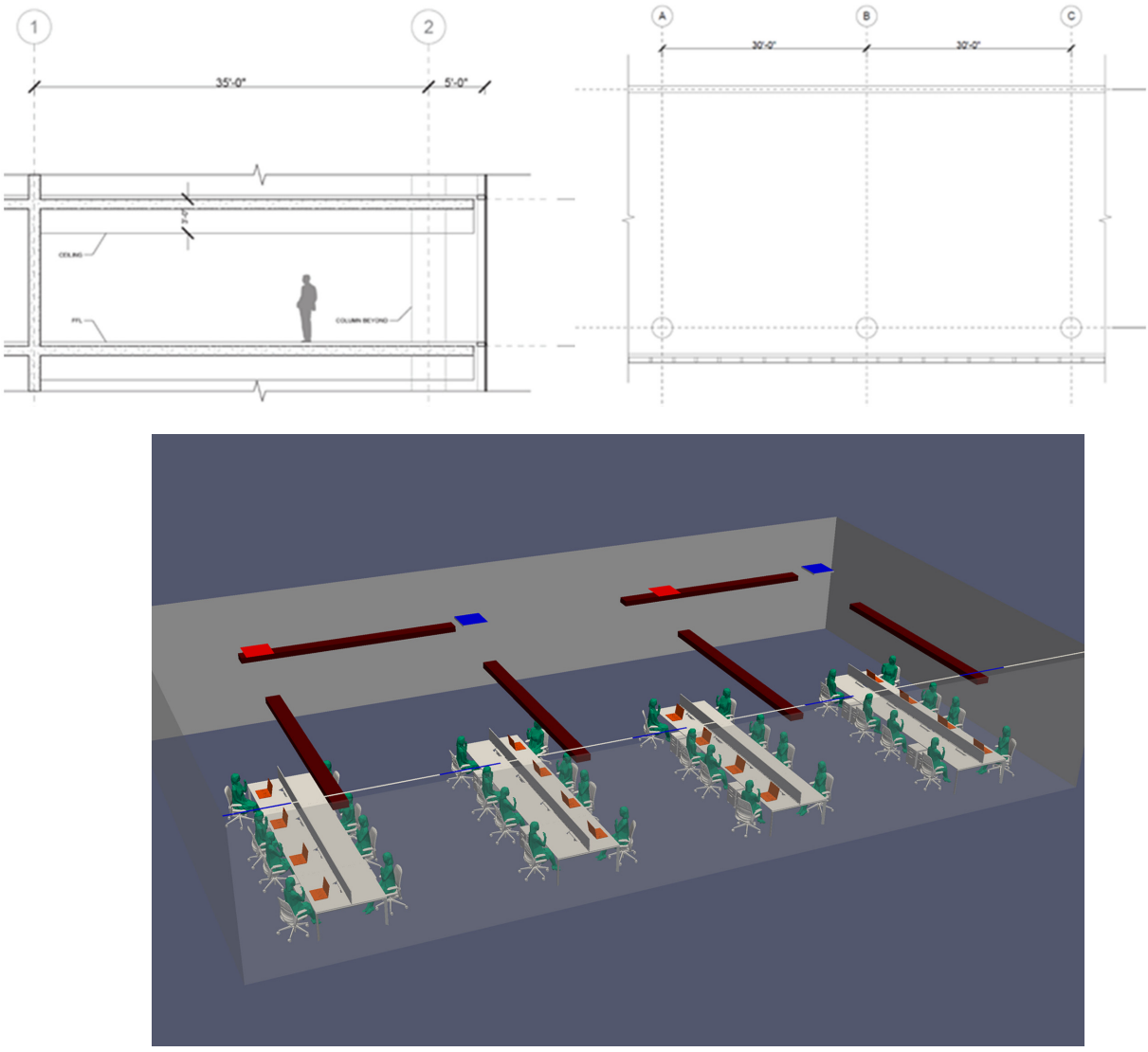


Figure 1. Typical Office Lease Space.

that altered the geometry and space division. We included each of these office layouts inside the ventilated space including people at each workstation with a laptop.

Although each furniture and occupant layout changed, the overall setup of the simulation was constant. Each simulation was done using the HELYX (OpenFOAM) CFD software, and was run as a steady-state simulation with the k-w SST turbulence model. The overall mesh count was 1,223,933, and the smallest mesh size was 0.0125 Meters.

The pre-pandemic layouts consisted of panel-based workstations and benching. Panel-based workstations are characterized by taller floor standing panels. Benching is characterized by shorter desk-height space division at the center of the work surfaces that are not floor-standing. The post-pandemic layout combines an angled geometry with desk-height space division.

We used two metrics to evaluate each furniture layout. "Age of Air" measures how long air remains in a particular space, this can help illustrate how effectively air is changed within that space. A high Age of Air indicates stagnant air that is not circulating well at that location, whereas a low age of air indicates the air is being replaced by new air more frequently and the space is thus better ventilated. The model was run for 2500 timesteps which had been previously determined to represent a steady-state condition and stable results. The results are represented in a spatial "heat-map" that identifies the presence and location of areas of lower ventilation (longer Ages of Air) on a scale from 0 to 900 seconds.

The scale for Age of Air is shown below.



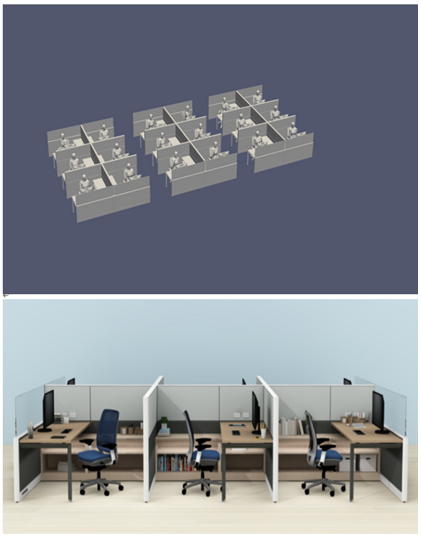


Figure 2. Pre-Pandemic Option 1 - "Panel Based Workstations"



Figure 3. Pre-Pandemic Option 2: "Benching"

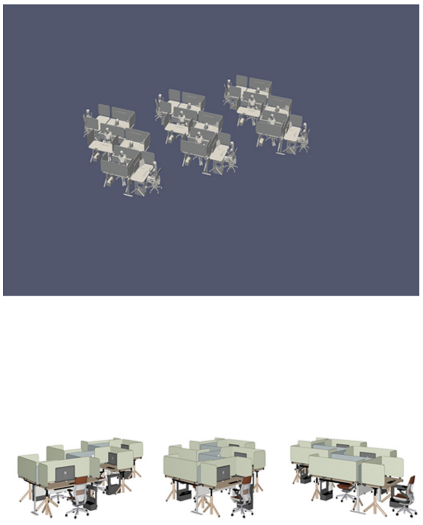
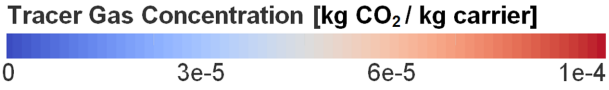


Figure 4. Post-Pandemic Scenario - Combined Effect of Geometry and Division

While age of air helps evaluate the effectiveness of ventilation systems, it does not necessarily reveal any direct impact on potential transmission of SARS-CoV-2. To more accurately understand how aerosols from a potentially infected individual may travel to neighbors and thereby infect them, we also used a Tracer Gas to simulate airborne transmission. The Tracer Gas was CO_2 and a surrogate for virus-infected air. The breathing rate was assumed to be 1.6 CFM at 59 FPM and 98.3°F. Several representative occupants were modeled to release tracer gas, which was then tracked throughout the space to show how their exhaled air interacted with neighbors. Each occupant was modeled as exhaling air, which contained 10% kg CO_2 per kg of air exhaled. The results are represented spatially in a 2-dimensional format with a scale that ranges from blue (zero tracer gas present) to red, which indicates a concentration of tracer gas.

The scale for Tracer Gas is shown below.



4. Results

The results are presented per layout, with the left image showing the spatial representation of the Age of Air, and the right image representing the Tracer Gas footprint. The location of the occupant emitting tracer gas is indicated by a green dot.

The Age of Air results for the pre-pandemic panel-based workstations scenario shows localized areas of longer Age of Air (white) at 900 seconds (15 minutes, 4 ACH) or more. Shorter Ages of Air are located toward the exterior wall (bottom of the figure) and towards the right side of the image, which is where there is an interior

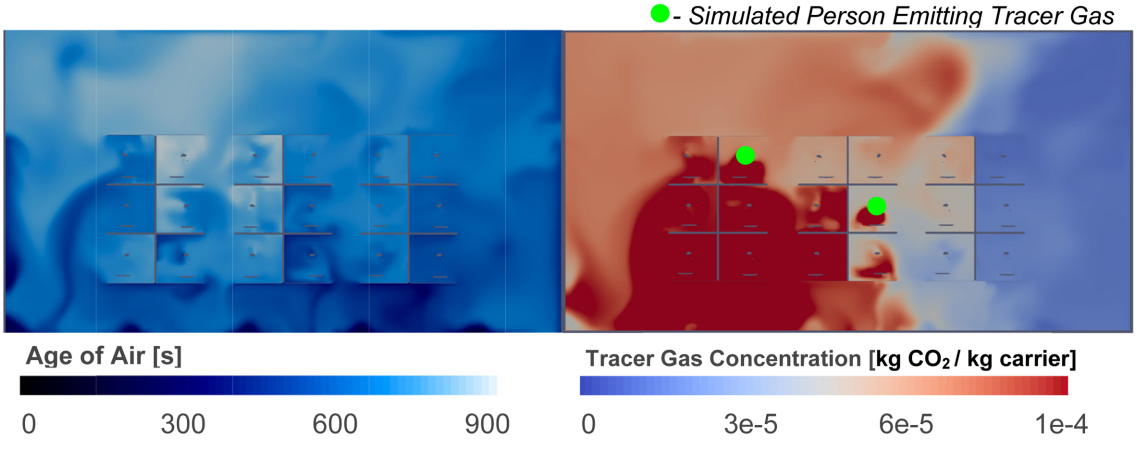


Figure 5. Pre-Pandemic - Panel Based Workstations Results.

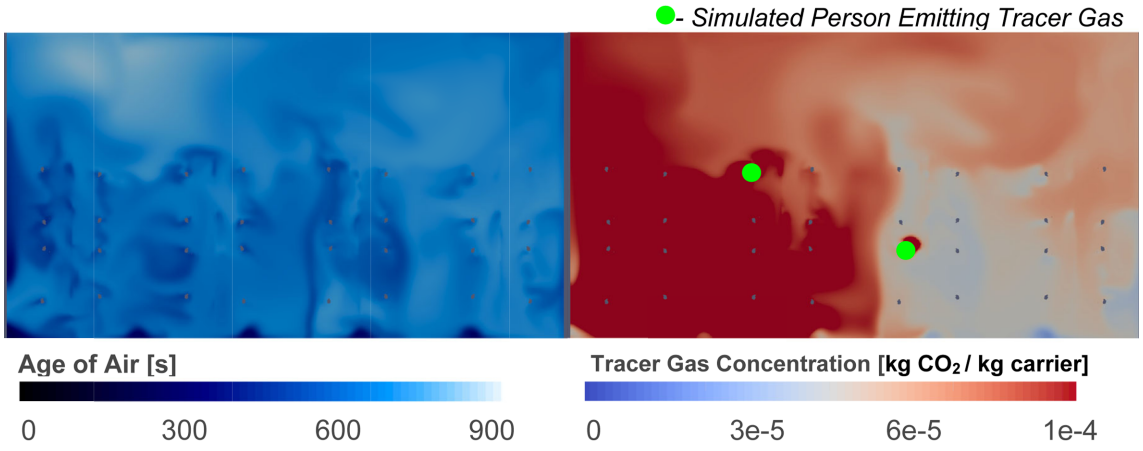


Figure 6. Pre-Pandemic - Benching Results.

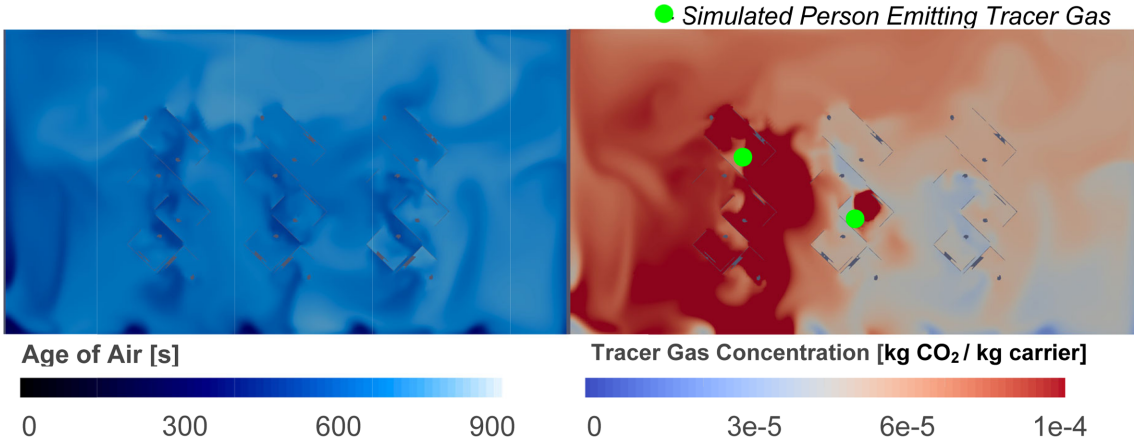


Figure 7. Post-Pandemic - Modified Geometry and Division Results.

supply diffuser.

The Tracer Gas footprint indicates a broad spread of the gas as shown toward the bottom left of the image. Where there are pockets of stagnant air, the tracer gas tends to spread to more occupants, which is why the tracer gas from the occupant located in the back of the room, on the right side of the image spreads farther in the space than the occupant on the right.

The Age of Air results for the pre-pandemic benching scenario show a relatively even distribution of Ages of Air across the space of 600 to 800 seconds (10 to 13 minutes, 5-6 ACH). Unlike the panel-based workstations, there are no pockets of stagnant air.

The Tracer Gas emitted on the supply side shows localization (a small footprint), whereas emission on the left side of the floorplate (the return side) indicates a broad spread of the gas as shown toward the bottom left of the image.

The Age of Air results for the post-pandemic modified scenario also show a relatively even distribution of Ages of Air across the space of 600 to 800 seconds (10 to 13 minutes, 5-6 ACH), and there are no pockets of stagnant air, as seen in the panel-based option.

The Tracer Gas emitted on the supply side shows localization (a small footprint). Emission on the left side

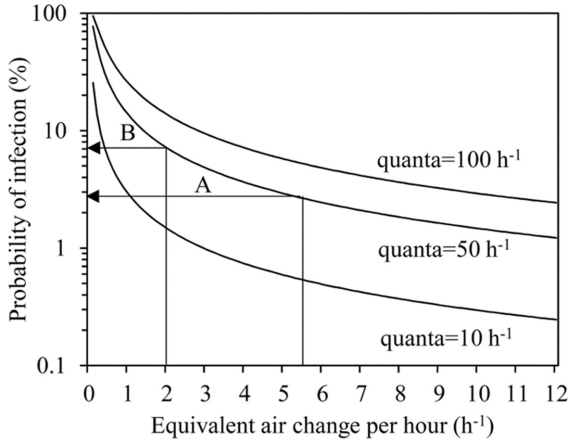


Figure 8. Impacts of Air Changes Per Hour and Probability of Infection with Different Quanta Rate. (Kenichi et al. (2020)

of the floorplate (the return side) indicates a broad spread of the gas with localized areas of less concentration. There was an improvement in the spread of the tracer gas between our post-pandemic option and the benching option because of the presence of partitions that separated the occupants but did not extend to the floor, which limited the impact on the overall age of air in the space and minimized stagnant pockets.

5. Discussion

The Age of Air can be thought of as the inverse of Air Changes per Hour, ACH. ACH can be a parameter to indicate the risk of infection in a space[3]. In Kenichi et al. (2020), higher levels of air changes can reduce the risk of infection given different quanta rates. About 3 ACH of clean air can eliminate 95% of the contaminants in a space. ASHRAE ETF also utilizes the Equivalent Clean Air approach (a combination of filters and air cleaning devices) to determine the total clean air available.

When we look at the results for panel-based workstations, we note that the white represents 15 minutes Age of Air, which is ~ 4 ACH for the worst areas of the cubicle/ panel-based system. In comparison, the benching and rotated post-pandemic systems indicate max Age of Air to be closer to 10-13 minutes, or 5-6 ACH. Essentially, we are looking for an average of 6 ACH with little variation. Note these air changes are the results from a VAV system, which will be worse in winter, especially in northern climates.

For the Tracer Gas results, we note that when the tracer gas is emitted on the supply side, it is localized in all layout scenarios. However, model results indicate that location on the return side shows greater spreading across the breathing zone in all the layouts, with the post-pandemic layout showing the best ability to maintain localized areas of tracer-gas-free zones.

Further studies (not reported here) of the panel-based workstation layout indicate that placing a room air purifier in the room helps to remove the tracer gas in the areas of highest concentration. Although there are many variables to consider, our results indicate that the best placement to mitigate the highest concentration of tracer gas is on the return side of the space where the concentration of the gas is expected to be higher irrespective of the location of the gas emission (the "infected" individual).

6. Conclusions + Design Considerations

Through our studies, we found that furniture type and configuration impact the local airflow conditions and indoor air quality in a typical leased office space. The conventional risk calculation using Wells Riley equation does not reflect the nuances of localized conditions within the space. These improvements in better air circulation not only will benefit occupants during pandemic times, but will also provide better circulation during normal times.

From this study, we have identified four design considerations.

1. The type and layout of furniture can impact both the normal air distribution and pandemic air distribution by creating potential stagnant spots with minimal air movement.
2. Identify ventilation. Whenever possible, identify ventilation type and location of supply and return vents on workplace floor plans, and prioritize positioning frequently-used settings nearer fresh air supplies.
3. Maximize air flow. When planning furniture layouts, consider how air will flow best to minimize disruptions. Consider how the geometry and division of the space can align with the ventilation path to maximize air flow.
4. Add air purification. Room-scale air purification devices can support air quality and flow when placed strategically.

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