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# Office Desks as Diffuser of Ceiling Fan Airflow and Collective Comfort

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***Abstract*—Ceiling fans are low-energy cooling solutions that can reduce cooling energy demand by 36% compared to full mechanical setups. However, their ability to provide collective comfort in furnished offices remains underexplored. This study investigates whether office desks act as diffusers of fan-induced airflow to improve comfort for multiple occupants. Using a mixed-methods approach, multiple desk layouts were analyzed via CFD (Computational Fluid Dynamics) simulations, followed by full-scale experimental study including air speed measurement and human-subject experiments conducted in a real office at TU Delft. A smart control system with 9 speed levels was developed using the open-source Home Assistant platform to enable flexible operation. Results show that desks redirect downward airflow horizontally, acting as passive diffusers that increased average air speeds at seated torso level (0.85m) by over 196% compared to empty spaces. While increased movement reduced thermal sensation, comfort did not improve linearly, likely due to localized drafts and individual sensitivities. At 28°C and 42.9% RH, participants preferred a seat-average air speed of 0.49 m/s. With group control, preferred speeds varied (0.49–0.78 m/s), highlighting the necessity for flexible systems in shared settings.**

***Index Terms*—air movement, ceiling fan, collective thermal comfort, office layout**

## I. INTRODUCTION

Rising global temperatures and increasingly airtight building envelopes have increased the risk of indoor overheating in both existing and newly constructed buildings. Energy renovations of buildings in moderate climates have also been shown to increase overheating risk due to improved insulation [1]. Conventional air-conditioning systems can effectively maintain thermal comfort but often require substantial energy consumption and contribute to peak electricity demand. As a result, low-energy cooling strategies that rely on air movement are receiving renewed attention. Increasing air speed using fans has been shown to improve thermal comfort in warm indoor environments while requiring significantly less energy than mechanical cooling [2] [3]. Experimental studies demonstrate that desk fans and ceiling fans can maintain acceptable comfort conditions at air temperatures around 28 °C during sedentary office activities when occupants wear typical summer clothing [4] [5] [6] [7]. In addition, air movement provided by fans can still alleviate thermal discomfort during extreme heat events, highlighting their potential as a heat-resilient cooling strategy [8].

The airflow generated by ceiling fans is strongly influenced by the spatial configuration of the room and the presence of furniture within the occupied zone. In office environments, workstations, desks, and partitions can interact with the downward jet produced by a ceiling fan and modify the resulting air speed distribution around occupants. Experimental studies have shown that workstation furniture can redirect the downward airflow from a ceiling fan into lateral directions, increasing air speed at seated height and producing a broader airflow distribution within the occupied zone [9]. At the same time, field measurements in real office environments suggest that dense furniture arrangements may reduce air movement by obstructing airflow paths [10]. Ref [11] also found that in commercial spaces, the measured air speed is generally low even with ceiling fans operating. These contrasting findings indicate that the interaction between ceiling-fan airflow and office furniture remains insufficiently understood. A better understanding of how workstation layouts influence airflow distribution is therefore important for designing indoor environments that effectively utilize ceiling fans as a low-energy cooling strategy.

Another limitation of existing research is that many studies focus on individual thermal comfort, often examining personal fans or single-occupant conditions [4] [5] [6] [7]. In practice, however, ceiling fans in office environments typically serve groups of occupants. Designing spaces that provide acceptable thermal conditions for multiple occupants therefore requires a better understanding of collective thermal comfort and the spatial redistribution of airflow within shared workspaces. Field studies have shown that shared control can play an important role in achieving acceptable conditions for groups of occupants. For example, Ref [12] reported that thermal acceptability in an office environment increased significantly when the air-conditioning setpoint was raised from 23 °C to 26 °C while occupants shared control over ceiling fans. However, this study focused on enabling higher air-conditioning setpoints rather than investigating how airflow distribution influences comfort. In addition, the interaction between ceiling-fan airflow and workstation layouts was not addressed. Consequently, the potential for ceiling fans, used as the primary cooling strategy without air-conditioning, to provide collective thermal comfort through airflow redistribution around office furniture remains largely unexplored.

This study investigates *"to what extent office desks can redistribute ceiling fan airflow and contribute to collective thermal comfort for multiple occupants?"* The research combines airflow analysis and thermal comfort evaluation in a controlled office-like environment. The objective is to examine how desk layouts influence the diffusion of ceiling-fan airflow and whether the redistribution can expand the effective comfort zone within the occupied area.

## II. METHODS

A multi-loop validation framework is developed, combining CFD (Computational Fluid Dynamics) simulations, lab-based air speed measurements, and human experiments to assess airflow distribution and perceived comfort across multiple desk configurations and fan speeds.

### A. *Test facilities*

The experiments were conducted in a meeting room located in the Office Lab at The Green Village, TU Delft (Figure 1). The room dimensions are 5.1 m × 3.25 m × 2.6 m (L × W × H). The space is not equipped with a dedicated climate control system, and its HVAC is connected to the entire office building. Therefore, room temperature during experiments was maintained using an 1800 W electric heater (Threesixty, Duux). Because the room was designed as a regular office space rather than a climate chamber, small fluctuations in temperature and relative humidity occurred during measurements.

The ceiling configuration is irregular and may influence airflow patterns. The ceiling consists of perforated panels that allow air passage, with exposed installations such as ducts, electrical pipes, and sensors located above the panels. These elements introduce additional geometric complexity compared to the simplified CFD model.

A Sulion Balcony M ceiling fan (diameter 1.07 m) was installed in the room. Due to existing installations, the fan was mounted eccentrically, with offsets of 0.12 m along the short axis and 0.35 m along the long axis of the room. The fan blades were positioned 2.3 m above the floor and 0.3 m below the ceiling panels. A customized nine-speed control system was implemented using Home Assistant to provide finer control over fan rotation speed during the experiments.

Four desks (1.25 m × 0.76 m × 0.72 m) were arranged in a 2 × 2 configuration forming a combined surface area of 2.50 m × 1.52 m. The centroid of the desk arrangement was aligned with the fan center.

### B. *Measurement instruments*

Environmental parameters were recorded using a Testo 400 indoor air quality (IAQ) set. Air speed was measured using a hot-wire turbulence probe, with measuring range of 0-5 m/s, an accuracy of ±(0.03 m/s + 4% of measured value), and a resolution of 0.01 m/s. Lab environment was monitored with a CO2 probe (for CO2 concentration, humidity and air temperature) and a globe probe (for globe temperature). Fan power consumption was monitored using a Shelly smart plug.

Figure 1. The test facility used for air speed measurement and human experiment, a realistic office meeting room in The Green Village, TU Delft. The TESTO 400 thermal comfort kit is placed next to the desks to monitor room condition

### C. *CFD simulation*

Computational Fluid Dynamics (CFD) simulations were conducted using Butterfly, a Grasshopper plugin based on OpenFOAM. The simulation domain was designed to reflect a simplified representation of the laboratory's room geometry. The aim of the simulation is to have an initial understanding of airflow pattern at room-level, and to help to select the desk configuration for further lab measurement.

To reduce computational complexity, the rotating fan blades were replaced by a simplified circular inlet surface representing the fan blade area. The inlet velocity was defined using the concept of Fan Air Speed (FAS) introduce in [13], calculated from the manufacturer-reported airflow rate divided by the fan blade area as in (1).

$$FAS = \frac{\text{Fan Airflow } (\text{m}^3/\text{h})}{\text{Blade Area } (\text{m}^2) * 3600} \tag{1}$$

Air speed was sampled using a grid of probe points distributed across the room. The primary evaluation height was 0.85 m above the floor, corresponding to seated chest level. Several desk layout configurations were simulated to investigate how furniture placement influences airflow distribution around seating locations.

### D. *Air speed measurement*

Air speed measurements were conducted to validate CFD simulation results and examine airflow diffusion around the desks. Measurements were performed using a grid with 30 cm spacing aligned with the probe locations used in the CFD simulations (Figure 2). Due to time constraints and the use of a single anemometer, measurements were primarily conducted at 0.85 m height, representing the torso level of seated occupants.

### E. *Human Subject Experiment*

A controlled experiment with 24 participants was conducted to evaluate perceived thermal comfort under different airflow conditions. Participants were exposed to an indoor environment maintained at approximately 28°C with typical summer clothing (0.57 clo) and sedentary activity level (1.1 met).

Each test session lasted approximately two hours and consisted of five airflow conditions presented in

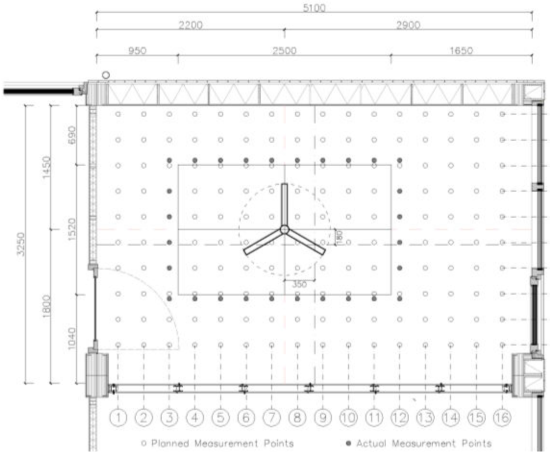

Figure 2. The lab configuration of ceiling fan and desks. The grey dots are the layout of measurement point.

randomized order: still air (fan off), three pre-defined fan speeds, and one group-selected fan speed. Participants completed questionnaires evaluating thermal sensation, thermal comfort, air movement perception, and overall acceptability during each session.

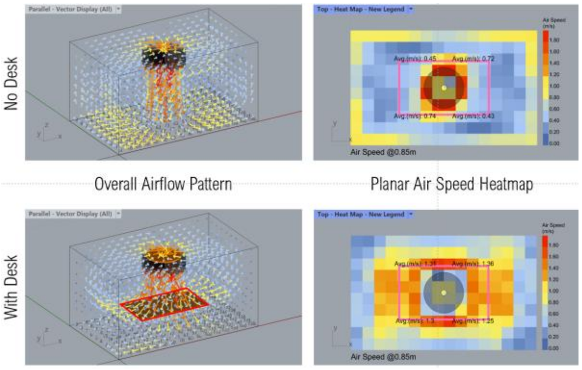

Figure 3. The visualization of CFD results from Case_0 (no desk) and Case_1A (with desks) by Rhino / grasshopper. The downward fan jet is redirected by the desk surface and increases the air speed at torso-level.

## III. DATA PRESENTATION AND DISCUSSION

### A. *CFD Results: Airflow Distribution*

The CFD simulations provide initial insights into the airflow distribution induced by the ceiling fan under different desk configurations. In the reference case (Case_0) without desks, a concentrated downward jet is observed directly beneath the fan. After impinging on the floor, the airflow spreads radially at low height, forming a horizontal outflow layer.

When desks are introduced beneath the fan (Case_1A, a 2×2 desk layout placed beneath the center of fan), the airflow pattern changes significantly (Figure 3). The downward jet is intercepted by the desk surface and redirected laterally at approximately desk height (0.85 m). This results in a redistribution of airflow from floor level to the occupied zone, particularly around seated torso level.

The airflow becomes more distributed spatially, with reduced concentration directly under the fan and enhanced coverage across seating locations. These results suggest that desks can act as passive diffusers, modifying both the direction and distribution of airflow.

### B. *Measurement Results: Air Speed Distribution*

Measurements were conducted to quantify the air speed distribution around the desk configuration (Case_1A) across multiple fan speeds (Figure 4). At 0.85 m height, the results show clear spatial patterns, with peak air speeds occurring at the midpoints of the long edges of the desk. Air speed decreases progressively toward the corners and outer regions.

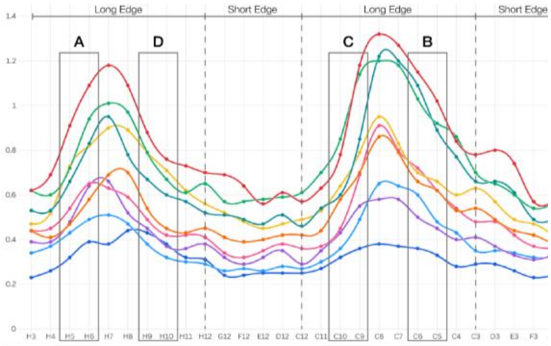

Figure 4. Measured air speed of Case_1A around desk surface at all 9 fan speeds. The peak can be found clearly close to the center point of long edges, while the air speed at short edges

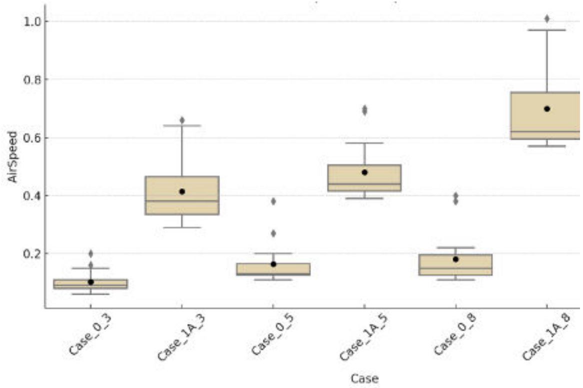

Figure 5. The comparison of measured air speed between Case_0 and Case_1A. A significant increase of air speed at 0.85m height can be observed when desks are introduced.

A comparison between configurations with and without desks indicates a substantial increase of approximately 200% in air speed at 0.85 m height due to the presence of desks (Figure 5). This confirms the strong effect of desks in enhancing airflow within the occupied zone.

A sectional measurement was conducted at 0.1m, 0.6m, 1.1m (ISO 7730 / ASHRAE 55 standard measurement height) and 0.85m (above desk surface, with equal distance to 0.6m and 1.1m). The sectional profiles indicate that air speed is highest near the desk level compared to other heights (Figure 6). At 1.1 m, peak velocities occur directly beneath the fan but decay rapidly with increasing distance from the fan center. In contrast, at 0.85 m, relatively elevated air speeds are maintained at seating locations, indicating effective redistribution of airflow within the occupied zone.

These results demonstrate that the desk configuration promotes a stable and repeatable airflow pattern, characterized by localized peaks near desk edges and sustained air movement at occupant level. Air speed measurements were conducted in the lab using the same desk configuration as the simulated case. Measurements focused on the seated torso height of 0.85 m, which corresponds to the level where occupants most strongly perceive airflow.

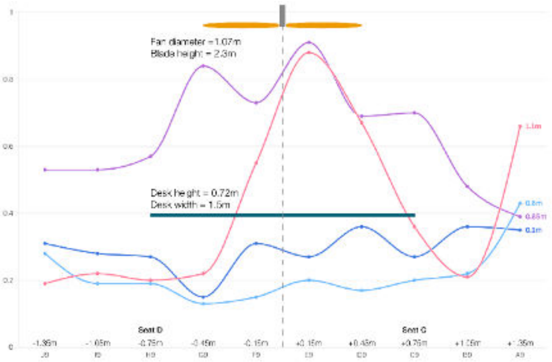

Figure 6. One sectional measurement revealed the elevated air speed of diffused airflow 0.85m height.

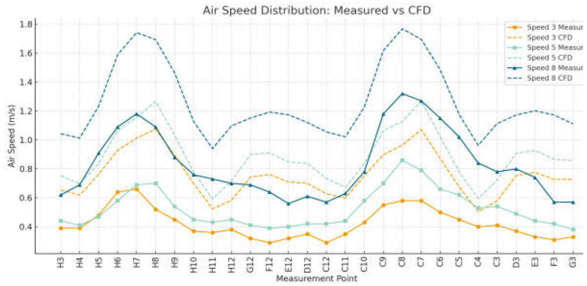

Figure 7. The comparison of CFD-predicted pattern (dashed lines) versus measured pattern (solid line) for 3 different fan speeds. The pattern of primary speed peaks is well predicted while the secondary peaks are not observed from the measured results. Overall, the magnitudes of air speed is over-predicted.

### C. *Comparison Between CFD and Measurements*

Although the absolute air speeds predicted by CFD were generally higher than the measured values, the simulation seems to capture the overall airflow distribution pattern (Figure 7).

The overprediction of air speed magnitude can likely be attributed to several factors. First, the CFD model simplified the ceiling geometry and neglected small-scale features such as perforated panels, ducts, and sensors that were present in the actual room. Second, the rotating fan blades were represented using a simplified inlet boundary condition rather than a fully resolved rotating fan model. Finally, turbulence modeling assumptions may also contribute to deviations in predicted air velocity.

Despite these limitations, the CFD model proved effective in predicting the spatial distribution of airflow and identifying areas of increased air movement around the desks. This confirms that CFD can serve as a useful design tool for evaluating airflow redistribution in ceiling-fan-assisted environments.

### D. *Impact of Air Speed on Thermal Perception*

The increase in air speed resulted in a clear shift in thermal sensation votes (TSV), from slightly warm conditions toward neutral (Figure 8). In parallel, thermal acceptability (TA) improved (Figure 9), indicating that a larger proportion of participants found the environment acceptable under elevated air movement. However, the thermal comfort vote (TCV) did not show a comparable level of improvement (Figure 10).

Two factors may explain this discrepancy. First, approximately 50% of participants reported a preference or higher tolerance for warmer conditions in the pre-experiment questionnaire. Consistently, even without air movement at 28°C, thermal acceptability was already high (87%), suggesting that the baseline condition was not perceived as strongly uncomfortable. This might reduce the potential for further improvement in comfort through increased air speed. Second, as air speed increased, reports of local draft discomfort also rose substantially, from 17% at fan speed 3 to 46% at fan speed 8. While higher air speeds contributed to cooler thermal sensation, the increasing perception of draft may have offset the potential comfort benefits.

The highest thermal acceptability was observed at fan speed 3, corresponding to a seat-average air speed of approximately 0.49 m/s. Under this condition, 87% of participants reported acceptable thermal conditions while maintaining relatively low levels of draft discomfort. Notably, the total power consumption of the ceiling fan at this setting was only 7.2 W, equivalent to approximately 1.8 W per person. This demonstrates that a modest increase in air speed can achieve high thermal acceptability with minimal energy use.

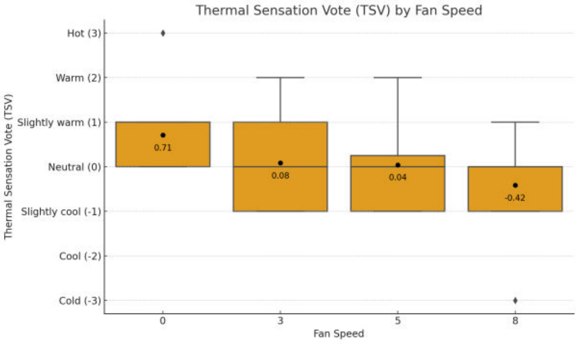

Figure 8. TSV decreased as fan speed increased, shifting from slightly warm sensation towards neutral.

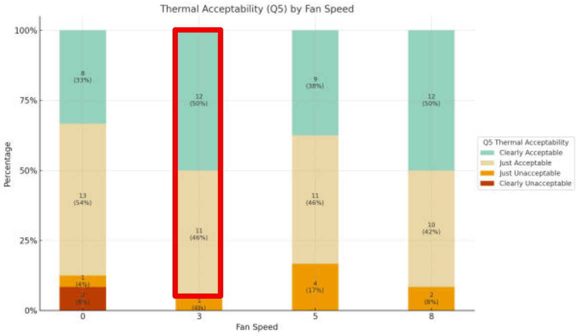

Figure 9. TA reached 96% at fan speed 3, with seat-average air speed of 0.49m/s. The power consumption of the ceiling fan is only 7.2W.

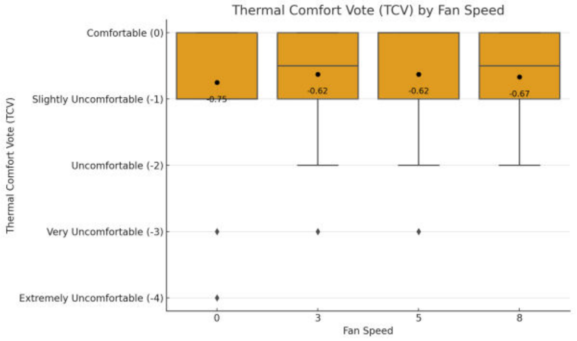

Figure 10. The improvement of TCV is limited as fan speed increased.

### E. *PMV Prediction Versus Actual Thermal Sensation*

To evaluate the predictive performance of thermal comfort models under elevated air movement, predicted mean vote (PMV) values were calculated using the measured environmental parameters and compared with the thermal sensation votes reported by participants (Figure 11).

Across the tested conditions, PMV values consistently predicted warmer thermal sensations than those reported by participants. In most cases, PMV indicated slightly warm conditions while participants reported sensations closer to neutral.

This discrepancy became more pronounced as air speed increased. At higher fan speeds, PMV predictions deviated further from measured TSV values, suggesting that the model underestimates the cooling effect of elevated air movement in warm environments.

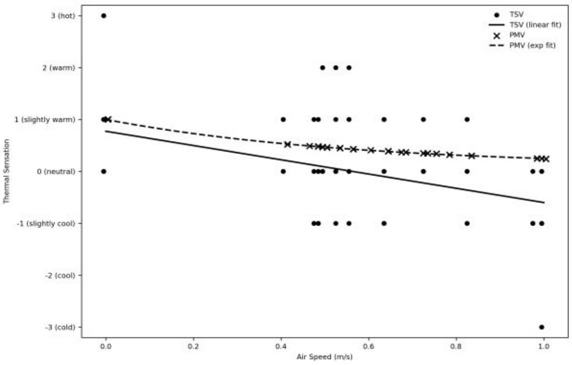

Figure 11. PMV prediction (cross) versus TSV (dot).

These findings are consistent with previous research showing that PMV may not fully capture the physiological and psychological cooling effects associated with air movement. The results therefore highlight the importance of considering dynamic air movement in thermal comfort assessment, particularly in fan-assisted environments.

### F. *Diffusion Power and Prediction of Seat Air Speed*

To quantify how effectively airflow generated by the ceiling fan is redistributed to the occupied zone, a dimensionless parameter termed Diffusion Power (DP) was introduced. Diffusion Power is defined as the ratio between measured seat-level air speed and the theoretical fan air speed derived from the fan airflow rate.

$$DP = \frac{Measured\ Air\ Speed\ (AS)}{Fan\ Air\ Speed\ (FAS)} \times 100\% \qquad (2)$$

The fan air speed (FAS) is calculated as the airflow rate divided by the fan blade area. Diffusion Power therefore represents the proportion of fan-generated airflow that effectively reaches the occupied zone.

Analysis of the measurement data shows that, on average, approximately one-third of the fan air speed remains effective at seat level. The average Diffusion Power was approximately 38% when considering only seating locations and approximately 33% when averaged across all measurement points (Figure 12).

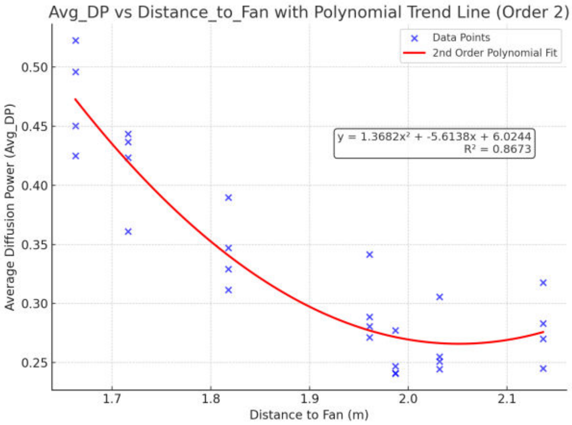

Figure 13. Diffusion power showed a quadratic relationship with the distance to fan center.

Further analysis indicates that Diffusion Power varies systematically with the distance from the fan center. By normalizing the data with respect to radial distance, a quadratic relationship between diffusion power and distance was identified (Figure 13).

This relationship enables the estimation of seat-level air speed using two easily available parameters: the fan air speed derived from manufacturer specifications and the distance between the seating position and the fan center. Such a simplified prediction approach could assist designers in identifying zones of higher and lower air movement during early-stage design.

Although the current model is based on a single fan–desk configuration, it provides a promising basis for further research on predicting airflow distribution in ceiling-fan-assisted indoor environments.

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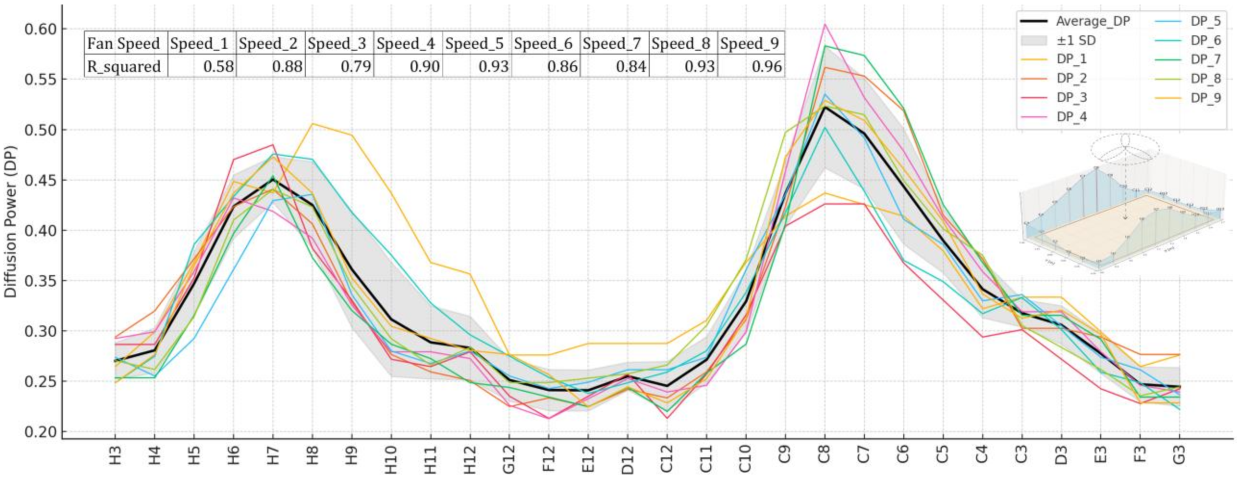
| Fan Speed | Speed_1 | Speed_2 | Speed_3 | Speed_4 | Speed_5 | Speed_6 | Speed_7 | Speed_8 | Speed_9 |
|---|---|---|---|---|---|---|---|---|---|
| R_squared | 0.58 | 0.88 | 0.79 | 0.90 | 0.93 | 0.86 | 0.84 | 0.93 | 0.96 |

Figure 12. The Diffusion Power (DP) per fan speed and overall average (black line). The seat-average DP maintained approximately 38% while overall average is 33%. The illustration on the right visualizes the diffusion power at different locations around the desk surface.

### G. Limitaion and Future Work

This study is subject to several limitations. Air speed measurements were conducted without occupants present, and therefore may differ from the actual airflow conditions during the human experiments, where the presence of the human body could influence airflow distribution. In addition, measurements were performed sequentially with only 1 anemometer, restricting the spatial and temporal resolution. A larger number of sensors would enable simultaneous measurements at multiple locations and heights, providing a more comprehensive understanding of the three-dimensional airflow pattern.

The experimental results are based on a single desk configuration and one ceiling fan, limiting the generalizability of the findings. Future work should expand the study to include multiple desk layouts and configurations, as well as scenarios with multiple fans, to investigate airflow interactions in more realistic office environments. Scaling up both the measurement setup and the human subject experiments would allow for a more robust evaluation of airflow distribution and collective thermal comfort. In addition, further refinement and calibration of the CFD model would improve its ability to predict air speed more accurately.

## IV. CONCLUSION

This study investigated the role of office desks in redistributing ceiling fan airflow and their potential to support collective thermal comfort. The results demonstrate that desks significantly modify the airflow pattern by redirecting the downward jet to the occupied zone, increasing air speed at 0.85 m height by approximately 200% compared to the case without desks. This redistribution enhances air movement at seating locations and supports more uniform airflow distribution.

The comparison between CFD simulations and in-situ measurements shows that simplified CFD models are capable of capturing the overall airflow pattern, but tend to overpredict the absolute air speed magnitude. Despite this limitation, CFD remains a useful tool for comparative analysis of layout configurations.

From a thermal perception perspective, increased air speed shifted thermal sensation from slightly warm toward neutral and improved thermal acceptability. However, thermal comfort did not improve to the same extent, due to individual preference for warmer conditions and the increasing occurrence of local draft discomfort at higher air speeds. The highest thermal acceptability was achieved at a seat-average air speed of approximately 0.49 m/s, with a low power consumption of 7.2 W (1.8 W per person), demonstrating the potential of ceiling fans as an energy-efficient strategy for improving indoor environmental conditions.

Overall, the findings highlight that desk layout plays an important role in shaping airflow distribution and enabling collective comfort. Rather than focusing solely on increasing air speed, effective design should consider airflow redistribution, occupant preference, and local discomfort. Strategically combining ceiling fans with thoughtfully arranged desk layouts offers a low-energy approach to enhancing indoor comfort while reducing reliance on mechanical cooling. In the context of increasing overheating risks due to climate change, such passive and hybrid cooling strategies can contribute to more heat-resilient and energy-efficient building design.

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