Distributed Sensing for Indoor Environments: Comparing Measured and Simulated Indoor Airflow Data for Complex Commercial Building Interiors

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Abstract

Improved monitoring towards understanding of indoor environmental quality (IEQ) and occupant exposures has become critical for commercial buildings, and a principal public health concern during the current pandemic. Here, we tested IEQ patterns within an industrial factory converted to hybrid spaces for offices, labs, and light manufacturing, serviced by a combination of HVAC, radiant slab, and high-volume, low speed (HVLS) fans. Multi-factor sensors measuring air speed alongside temperature, humidity, and carbon dioxide (CO_2) were run in parallel with a computational fluid dynamics (CFD) model, examining multiple boundary conditions to investigate opportunities for HVLS fans to improve workplace safety and well-being.

Key innovations

- Air speed detection was added to a low-cost, multi-factor sensor with temperature, humidity, and CO_2 detection, contributing data on IEQ and thermal comfort towards predicting and monitoring these parameters, and prevalence of biological components of the aerobiome, with indoor air mixing being a potentially impactful, but poorly characterized factor of viral exposures within indoor spaces
- Proof-of-concept protocols for future integration of feedback loops between combined IEQ factors and occupancy sensing that informs the integrated energy and CFD model, with recommendations for real-time operational and maintenance decisions for integrated HVLS fan and heating, ventilation, and air conditioning (HVAC) operation.
- Operating characteristics and recommendations for HVLS overhead fan operation derived from CFD + sensor data
- Protocols developed for data acquisition and interactive visualizations, including integration of metadata and annotation (knowledge of the sensors and airflow equipment, and performance implications of the resultant patterns), as sensors were iteratively deployed and re-deployed

Practical implications

Low-cost sensors with appropriate detectors (temperature, humidity, air speed, CO_2) are deployable for continuous monitoring of thermal comfort in adaptive re-use spaces, informing operation of multi-mode HVAC with hybrid air-side, radiant, and re-circulation capabilities. Commercial energy-modeling-integrated CFD was helpful, if limited, for characterization and checks of airflow patterns.

Introduction

Utility of spatialized, continuous monitoring

Although investigations into built-environment phenomena are traditionally rooted in reductive methods of isolating controllable variables and observing specific outcomes, more integrated methods of eco-systemic analysis, involving a greater number of interrelated variables, could be necessary to assess public health exposures, as built environments are increasingly understood to exhibit deep systems-level complexity.

For example, to characterize the real-time impact on complex occupancy patterns of indoor environmental quality (IEQ) and adaptive air flow regimes, these factors must be integrated through multiple frameworks, such as envelope thermal performance, occupant behaviours, and HVAC control strategies.

Improved design and verification of airflow in different indoor building types has long been important but is now critical to the global health crisis response. Moreover, reliable verification of building air flow behaviors is critical for assessing IEQ management technologies such as next-generation HVAC, or alternatives such as smart fans, and various devices for air cleaning.

At the room and building scales, granular spatio-temporal IEQ data describes occupant experience, and is therefore relevant not only to them, but to the stakeholder stack invested in built environment (BE) performance per metrics of inhabitability, operation, sustainability, and well-being. Current observational methodologies combine discrete environmental and system-state monitoring, with occupant survey and feedback (Choi, Loftness, and Aziz, 2011, and Loftness et al., 2018). Factors such as airflow can be indirectly gauged through related signals (such as CO_2 concentration) by hybridizing sensor types and analytical methods (Xiang et al., 2013). Administration and processing of these methodologies is, however, time consuming, requiring specialized domain expertise. The methods have therefore been relegated to research, or a minor subset of projects with strong institutional backing, and/or which are aspiring to voluntary performance criteria (USGBC, 2013, and ILFI,

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2019). But nowadays, with the proliferation of low-cost technology (such as metal oxide-based detectors), quantitative, structured IEQ sensing has developed, and mature hardware/software solutions are available to produce actionable data for both research and commercial applications, through open-source and commercialized channels (Kumar et al., 2016, Frei et al., 2020, and Parkinson et al., 2019).

Despite these recent advances, monitoring of impactful IEQ factors of a building remains a significant task, due to their variety in type and spatialization. Air speed is particularly quixotic, being multi-dimensional, highly variable, and integral to perceptions of environmental quality and thermal comfort, but complexly determinant of occupant satisfaction, (either increasing or decreasing, depending on other factors), and both highly localized, but coupled to (and therefore indicative of) overall thermal and ventilation processes. Air speed measurement (anemometry) is well-developed, and widely used in controlled-environment experimentation (such as Zhang et al. 2010). Anemometry is included in protocols developed with station-based sensor suites for post occupancy analyses (such as by Chiang et al., 2001, Kim and Haberl, 2012, Choi et al., 2011, Webster et al., 2013, and Karami et al. In 2018), and can be deployed usefully (Gatland et al., 2018). Miniaturized, distributable detectors have been conceived and developed as early as 2000 (by Kang and Park). However, air speed and velocity detection are not routinely included in spatialized multi-factor sensors designed for continuous monitoring (according to reviews by Dong at al. In 2019, and Saini et al., and Chojer et al., in 2020), despite the potential utility of the information they generate.

Continuous air speed monitoring has value for HVAC operation as well. While spot checking velocities is useful for verification of air-side systems operation, continuous monitoring can aid in optimizing the interaction of different systems in hybrid control scenarios. It's understood that increasing in-zone circulation and local air speed can be an energy-efficient strategy for offsetting discomfort from increased HVAC supply enthalpy, if the experienced air speed is in a reasonable range, and provided with sufficient efficiency (Schiavon and Melikov, 2008), such as with HVLS fans (Kiatreungwattana et al., 2016). To this end, work has recently gone into experimental characterization of re-circulating equipment (overhead fans) to aid in their design incorporation (Raftery et al., 2019).

Monitoring IEQ in spaces under hybrid environmental control strategies

Continuous monitoring becomes more important as environmental control strategies become more complex. Thermal comfort and ventilation requirements can be satisfied with air-side HVAC alone in spec commercial spaces with small and well-defined zones. But air-side environmental control is more complex in the larger, more complex volumes of warehouses, adaptive re-use, and open-plan architecture. Additional systems become useful, such as radiant slab and in-zone circulation. The performance of a complete strategy is then not defined by a simple additive relationship between enthalpy contributions or air changes from different components, but rather the interplay of systems, program, indoor-outdoor exchanges, and interior air flow and convection regimes. This interplay can be successfully represented in the design process through simulation tools. However, because operational states vary widely, and shift dynamically, continuous monitoring can help guide best-practices for operational strategies over time, particularly by comparing real-time conditions and trends to expected regimes developed through design tools.

Potential impacts for industry and research

The adaptive re-use, renovation, and modernization of different building typologies represents an increasing market share for the architecture, engineering, construction and operations (AECO) industry. Efforts are being made to reduce environmental impacts and meet net-zero carbon goals, while the pandemic has shone a harsh light on endemic questions and issues around indoor air quality. The potential conflicts between these drivers (such as greater ventilation vs better efficiency) make progress in this field crucial. Combining spatialized measurements of factors (including air speed) with CFD simulations, to evaluate adaptive re-use spaces as-occupied, could help guide towards healthy, productive built environments, and optimize performance, providing detailed and digestible information on the unseen conditions that a building's occupants experience. And specifically, this workflow could provide a driver for dynamic control over and integration between systems, as static (or scheduled) operation may not be sufficient to match design requirements. To these ends, this research evaluates select thermal comfort and IEQ characteristics of a high-bay, adaptive re-use, open plan office space serviced by hybrid environmental controls, including HVLS overhead fans.

Methods

To gauge its utility for general trend observation, a wireless IEQ sensor network (WSN) was designed, constructed, and deployed. The WSN comprises proof-of-concept multi-factor sensor hardware (including point-in-space air speed detection), along with requisite communications, timeseries database, metadata and annotation logging, and a dashboard monitoring stack. Sensors were deployed at occupied locations in an open plan commercial (office/mixed use) building—an adaptive re-use of a historical factory, to generate thermal comfort and air quality data. Data was logged over five months, to capture multiple (seasonal) operation patterns.

In parallel to monitoring, CFD simulations were constructed and run for multiple heating and cooling scenarios, as well as different operating speeds for the installed HVLS fans to represent both as-sensed and possibly-revised operating conditions. Comparisons were then drawn between measured and modeled results, specifically for recommendations on fan optimization towards thermal comfort. Characteristic CO_2

concentrations were observed as well, as additional factors that might be influenced by fan operation, and are indicative of normalized occupancy and mean age of air.

Building and site context

During the industrial revolution, warehouses conquered the urban landscape. This building typology gradually changed, and almost dissolved, hidden behind the modern materials and advanced building technologies. However this type had embedded into its DNA great adaptability and versatility, and they are being retrofitted into modern commercial spaces. These buildings are usually rectangular in plan, built with heavy brick wall-sections and a double pitched roof. The simple, open plan interiors make re-adaptation simple, although existing equipment (such as gantry cranes) can complexify designs. Wide, high windows were typical, originally, necessary to light the vast space inside. All these features arose for functional reasons. The warehouses were often located in prominent locations near railways or rivers, to receive and ship goods. As the warehouse typology presents multiple added values to be retrofitted, it also presents unique challenges. To address the challenges of delivering climate control and comfort, as well as indoor air quality, hybrid mechanical systems design is strategic. In this warehouse, a full radiant layer was added as a topper to the existing slab (also raising the ground plane for flood control), forced air ventilation was supplied from the side walls, and HVLS fans were hung to provide in-zone air mixing and movement.

Multi-factor proof-of-concept sensor description

The sensors deployed within the warehouse incorporate multiple detectors, to stream measurements of: Temperature (T); Relative Humidity (RH); CO_2, total volatile organic compounds (TVOC), and particulate matter (PM) concentrations; sound levels, lighting levels, barometric pressure, and air speed (AS) (relevant details in Figure 1). The intention for the multiple parallel data types is for cross-correlating confounding factors that indicate conditions affecting the indoor environment. These sensor modules are operational proofs for a design that can be produced in volume, referenced against a calibrated standard, and distributed volumetrically, and/or with an occupancy-oriented approach, throughout a space. The sensor module design leverages current detector technologies and communication/network protocols to collect and log data reliably.

It was noted in the design phase that placement of detectors within the sensor body (for temperature) and at a limited standoff distance (for air speed) might bias their generated signals. These detectors were positioned on the chassis as possible to reduce these effects. Enclosure design iteration is ongoing to address this and other functionality. The sensor fleet as deployed demonstrated consistent results across individual instruments in common environments.

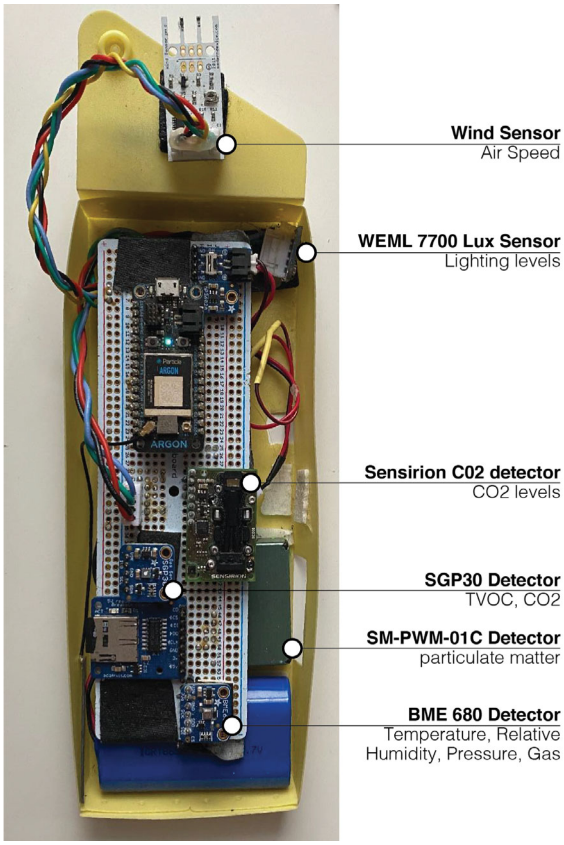

Figure 1. Multi-factor sensor, as deployed, with detectors for psychrometrics, air speed, CO_2, particulates, TVOCs.

Sensor calibration/self-referencing

Sensor calibration was performed to the end of trend analysis, rather than absolute real time measurements, in keeping with the goals of the experiment (comparison between real-world conditions and simplified CFD results). Air speed detectors (generating voltage signals) were calibrated prior to acquiring data. Two-point calibration was done for each individual detector. Coefficients in the voltage-speed relationship were adjusted to minimize reported error in (1) a no-wind reference environment (under a jar) and (2) the wash of a desktop fan, as measured by a recently calibrated hot-wire anemometer (TSM/Alnor model AVM440-A).

The balance of the detectors in the multi-factor sensors were not calibrated beyond factory settings, with the understanding that, for long-term deployment, drift could produce inaccuracies. To confirm their initial consistency with respect to each other, however, they were monitored in a common environment (a closed, insulated chamber with continuously mixed air from a small fan) for a period of three hours, during which no observations were made of unusual discrepancies.

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Setup of monitoring and sensors

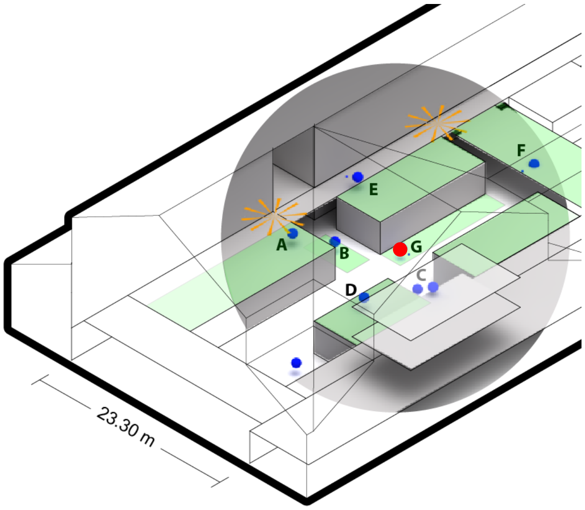

Figure 2. Sensor locations (lettered) and fan locations. Normally occupied areas in green. Sensor G (red) situated directly in down wash of HLVS fan.

The sensors' compact form allowed them to be placed throughout working areas on both ground (first) and mezzanine (second) floors. Since this study focuses on comfort conditions (rather than volumetric conditions), the sensors were deployed on desks and shared work tables, to report conditions where people spend a good deal of time, and, on the mezzanine, on the edge of the deck, to capture vertical airflow (Figure 2).

Data acquisition

Sensors generally published at 1/min intervals. Data is stored at the resolution it's ingested, but for the analyses in this study, a common timescale of 5-minute intervals was determined, and each signal timeseries was binned and averaged into the 5-minute increments.

The air speed detector produces a voltage signal, rather than the processed digital signal representing physical units, sent by most other detectors on-board. For one data point, voltage was determined as the mean of 32 samples taken through the MCU's ADC at 3ms intervals.

Sensor data and metadata was recorded to a cloud-hosted time series database through layers of ingestion script.

A logging system was developed to annotate relevant events (such as observations from the monitored space, calibration procedures, and placement/movement of sensors). Logged events are automatically parsed and back-filled with spatial coordinates and human-readable position tags to support analysis of the generated data set.

Fan speed was notably constant throughout the day, week, and season, at 21 rpm. According to product data, this correlates to rated airflow of 23000 L/s (48000 cfm).

Computational fluid dynamics setup

The Integrated Environmental Solutions Virtual Environment (IES-VE 2018) software was used to model and simulate energy use and airflow within the adaptively reused building. The MicroFlo application within IES-VE was used to generate and run CFD simulations based on boundary conditions from the IES-VE energy model. The CFD simulation was 3-dimensional, steady state, and used a k-epsilon turbulence model, program-calculated surface heat transfer, orthogonal only mesh grid, and upwind discretisation.

Certain bounds on the model's complexity were determined to be important, so that MicroFlo could be effectively used. A cropped version of the full-size building model geometry was generated, due to computational cost and limitations of the package. A model is limited to 3 million mesh cells (for a quad core computer), which would result in many cells of several meters in characteristic length in important locations – too coarse. Increasing cell dimensions reduced the number of cells in the mesh below the 3 million threshold but created a mesh with several high aspect ratio cells, which hindered the convergence of a solution. The included mesher is simple; adjusting cell shapes is possible, but not systematically. Therefore, a section of the building was selected that included an HVLS fan and several sensor locations, but no end-walls, to reduce local impacts from door openings. The resulting virtual surfaces were defined as adiabatic, with no mass flow.

The dimensions of the studied area were 30 m (99 feet) long, 26 m (84 feet) wide, and 22 m (72 feet) tall. The simulation was set up and run with a grid space of 22.9 cm (9 inches) and grid line merge tolerance of 7.6 cm (3 inches), resulting in 1.3 million cells and a maximum aspect ratio of 13:1. The fidelity of the mesh and results could be improved for future simulations by reducing the dimensions of the modeled building geometry and grid space, but with the large volume of the building, the adiabatic surface definitions increase the inaccuracies inherent in the simulation.

Corresponding to sensor locations in the monitored space, display cells were chosen that report velocity (as x, y, and z components), temperature, turbulent kinetic energy and rate of dissipation, and local mass flow.

Boundary conditions were imported to the CFD model from specific timesteps in the building energy simulation. The HVLS fan, supply diffusers, radiant floor, and returns were modeled after their real-world counterparts that manipulate air flow and enthalpy (Table 1).

Table 1: CFD model inputs and components.

Component	Properties
HVLS overhead fan (Big Ass Fan PFX2.0-20')	Area 29.6 m^2 Three fan speeds studied: 0 L/s; 23000 L/s; 34000 L/s
Diffusers	6 Supply Diffusers; each at 1200 L/s; T, air setpoint: 24°C (Warm); 21°C (Cool); 21°C (Cold) T, air supply: 13°C (Warm); 32°C (Cool); 32°C (Cold)
Extract grill	7200 L/s exhaust
Radiant floor	Off during Warm; 24°C during Cool; 24°C during Cold

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Airflow patterns and space conditions were simulated in three characteristic weather conditions and at three fan speeds. The modeled weather conditions were: warm and sunny; cool and overcast; and cold and overcast. The three HVLS fan rates were 0 L/s (off), 23000 L/s (48000 cfm) as observed, and 34000 L/s (72000 cfm) for 50% increased airflow. The varied thermal conditions and fan speeds were completed to study if improvements could be made to the existing comfort conditions of the space.

Results and Discussion

Preliminary conclusions are drawn on the efficacy of the integrated air flow and thermal comfort management strategies, comparing logged data to simulations.

Monitoring insights

During warm weather (cooling conditions) it was observed that, during repeated stretches of occupied hours, elevated temperatures at several occupied locations resulted in calculated PMV above 0.5, while air speed at these locations was negligible. This was true despite the location of some of these positions directly in the downwash of overhead fans (Figure 3).

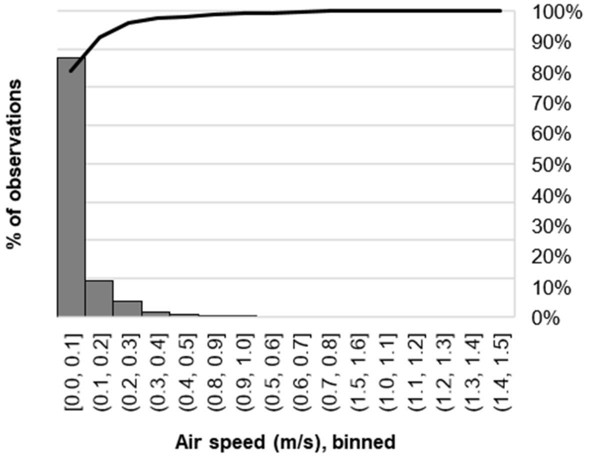

Figure 3. Histogram of recorded air speeds at sensor G (directly in HVLS fan downwash) during warm-weather operation show typically negligible flow.

Moments were rare when increased air flow would benefit some positions but reduce comfort in others. Inasmuch, if increased fan rates could increase local air speeds without overmatching the reduction with increased temperature, improvements could be generally made to comfort levels. A sensitivity analysis in CFD of a range of HVLS fan speeds confirmed headroom was available for much higher airflow from fans, and air speeds at sensor positions, without significant disruption.

It was also determined from linear regressions of PMV vs air speed data that slightly higher air speeds corresponded to moments of thermal neutrality in the warm-weather conditions than in cold conditions (Figure 4).

Given the encouraging results achieved with relatively coarse data (measured and simulated), integrating this sensors and simulation workflow is anticipated to contribute towards a developing holistic understanding of the built environment, and ubiquitous application in low-cost building management strategies, through the integration into visualization methodologies.

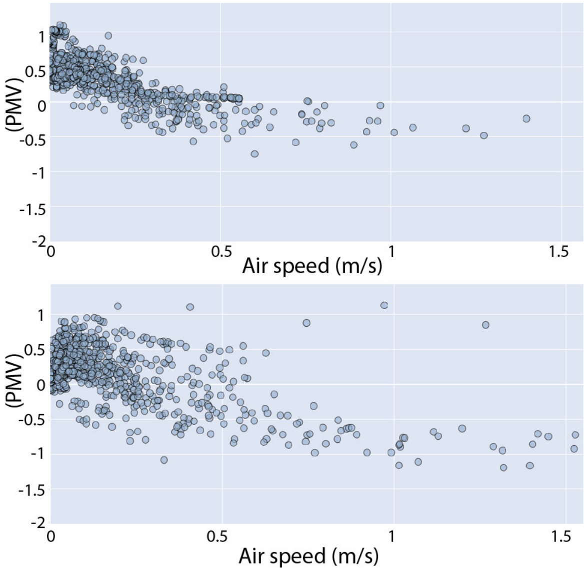

Figure 4. Calculated PMV vs observed air speeds, in warm-weather conditions (top) and cold (bottom), indicate neutral PMV most likely with air speed in 0.2 – 0.4 m/s or 0.1 – 0.2 m/s range, respectively.

Accumulation of CO_2

It was observed that across all monitored positions on the ground plane that CO_2 levels climbed through the day, typically reaching above 600 by 2pm in the afternoon, and often reaching 800ppm and above (Figure 5).

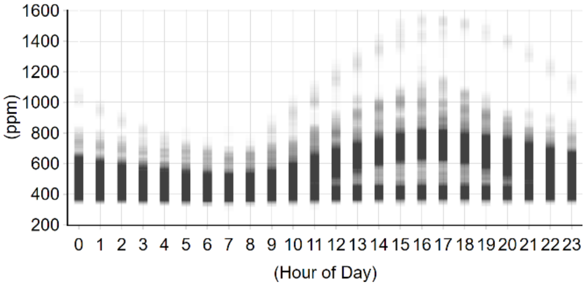

Figure 5. CO_2 concentrations typically increased during working hours. (Afternoon measurements around 400ppm were typical of weekends.)

Higher concentrations were noted that corresponded to all-weekend hackathons in the space, and although the mezzanine positions at times echoed the day-over build up, that was less common, and levels typically bottomed out below 500ppm overnight.

Although not strictly harmful at levels measured, it's been demonstrated that CO_2 levels beyond 500ppm correspond with decreasing cognitive capacities (Allen et al., 2016), which is relevant in a knowledge-industry workspace. And in light of the on-going threat of SARS-CoV-2 and other airborne pathogens, the proxy relationship between CO_2 and mean age of air suggests that minimizing CO_2 has public health benefits. Given the volume of the building, it's possible that pulsing HVLS fans could be a strategy to dilute CO_2 during work hours, allowing ventilation over-night to pull concentrations throughout down towards the baseline (currently around 400ppm).

CFD simulation results

The CFD simulations all ran for roughly 7000 iterations, to a termination residual of $\sim 1e^{-4}$. Lower residuals were not achievable, perhaps due to dynamics between the supply/return ducts and HVLS fan: In winter simulations, as the solver iterates, warm supply air oscillates between mainly-rising, to be pulled through the fan, and entrainment in the fan downwash. Given that our boundary conditions represent one of a wide range of possibilities, the oscillation suggests the possibility of both modes of airflow. At the higher HVLS fan airflow rate of 34000 L/s (72000 CFM) the entrainment behavior generally disappeared, and the supply air was pulled more completely through the HVLS fan, before arriving at the occupied zone, reducing its effect on the local condition. Additional analysis might shed light on the drivers of these different modes, and offer operational guidance, as the relationship between HVLS fan rate and effectiveness of supply appears nonlinear.

After matching simulated fan rate to observed speeds, the air speeds measured at sensor locations were compared to corresponding display cells in the simulation. During a cold/overcast condition (November 12th), simulated air speed directly below the fan (at desk height on the ground floor) was 0.04 m/s (8.33 fpm). The measured speed at that point (averaged over all points from 8am through 8pm) was 0.08 m/s (11.63 fpm). Both values are below the upper air speed limit of 0.20 m/s (40 fpm) from the PMV model recommendation of ASHRAE 55.

During the Cool/Overcast and Cold/Overcast times of the year, the simulated use of the HVLS fan at 23000 L/s (48000 cfm) increased air temperatures (and thermal comfort) in occupied spaces by drawing down air that was otherwise thermally stratified. Simulation results during the Cold/Overcast period (Figure 6) showed, with HVLS fans, warm supply air flowed upward despite the downward angle of the diffusers. The HVLS fans circulated that warmth down to the occupied ground plane, improving PPD at that point from 8.3% to 5.4%. A reference simulation was run with same boundary conditions and fan speed, but without the radiant floor, resulting in PPD = 22.6%, indicating the floor contributes warmth (increasing comfort).

The use of a HVLS fan during heating-degree operation runs contrary to conventions of overhead fan usage. But here this operation provided observable benefits (at least within a specific rate range), which could have utility in industrial-space type applications and other building typologies with large-volume spaces.

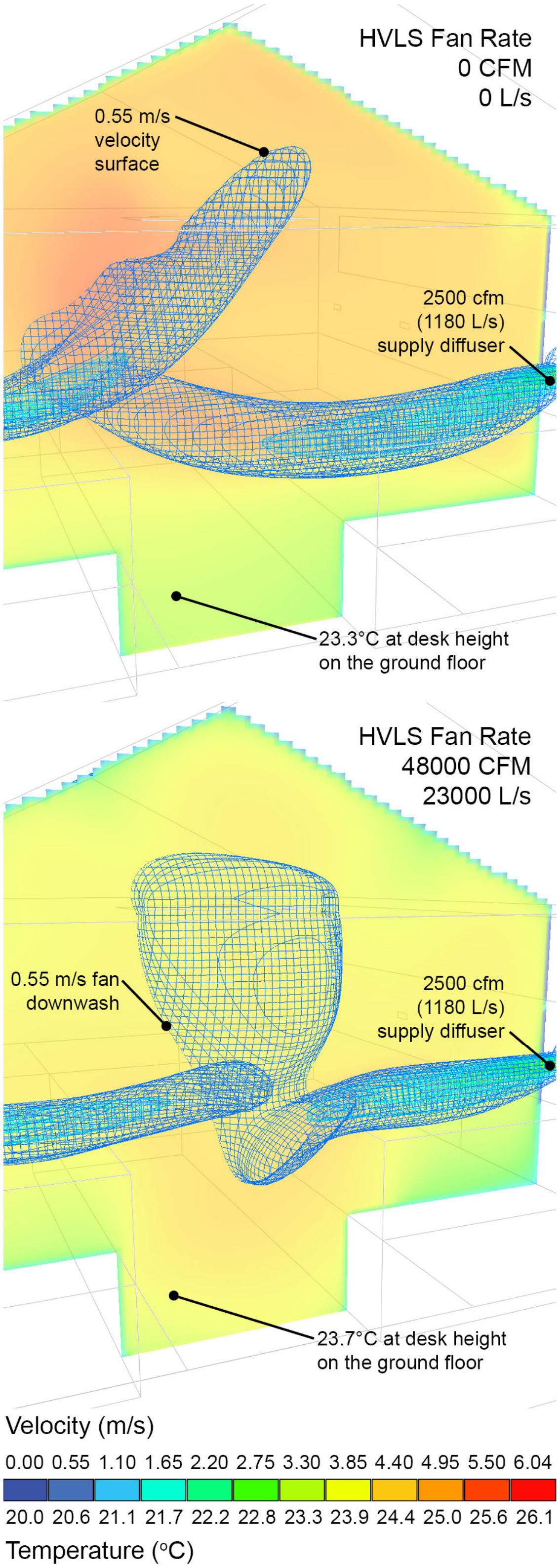

Figure 6. Comparison of CFD results for air velocity surface and temperature filled contours during the Cold/Overcast period for HVLS fan air flow rate at 0 and 23000 L/s (48,000 cfm). Air speeds arrows below 0.15 m/s (0.5 ft/s) not displayed.

Additional simulations were run with HVLS air flow rate increased by 50% to 34000L/s, to study if increased air movement could improve thermal and occupant comfort conditions. Increasing the fan rate resulted in significantly more mixing of warm air throughout the space, but observed air speeds at occupied zones became too fast. Warm air from supply diffusers was drawn upwards by the HVLS fan. Temperatures throughout the four-story volume became more evenly distributed, with little thermal stratification. However, the air speed in occupied locations exceeded 0.15 m/s (29.5 fpm), which is unfavorable in heating-degree times due to draughty conditions and occupant discomfort.

During the warm/sunny period, when lower temperatures are favorable, thermal stratification was observed in the CFD simulation to reduce the temperature at the occupied zone when the HVLS fans were off. With the fans off and an air flow rate of 23000 L/s (48000 cfm), warm air from the ceiling was mixed into the occupied zones increasing the temperature there by 0.44ºC (0.8ºF). However the PMV decreased 0.22 because air speeds increased to 0.25 m/s (50 fpm) – a 53% increase. according to the ASHRAE 55 figure for air speed required to offset increased dry bulb and radiant temperature, a 0.25 m/s (50 fpm) rise in air speed allows a temperature rise of 0.56ºC (1.0ºF), which these results fit within.

Practical applications, limitations of CFD workflow

The chosen software's CFD capabilities were sufficient to generate internal air flow and thermal studies at a steady state that appeared rational (if slightly ambiguous, due to oscillation) and with relative ease, once boundary conditions were generated from the energy model. The benefits of this integration to practice are in time savings and error reduction. The CFD contributed to the work done here (corroborating time-averaged monitoring data), but functional limitations of the software suggested that, for more sophisticated work (such as developing a library of states for dynamic HVLS control) the workflow would benefit from coupling with external processes, which, as part of a self-contained analysis environment, the package could not do. (The software suite has its own applications for operational simulation-measurement calibration, but these were not explored in our work.)

Several specific limitations of the CFD application were encountered that affected this exploration. As the application does not support transient CFD, it was not possible to model the build-up of CO_2 and moisture at people sources over time. (CO_2 and moisture sources were applied to the model but quickly dissipated into the surrounding space, which acted as a reservoir.) The mesh generator was rudimentary, capable only of making cubic cells using an orthogonal grid. The mesh generator did not have automated methods for addressing generated cells with too-high aspect ratios, relying instead on smaller grid dimensions and manually created grid regions to correct the mesh. The mesh region could be added to or manually altered using a power law generation, but this process was found to be too time intensive on a large study region. Another limitation found was operational, in that mesh results could not be exported for analysis, and were only accessible with the built-in viewer.

Recommending operational changes

Due to the limitations of the CFD workflow, it was not feasible to iterate airflow simulations for all representative measured circumstances, toward dynamic simulation coupled to the energy model. But since CFD confirmed a range of possible air speeds beyond what was measured, sensitivity of simulated comfort metrics was evaluated, by regressing measured temperature and humidity data, against a range of air speeds (Figure 7).

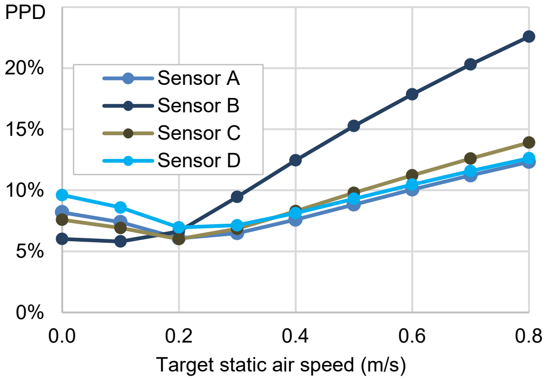

Figure 7. Parametric simulation of PPD against a range of air speeds suggests a target of 0.2m/s for comfort in widest range of circumstances.

There is an optimum in the combined data at 0.2m/s, echoing the similar result from sensors (Figure 4) and reinforcing the utility of higher fan speed and airflow. (It should be noted that the calculation for PPD with elevated air speed has a transition at 0.2m/s, below which the standard calculation is used.) But the non-linear relationship between air speed and comfort indicated by the CFD suggests that more sophisticated airflow analysis (and feedback with monitoring systems) would be warranted for optimization of comfort, as well as other parameters such as energy use and mean age of air.

Conclusions and future work

An easy-to-deploy simulation and sensing workflow for checking and recommending thermal comfort and IEQ in real-world conditions using standard industry tools and low-cost sensors was explored, in the context of an occupied commercial office/mixed work building, an adaptive reuse of a historic factory. Spatialized air speed and IEQ data was collected over several months, and CFD simulations of the space were performed using a lightweight package incorporated into commercial energy modeling software, to test if thermal comfort could be expected to improve with modifications to operation of existing HVLS fans (which were observed to operate at a constant speed in both heating- and cooling-degree operation). It was observed that in the warm season, calculated PMV were periodically higher than design conditions dictate, while CFD of a similar scenario indicated fans could supply additional air speed to occupants without losing entrainment of the chilled supply air. In cooler seasons, comfort was more often within design parameters, suggesting a mechanism for dynamic response of the fan rate to building conditions could increase comfort in certain conditions, without impacting already-moderated conditions. Further to this effort, research into semantically contextualized feedbacks between thermal perception, enhanced monitoring, and building controls could be fruitful for understanding the local exposures of individual (and mass) occupation, as the indoor environment continues to be a major, yet poorly understood, determinant of both health outcomes and sustainability metrics.

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