



# OnlyFAN

*Exploring the Diffusion of Ceiling Fan  
Airflow around Desks Layouts and the  
Potential to Increase Collective Comfort*

*Presented by:*

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*First Mentor:*

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*Second Mentor:*

**Dr. A. Luna Navarro**

*Industrial Partner:*

**Sulion**



# How are you feeling now?

Slightly cool? Neutral? Slightly warm?



# How would you like to cool yourself down?

Air conditioning? Fan? Ice-cold drinks?



Let's start from a broader perspective:

# Heat Resilience for Climate Change





dezeen



dezeen



dezeen



dezeen



UK Green Building Council warns **British buildings "not ready for extreme weather"**

The UK Green Building Council has warned that many homes, schools, offices and care homes in the UK are not prepared for the effects of global warming, calling for millions of buildings to be adapted to mitigate the effects of rising temperatures.



The report claimed that, compared to older buildings, modern offices are more susceptible to overheating because of expansive glass facades and lightweight construction.

Proposals in the report to adapt buildings for rising temperatures include installing solar shading devices, replacing conventional glass with solar glass, and opting for passive cooling techniques over energy-intensive air conditioning.

602 14 23

602 14 23

602 14 23

626 17 23







# Options for Cooling

- Energy renovations of houses in moderate climates increase overheating risk (Psomas et al., 2016)
- Installing AC might not be an economically feasible option.
- Energy saving potential when hybrid cooling is adopted: 10% for each degree Celsius increase in the setpoint (Hoyt et al., 2009)
- Options for a 16.6m<sup>2</sup> room:



€399 / 26W



€1024 / 20.1W

OnlyFAN



€2459





# Research Question

How effective are ceiling fans in warm environments to **diffuse air flow** and expand thermal comfort zone to **achieve collective thermal comfort** across different desk layouts?



# Sub Research Questions

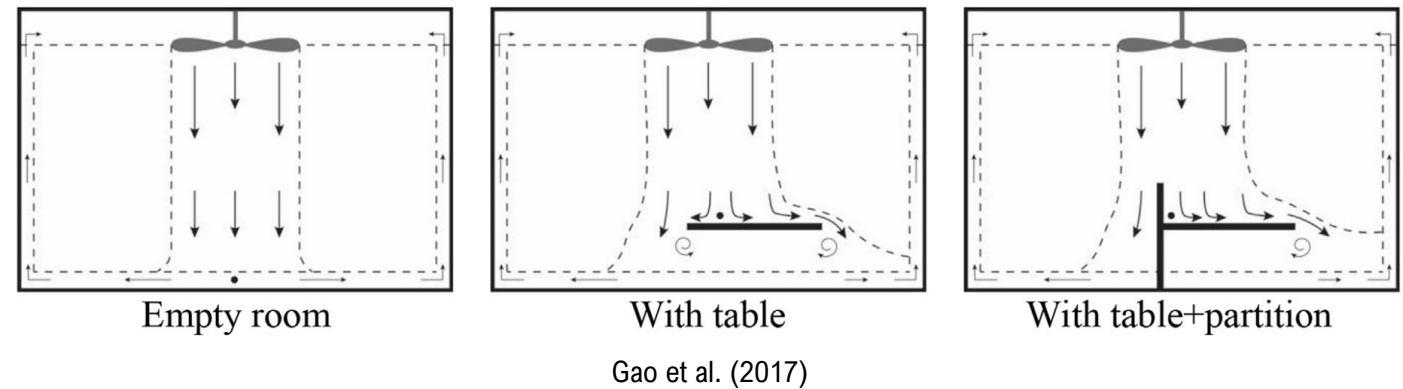
1. ***How do the desk layouts impact the air speed distribution?***
2. *To what extent can the simplified CFD simulation predict the air speed with different layout cases?*
3. *Does the prediction of thermal comfort models (PMV, SET\*, modified SET\*, etc.) match the experiment result of human subjects?*
4. *Can a single ceiling fan provide collective thermal comfort for a group of (up to) 4 people?*





*“Adding workstation **furniture** redirects the jet's airflow laterally in a **deeper spreading zone**, making room airflows more complex but potentially **increasing the cooling experienced** by the occupants.”*

Gao et al., 2017: Ceiling fan air speeds around desks and office partitions

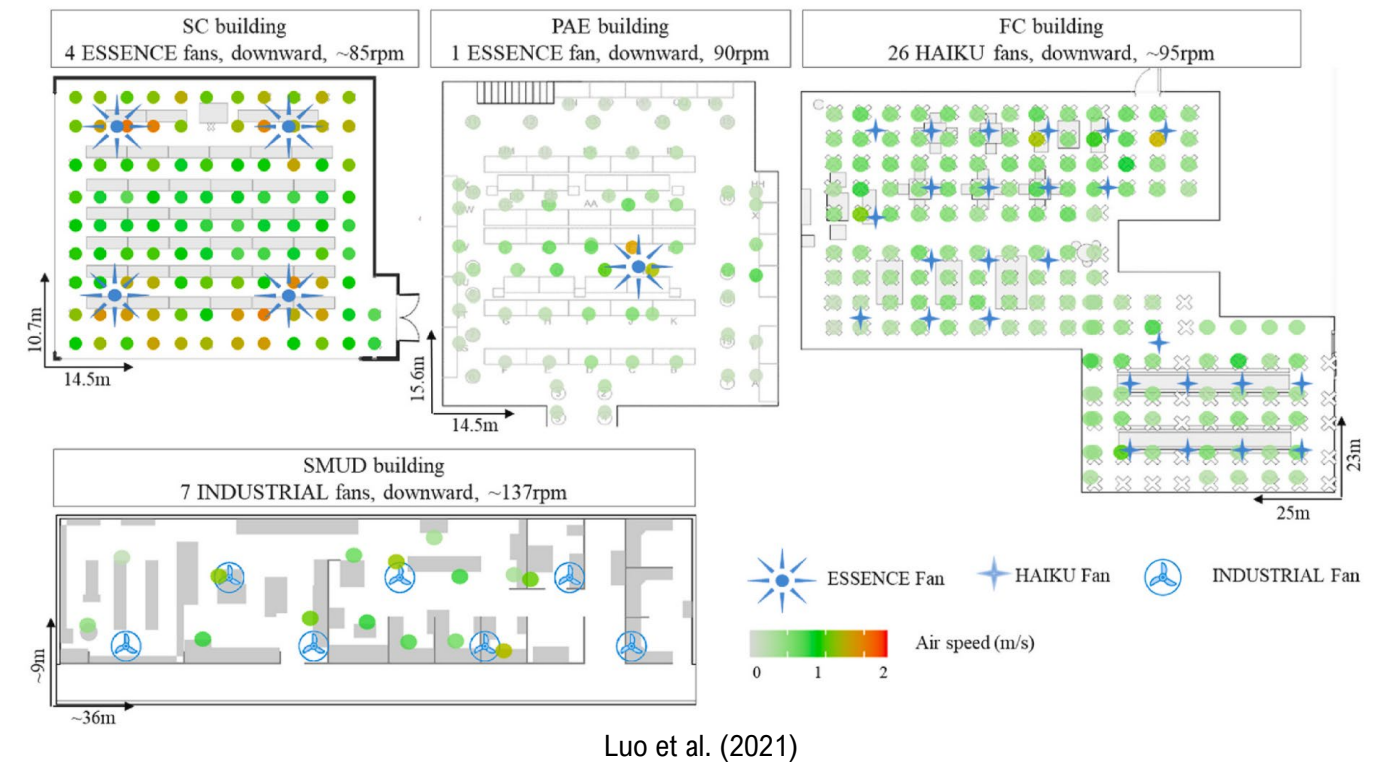


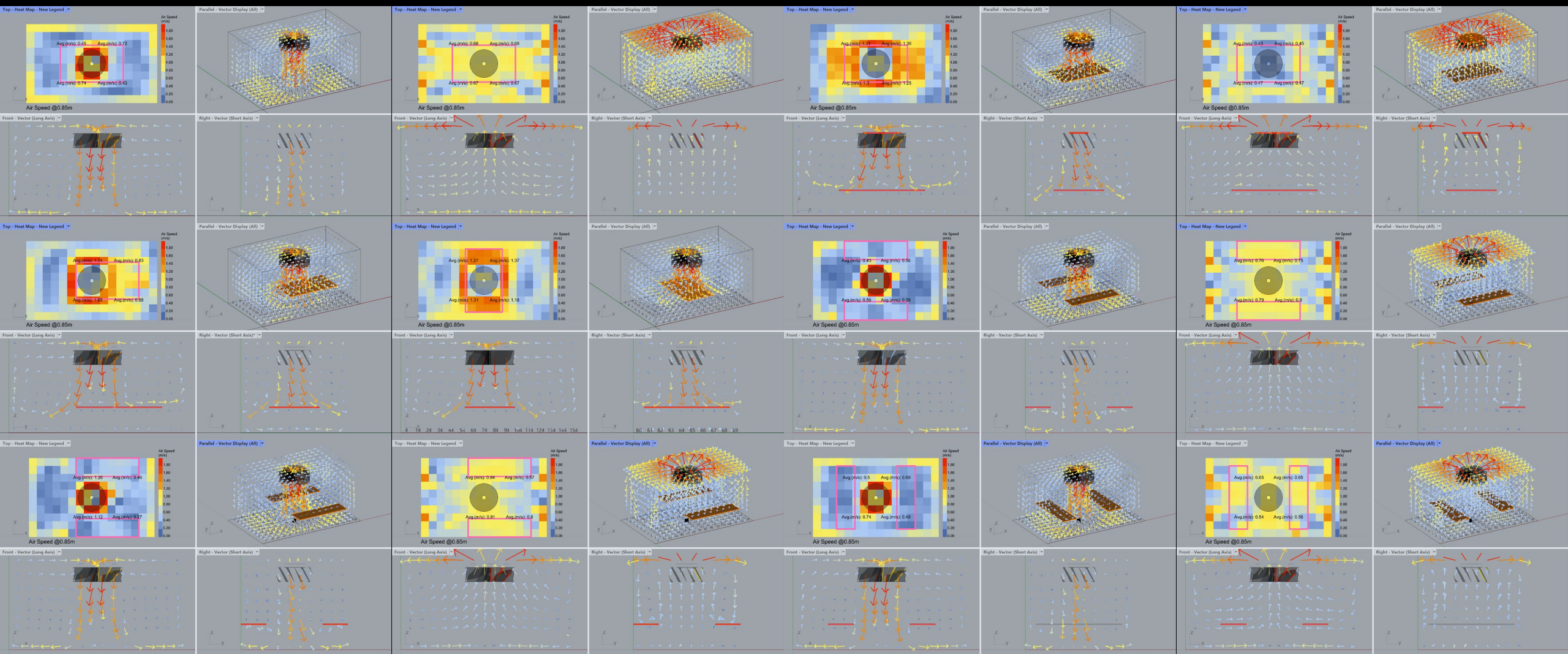
*“In situ air speed measurements at five of the projects revealed the **ceiling fans' operation** results in **generally relatively low airspeeds**, often **under 0.2 m/s**.”*

Present et al., 2019.: Ceiling fans in commercial buildings: In situ airspeeds & practitioner experience

*“There appears to be a **negative linear relationship between furniture density and air speed** in the occupied zone. Furniture in real buildings lowers the air movement in occupied zone by impeding the path of air movement.”*

Luo et al. (2021): Detailed measured air speed distribution in four commercial buildings with ceiling fans



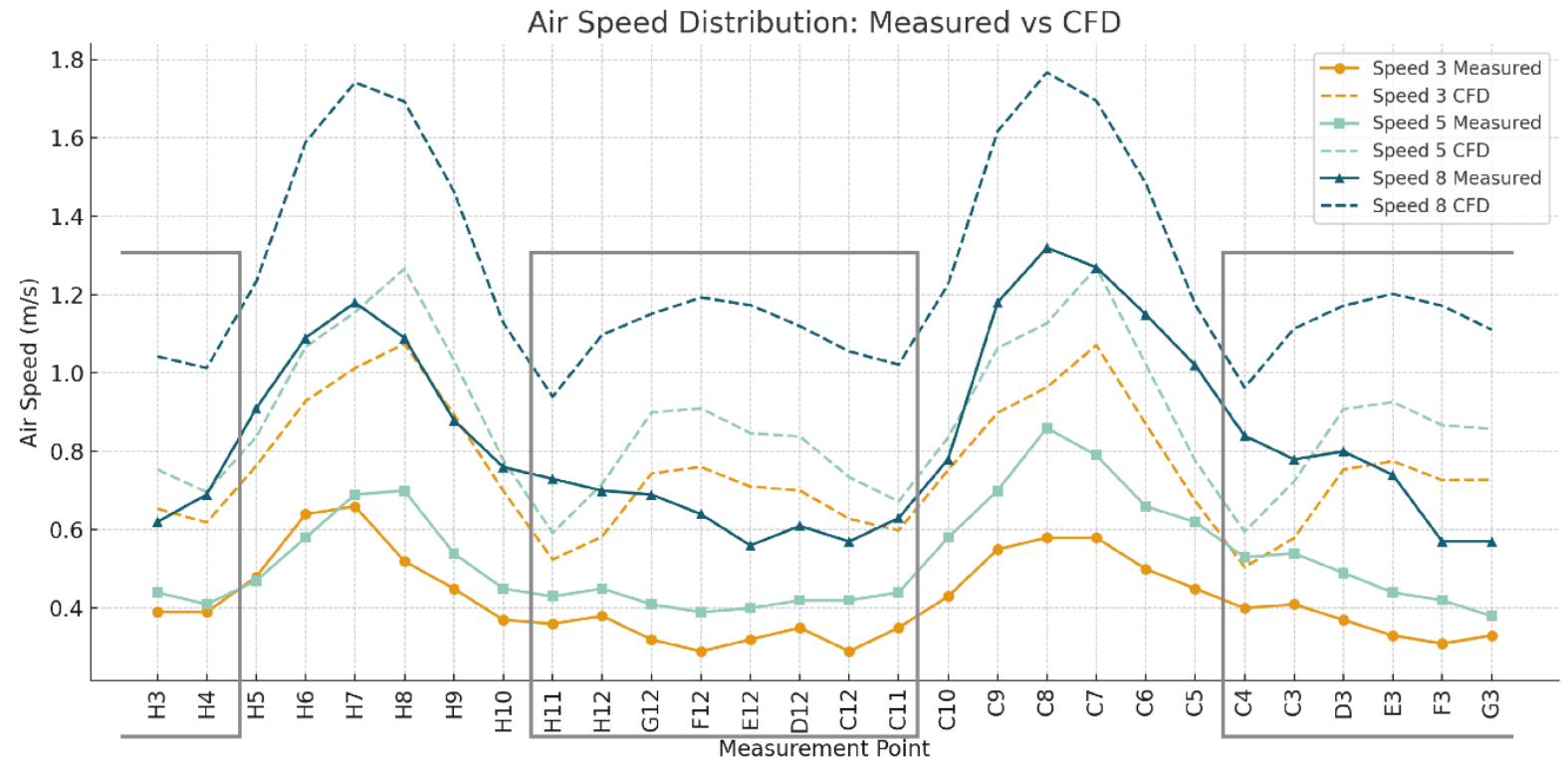




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Measurement height	Speed RPM	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5	Speed_6	Speed_7	Speed_8	Speed_9
0.85m	A	0.36	0.46	0.56	0.6	0.53	0.78	0.75	0.83	1
	B	0.35	0.54	0.48	0.67	0.64	0.68	0.99	0.98	1.09
	C	0.34	0.43	0.49	0.57	0.64	0.72	0.73	1	0.98
	D	0.41	0.35	0.41	0.46	0.5	0.75	0.64	0.73	0.82
	Avg_seat	0.37	0.45	0.49	0.58	0.58	0.73	0.78	0.89	0.97
	Avg_all	0.31	0.39	0.42	0.5	0.52	0.63	0.68	0.77	0.83

## 13





# Sub Research Questions

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2. *To what extent can the simplified CFD simulation predict the air speed with different layout cases?*
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a. Chamber configuration



b. Air speed measurement

Zhai et al. (2013)

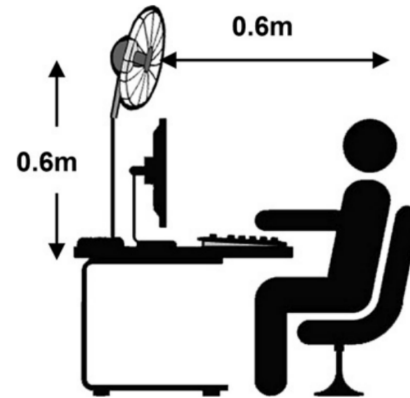
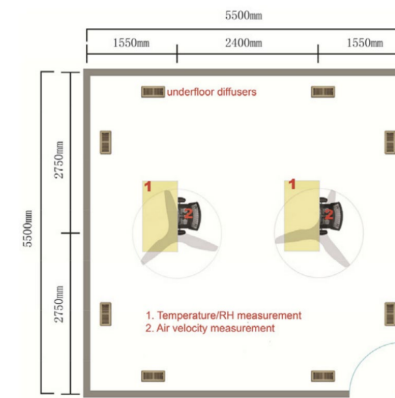


Fig. 3. The relative position of the subject and the fan.

Huang et al. (2013)

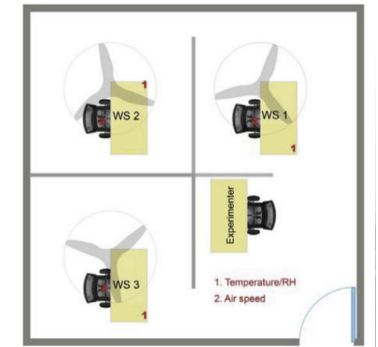


a. Chamber set up

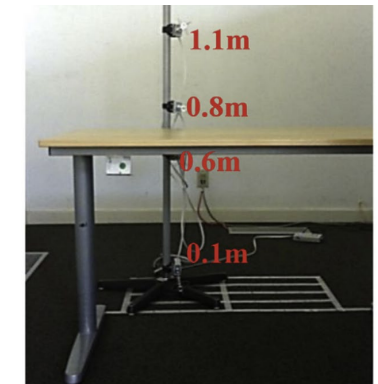


b. Human subject tests set up

Zhai et al. (2015)



a. chamber setting

b. air speed measurement  
heights  
Zhai et al. (2017)

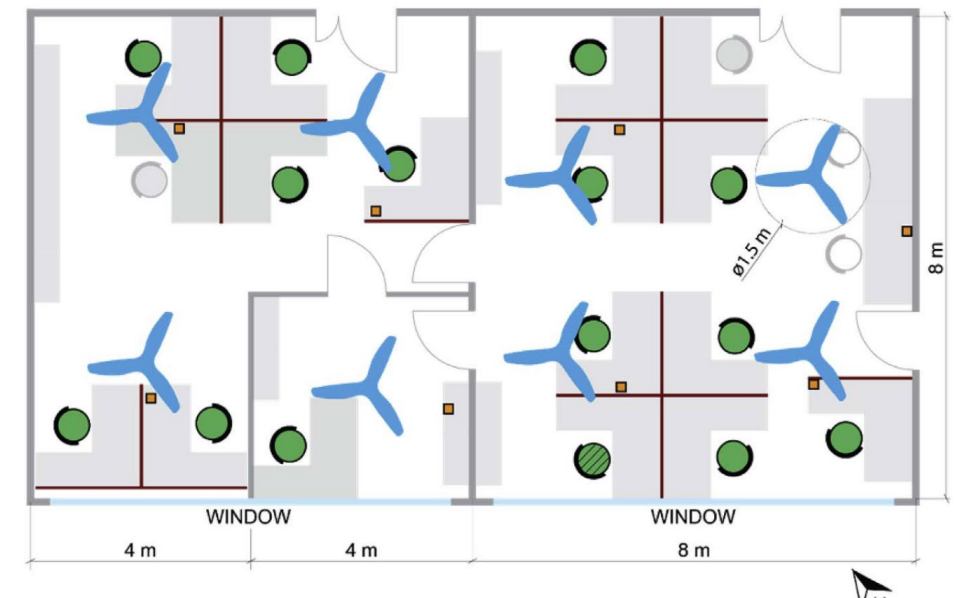




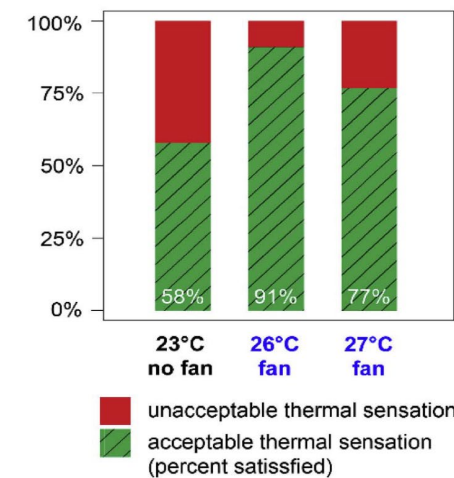
*“In a real-world office environment in the tropics that if we **increase** the temperature **setpoint** from 23°C to 26°C, while simultaneously **providing occupants shared control over ceiling fans**, we can obtain a **major increase in thermal comfort**”*

*“...the **energy usage** for comfort cooling can be **decreased by roughly a third**.”*

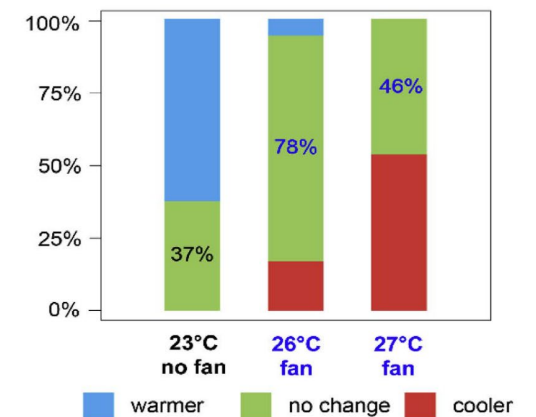
Lypczynska et al., 2018.: Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics



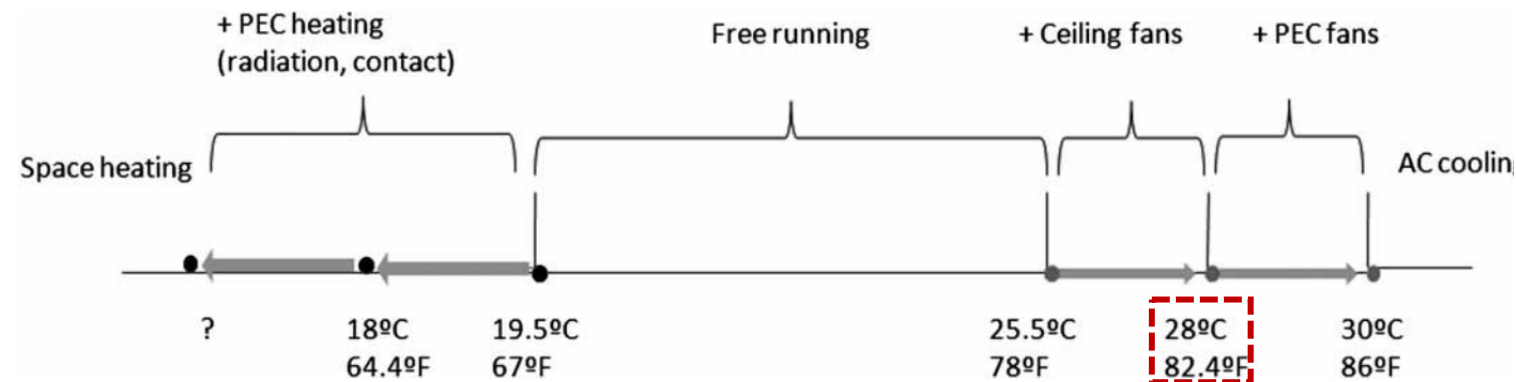
a) Thermal sensation acceptability



b) Thermal sensation preferences

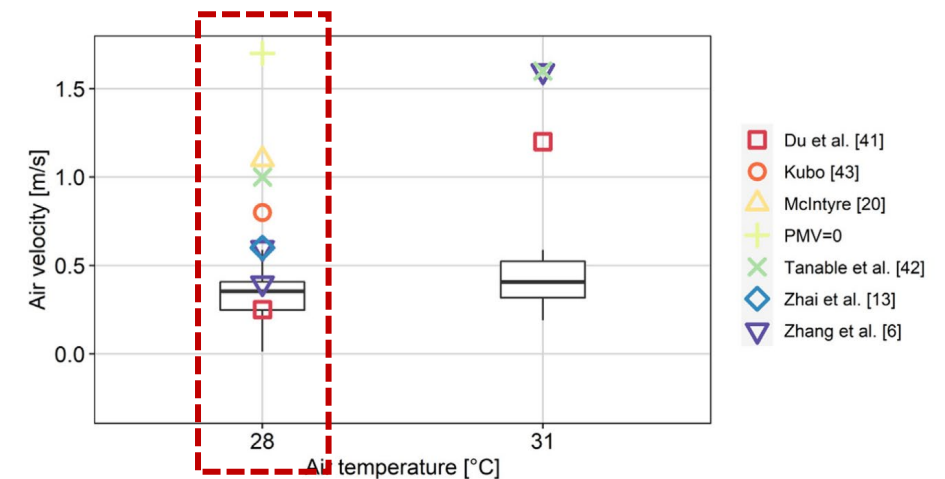


Luo et al. (2021)



Thermal comfort temperature ranges for HVAC buildings with fans and radiant sources in buildings.

Zhang et al. (2011)



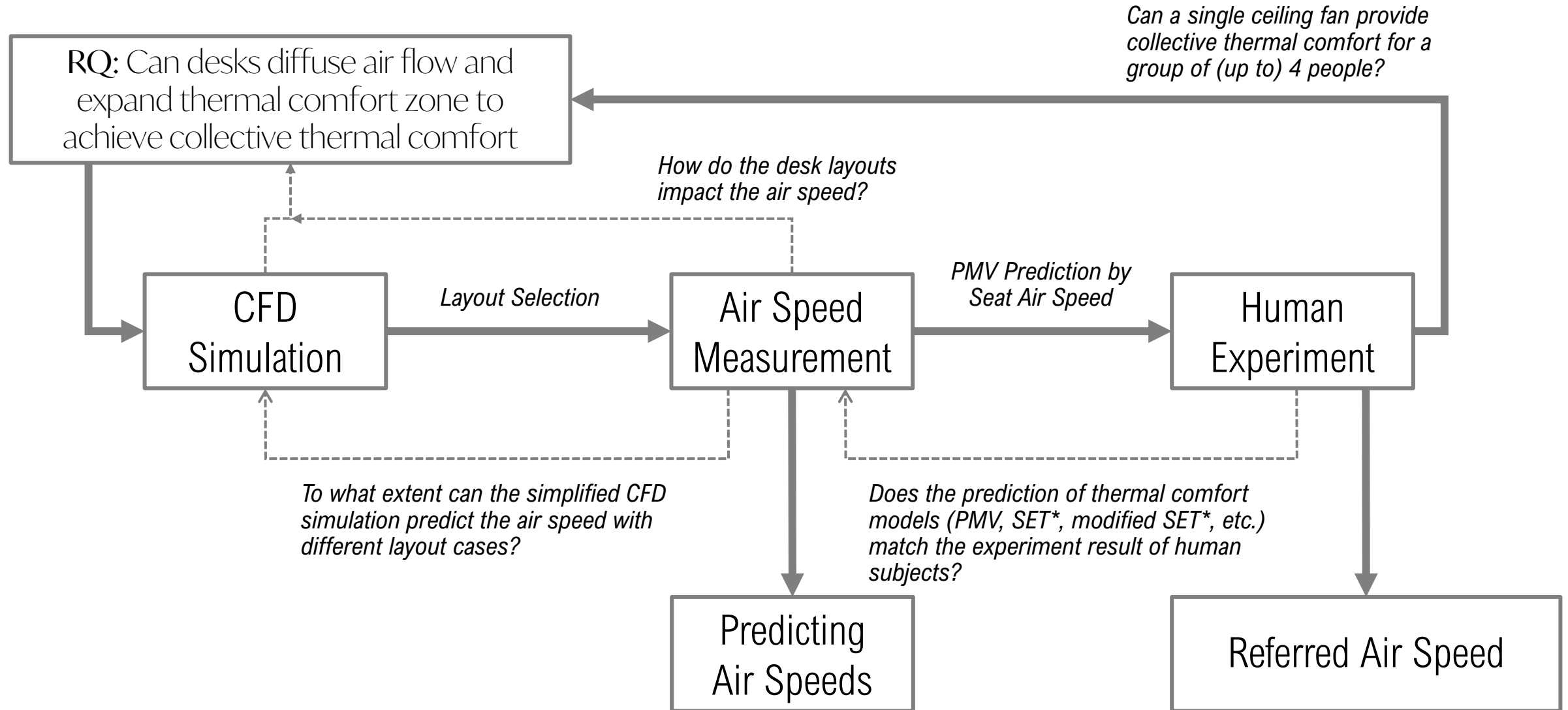
Riseto et al. (2021)







# Multi-loop Validation





# CFD Simulation

Initial insight to the air flow pattern with different desk layouts



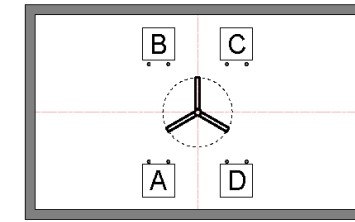
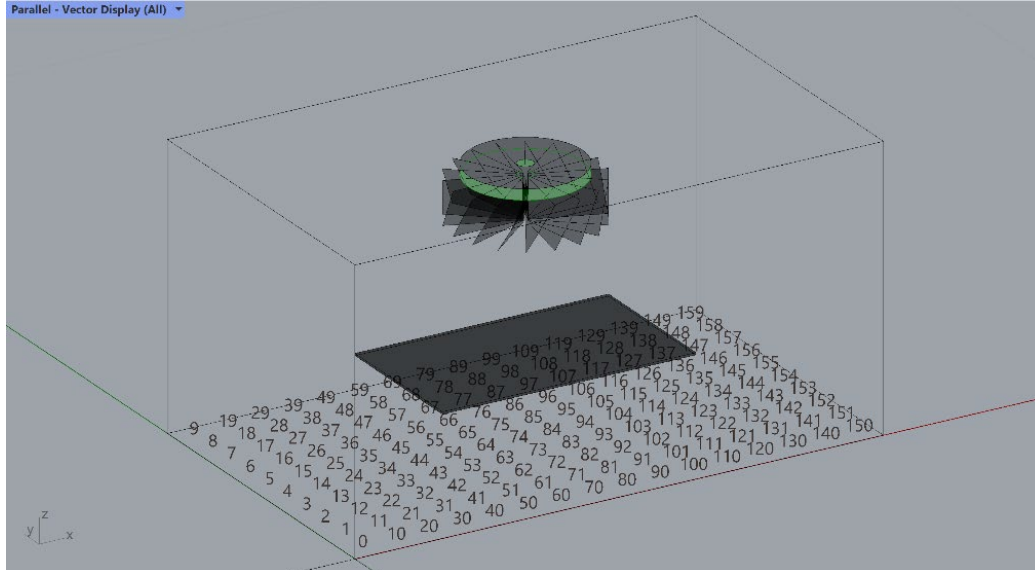
# CFD Simulation Setup

## Simplified CFD setup:

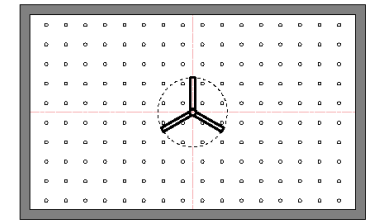
- No rotating fan blade
- Circular surface as air inlet and outlet
- Tilted air foil to mimic swirling airflow

## Probes:

- 10x16 planar point grid at 8 heights
- **0.1 / 0.6 / 0.85 / 1.1 / 1.4 / 1.7 / 2.2 / 2.5m**

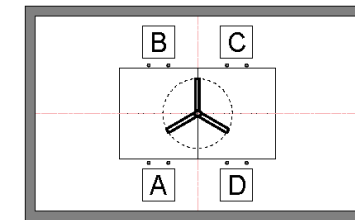


Case\_0



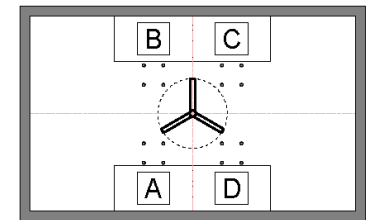
Probe Points

## 2x2 Layout



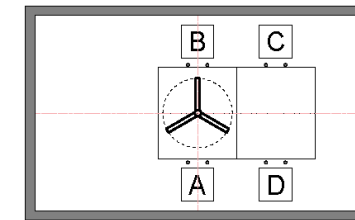
Case\_1(A/B)

## 2-side Layout

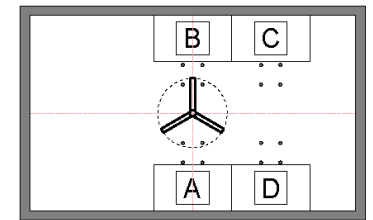


Case\_4(A)

X-offset = 0.0m  
Orientation = 0°

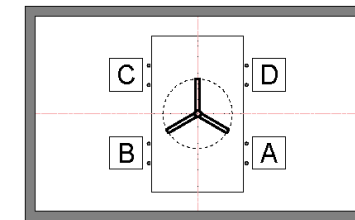


Case\_2(A/B)

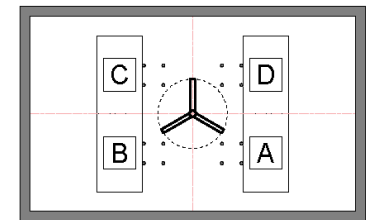


Case\_5(A)

X-offset = 0.6m  
Orientation = 0°



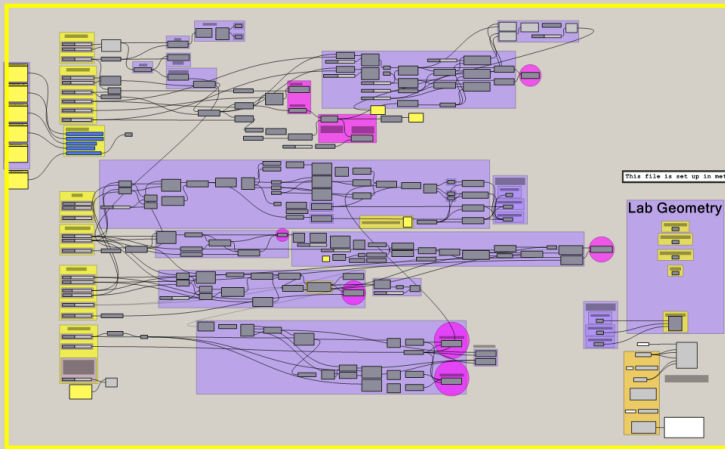
Case\_3(A/B)



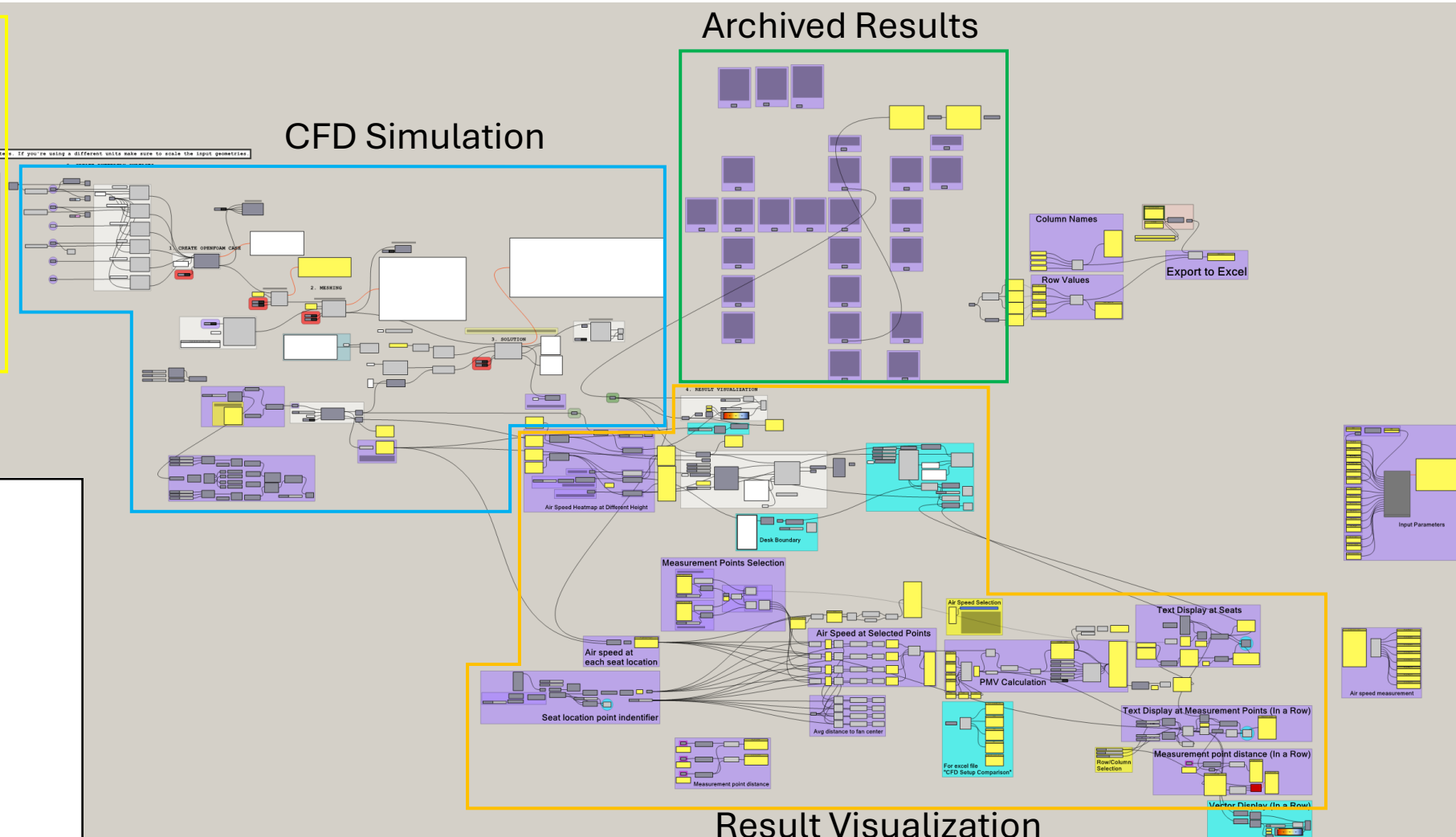
Case\_6(A)

X-offset = 0.0m  
Orientation = 90°

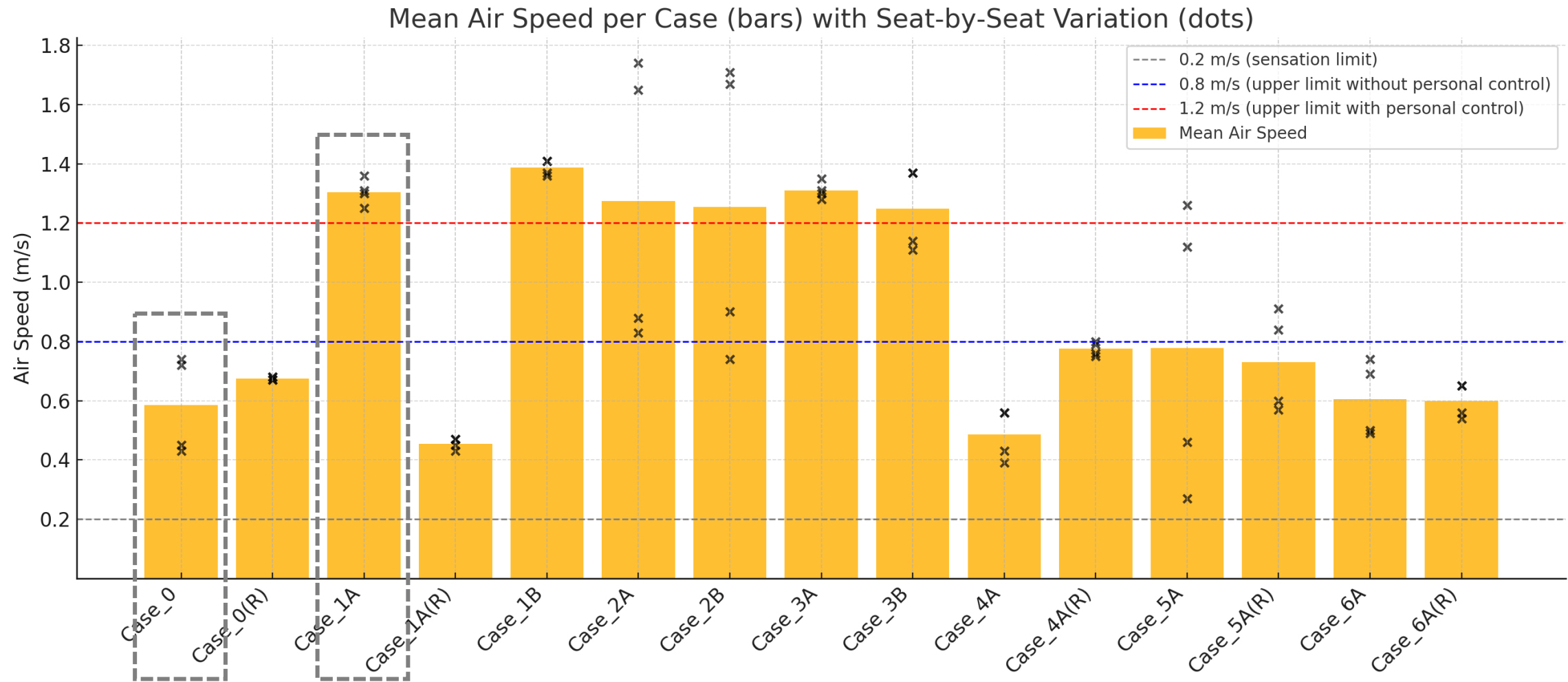




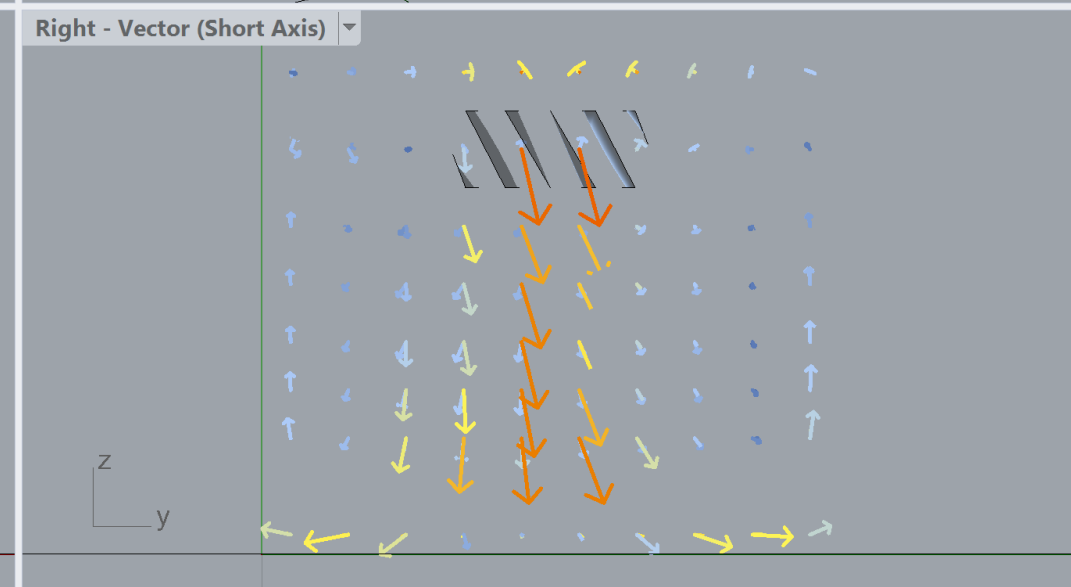
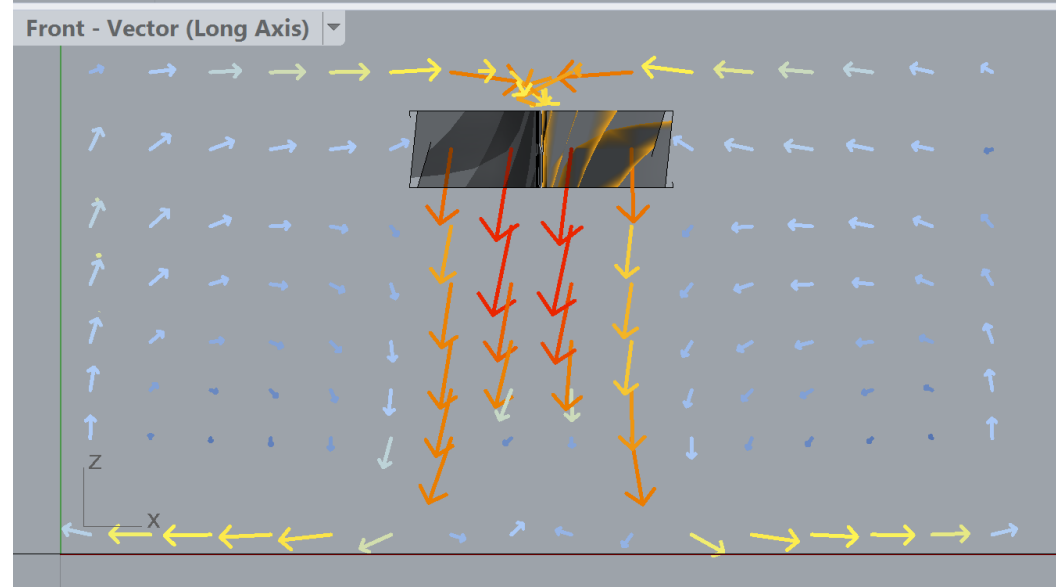
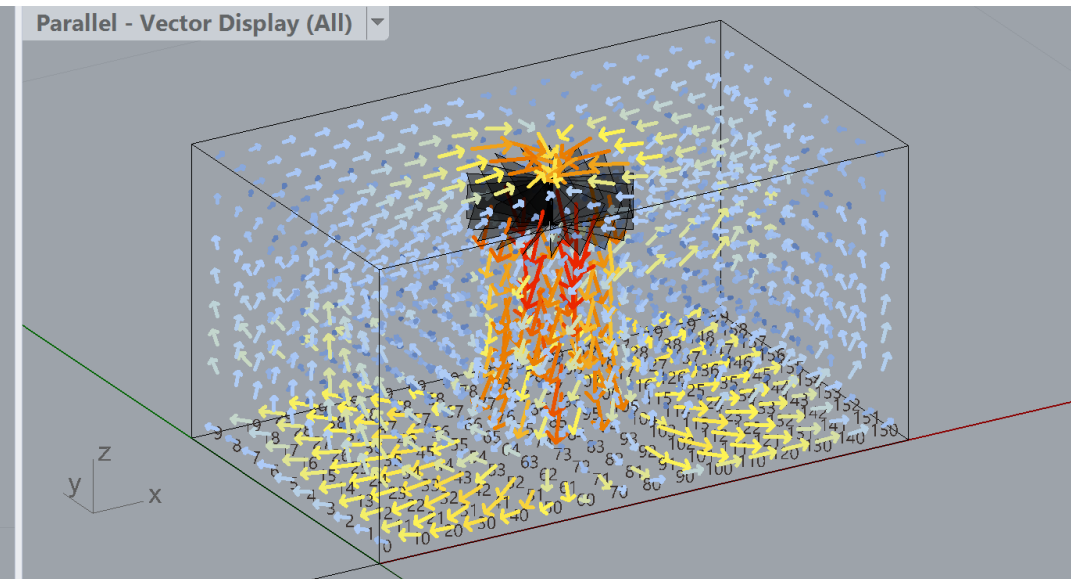
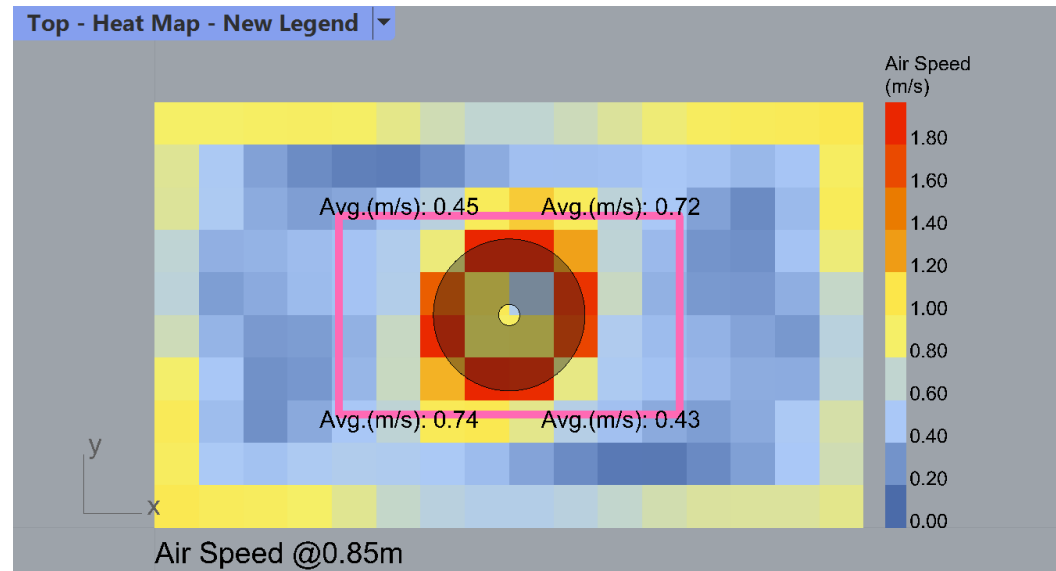
Define Geometry

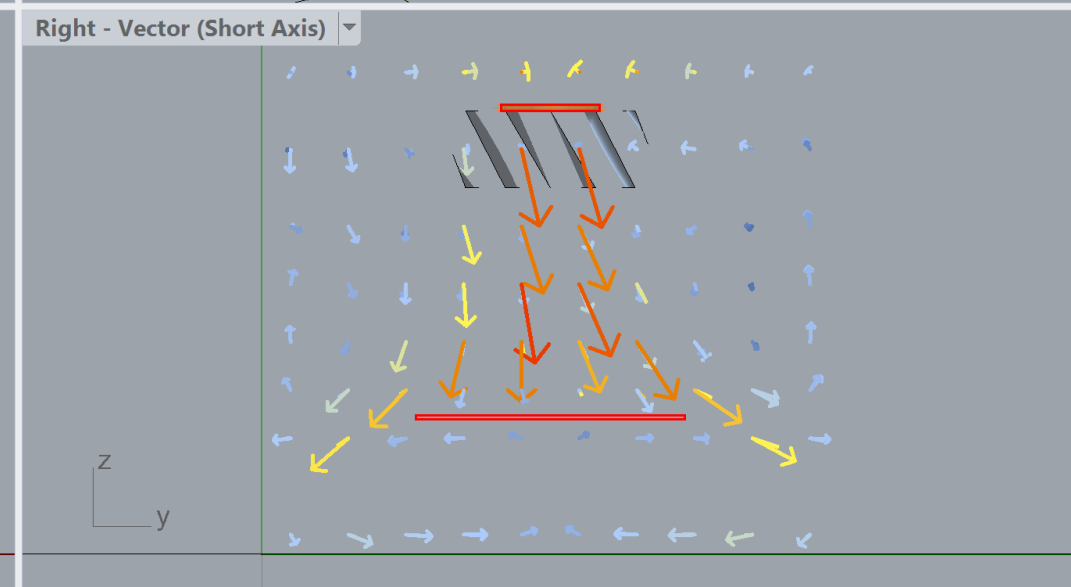
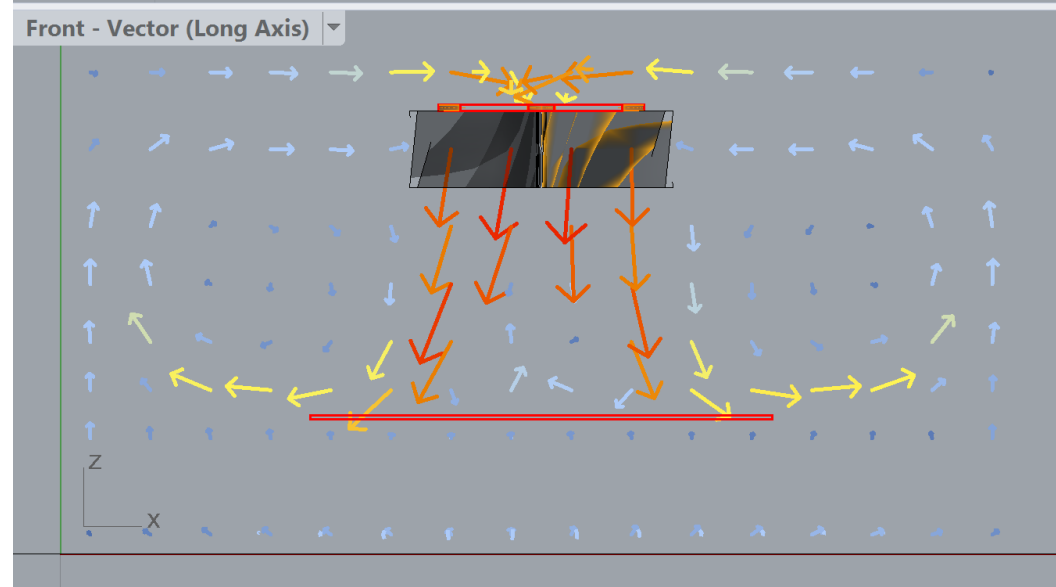
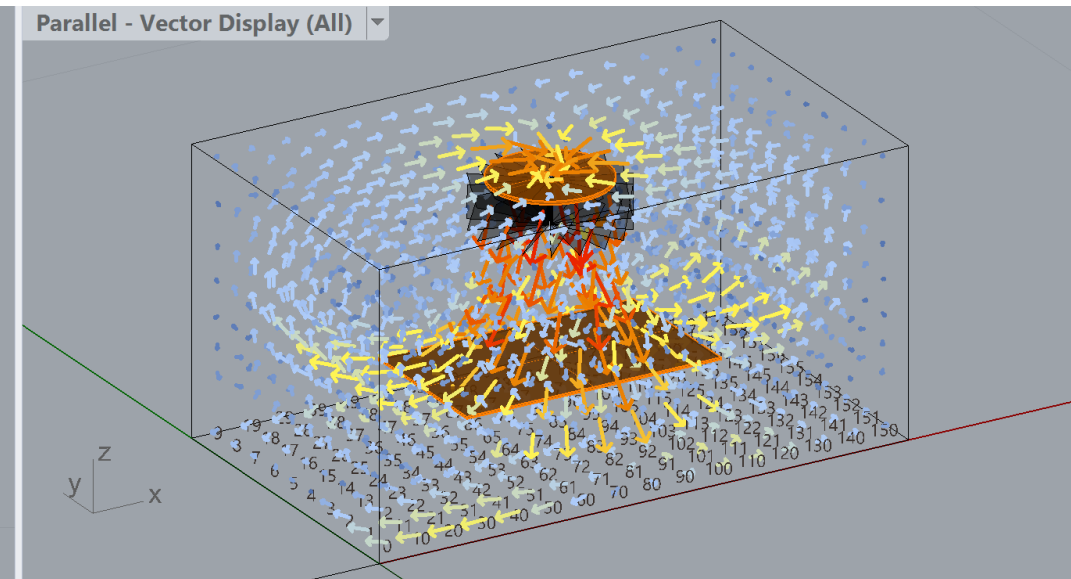
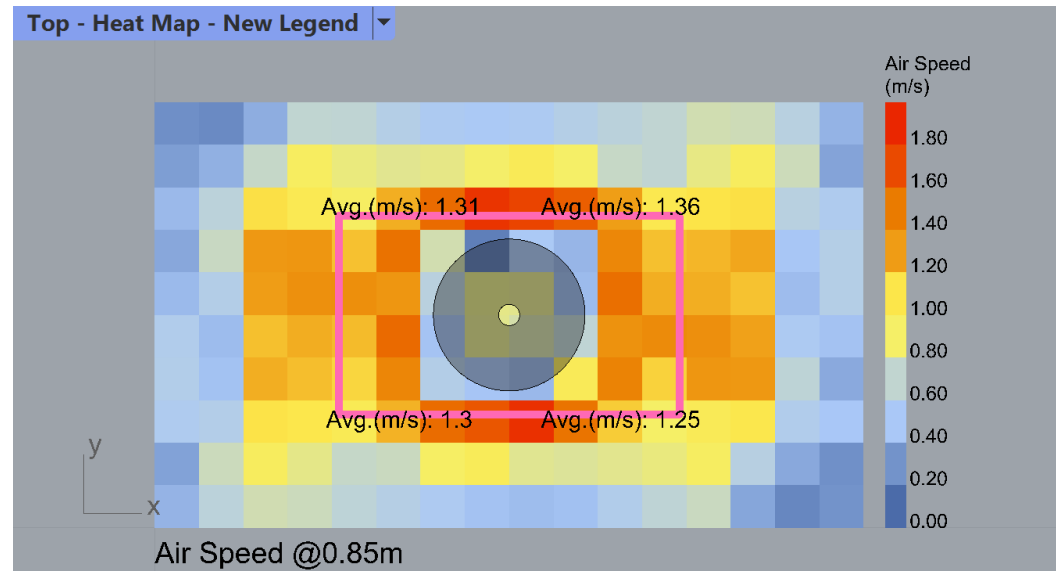








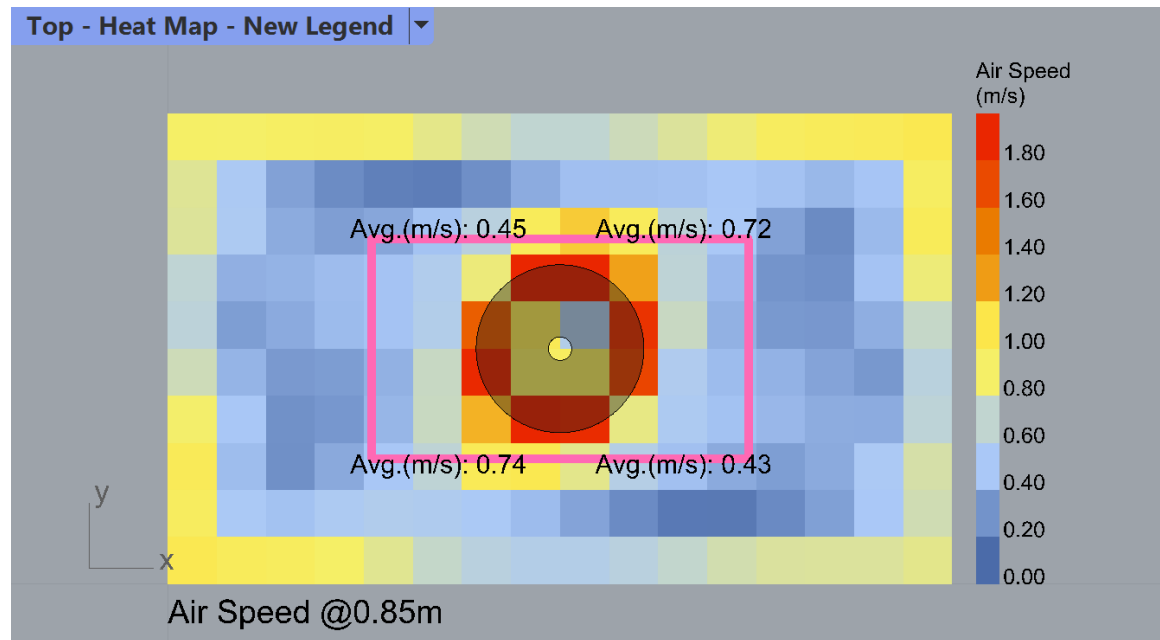




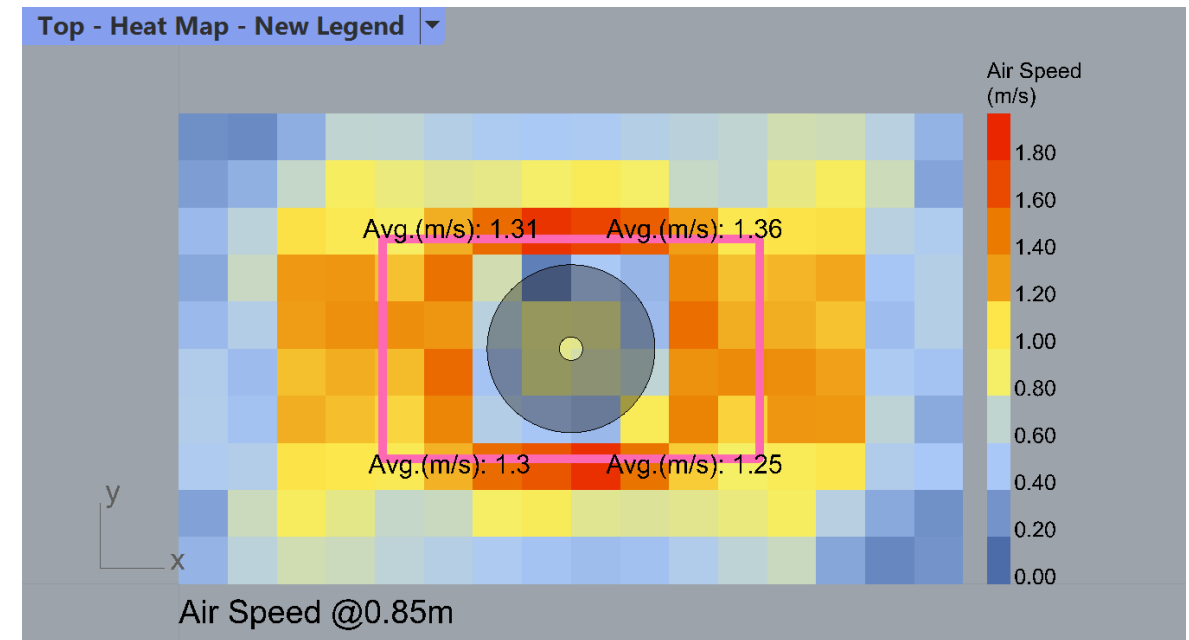


# Conclusion CFD

- The desks increased the air speed at chest level (0.85m height)
- Air speed of Case\_0, 1A will be measured in the lab



Case\_0



Case\_1A



# Air Speed Measurement

Validating the CFD results with lab measurements





# Fan mounting and Wiring

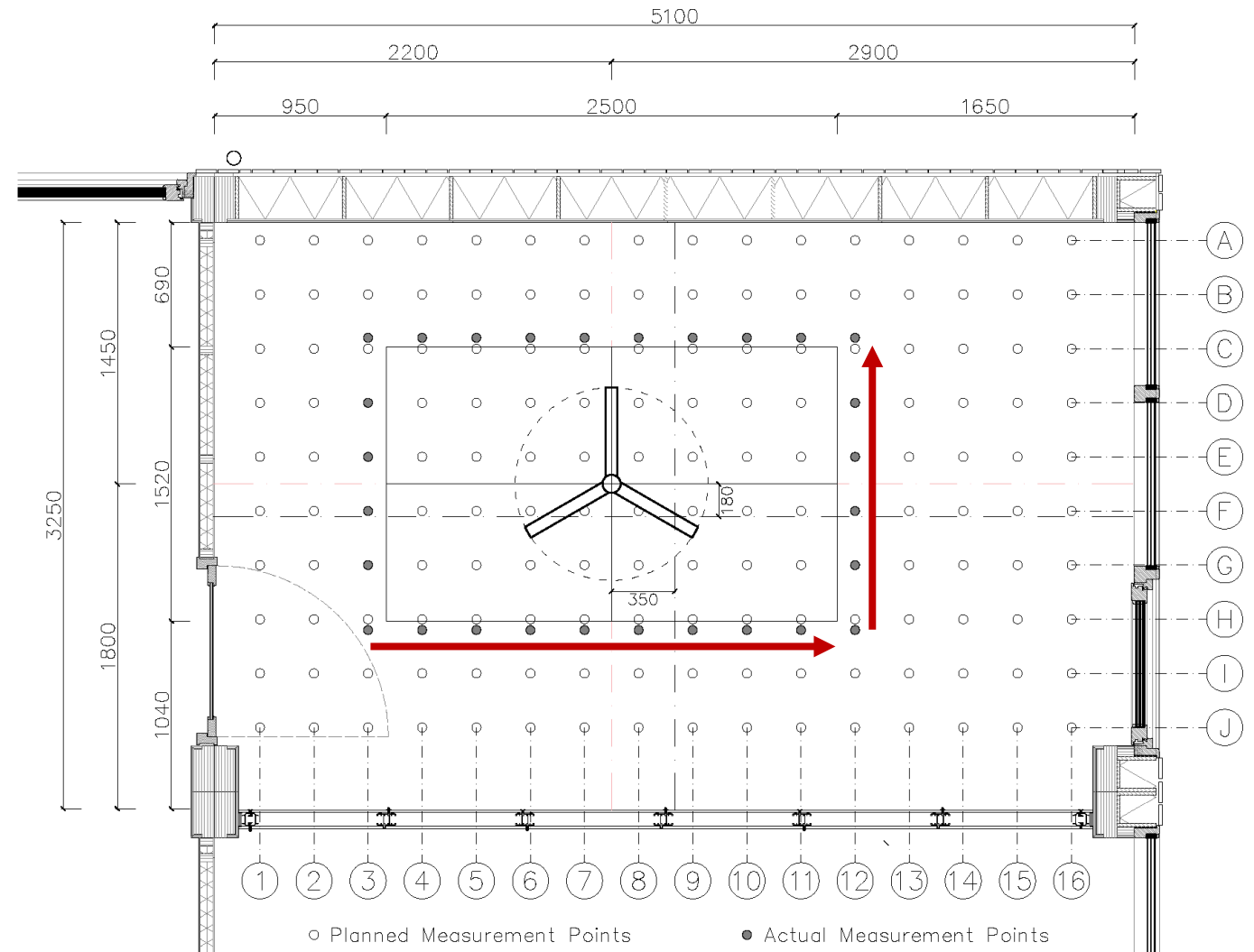






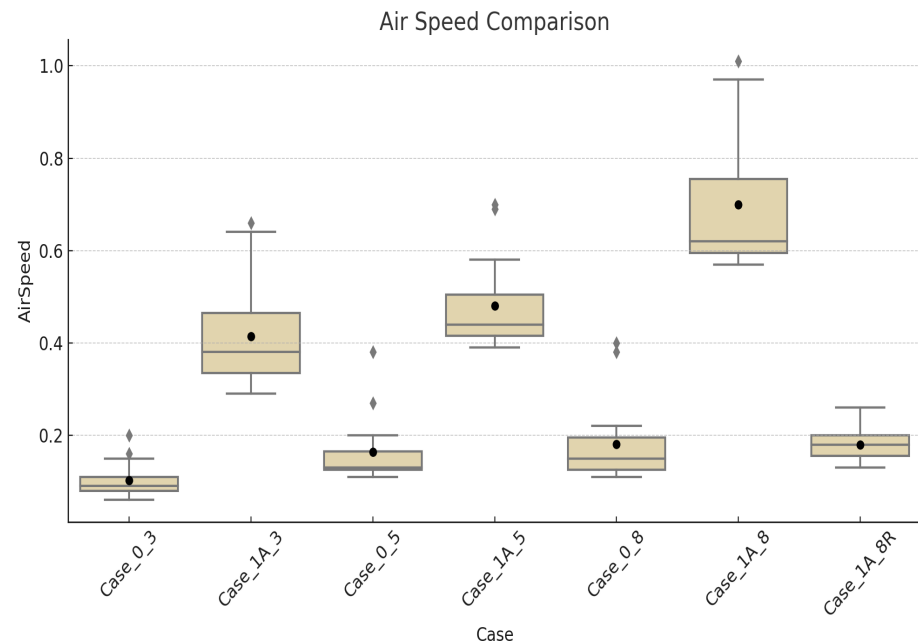


# Measurement (1)

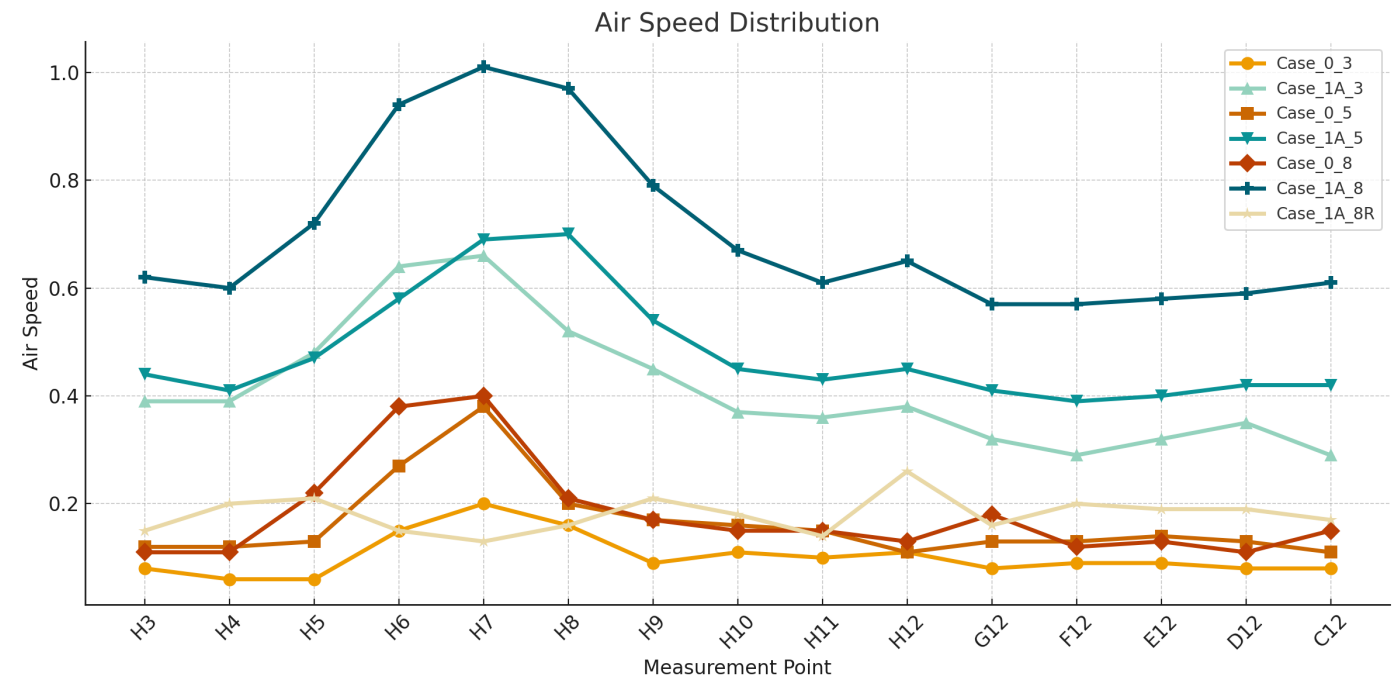




# The Influence of Desk and Fan Direction (Fan Speed 3 / 5 / 8)



Air speed around the desk surface at 0.85m height increased more than 194% !

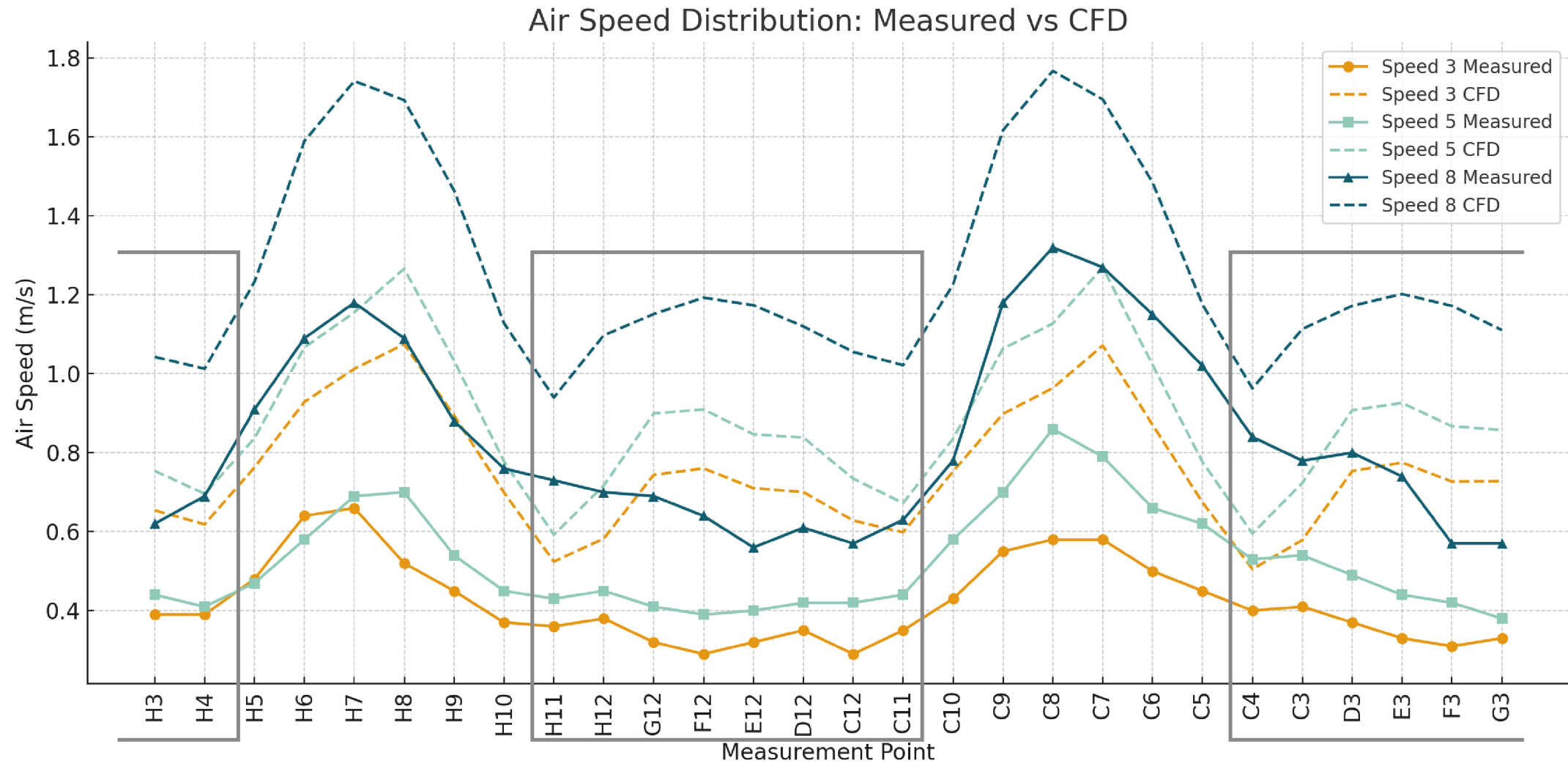


Case/Fan Speed	Case_0_3	Case_1A_3	Case_0_5	Case_1A_5	Case_0_8	Case_1A_8	Case_1A_8R
Avg_all (m/s)	0.10	0.41	0.16	0.48	0.18	0.70	0.18
Increase	303%		194%		286%		





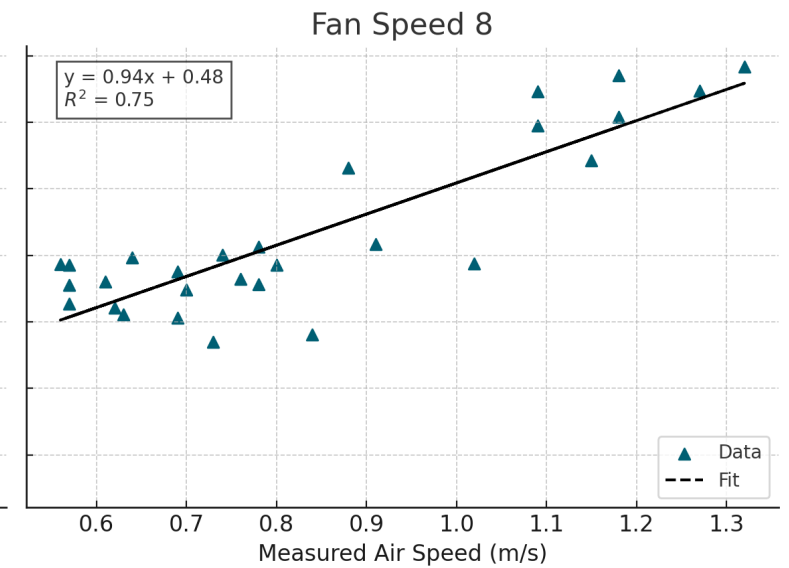
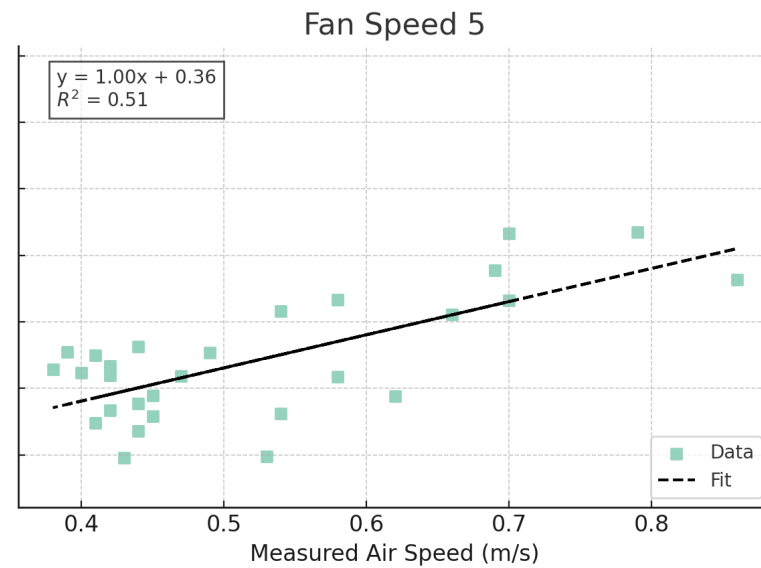
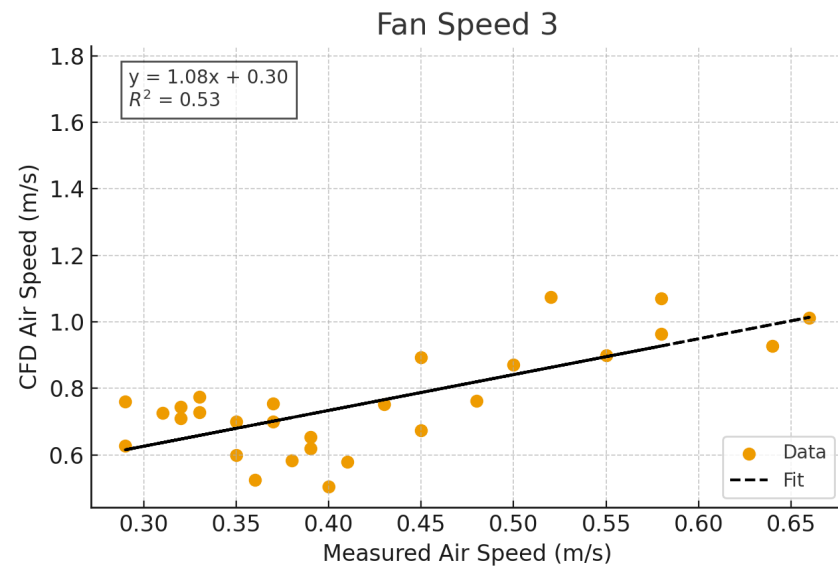
# CFD vs Measurement





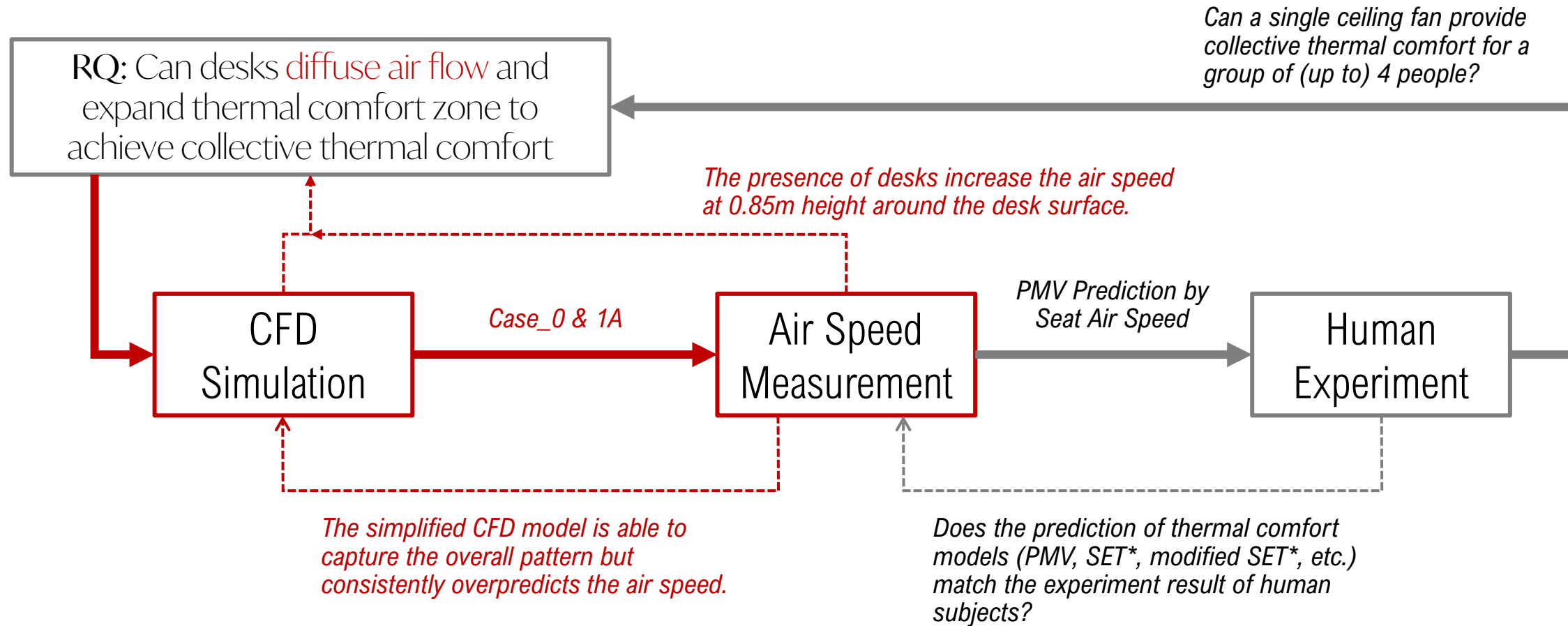
# CFD vs Measurement

Linear Regression: Measured vs CFD Air Speeds



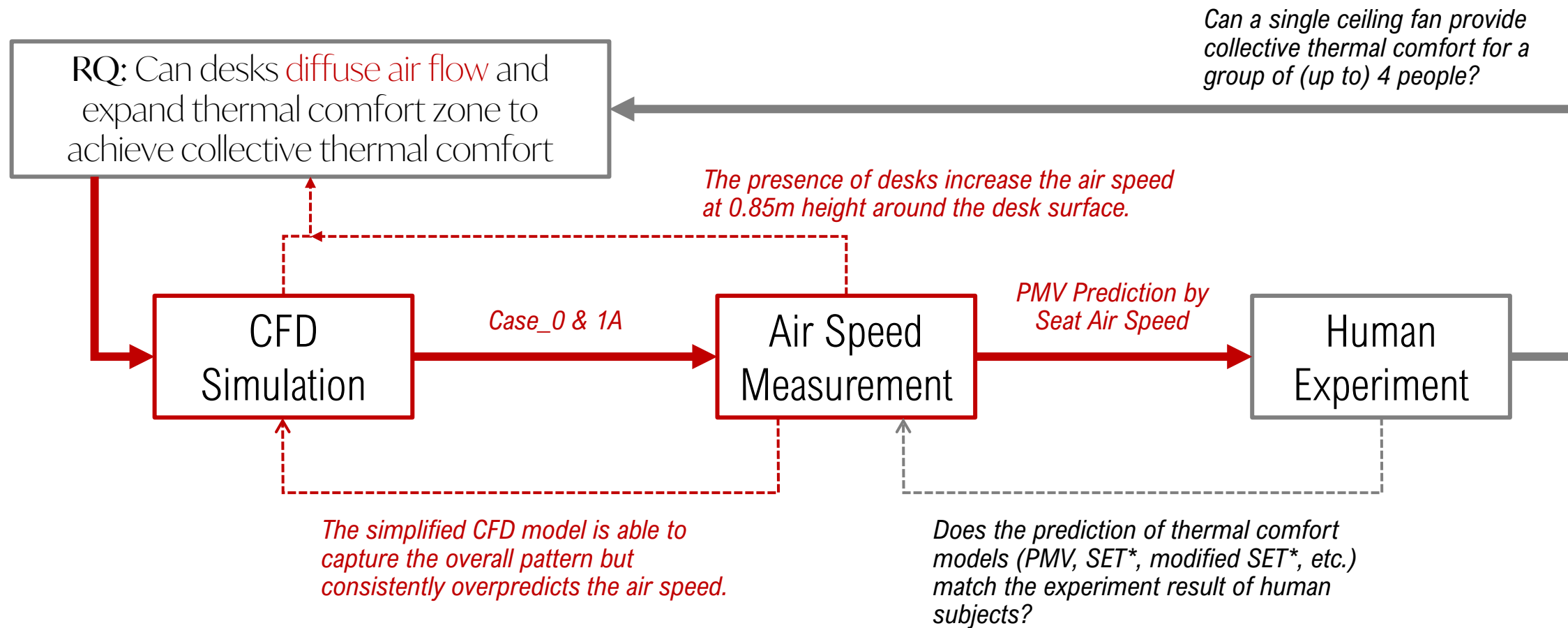


# Multi-loop Validation





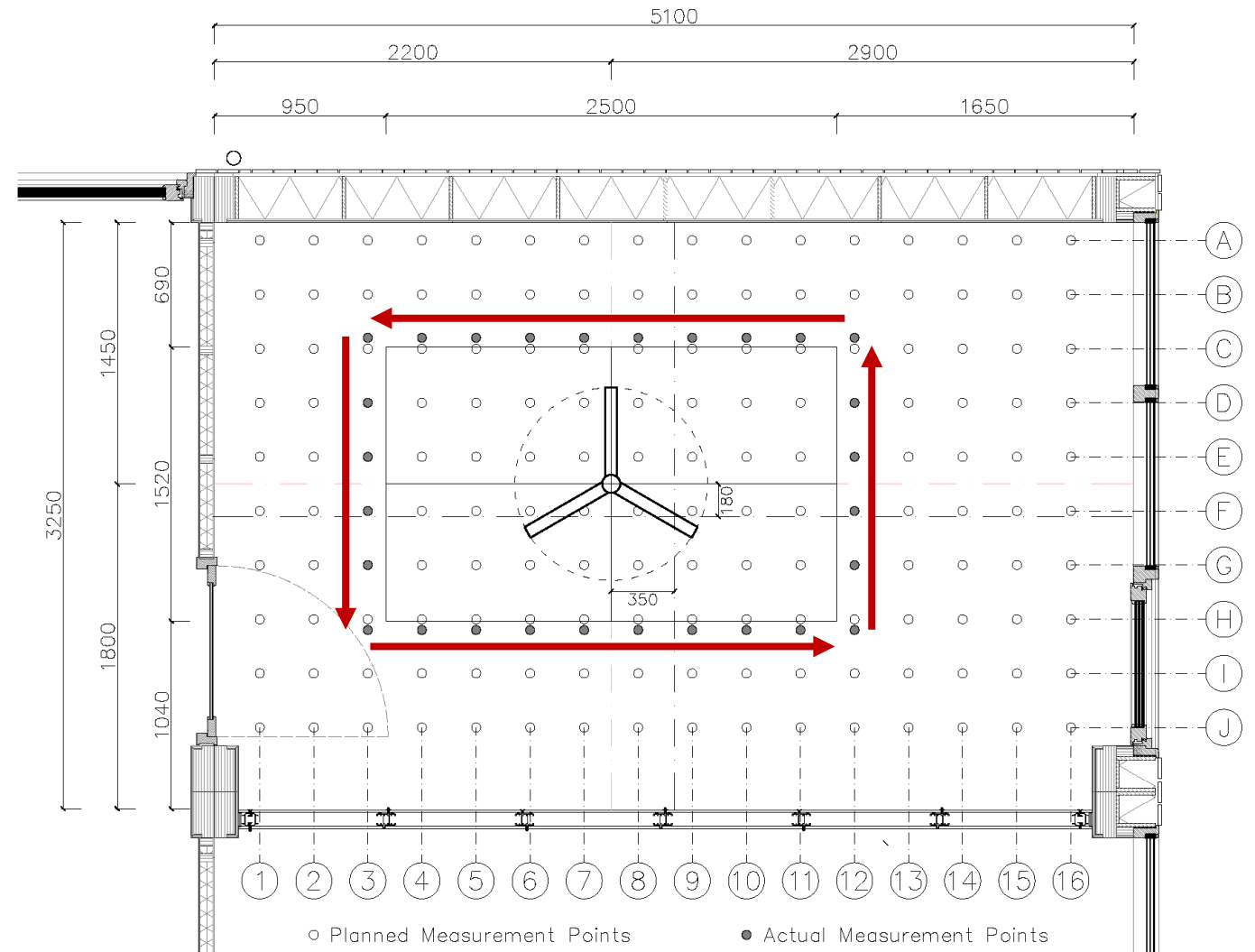
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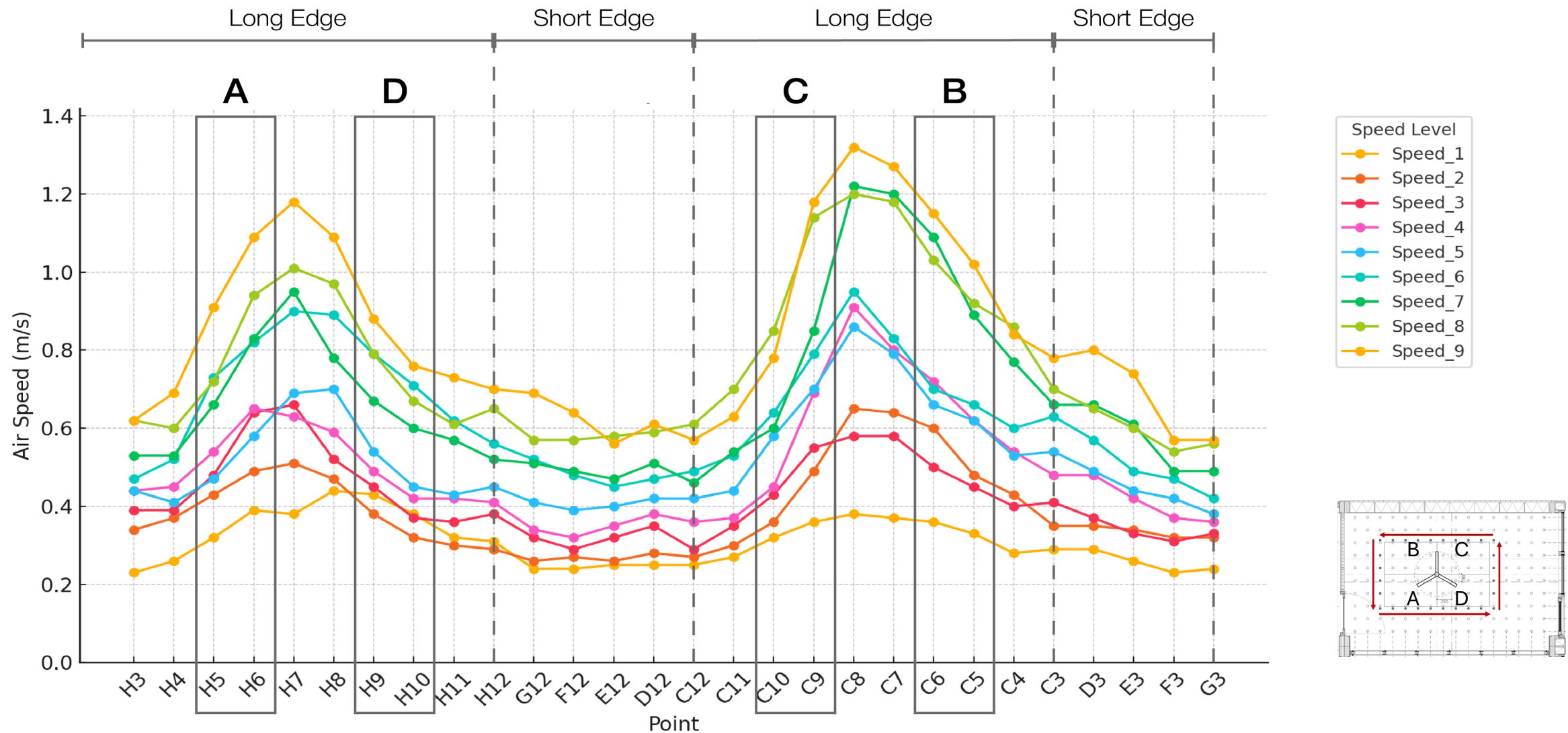


# Measurement Plan



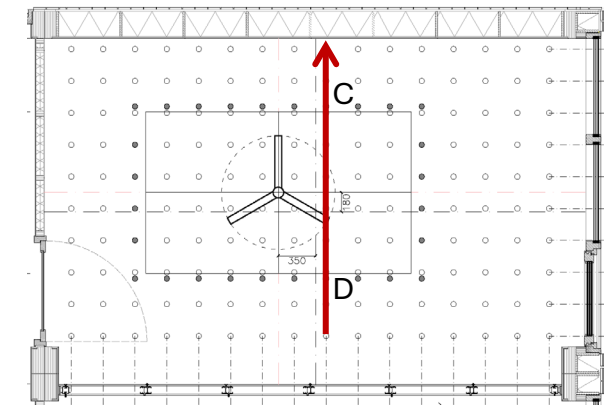
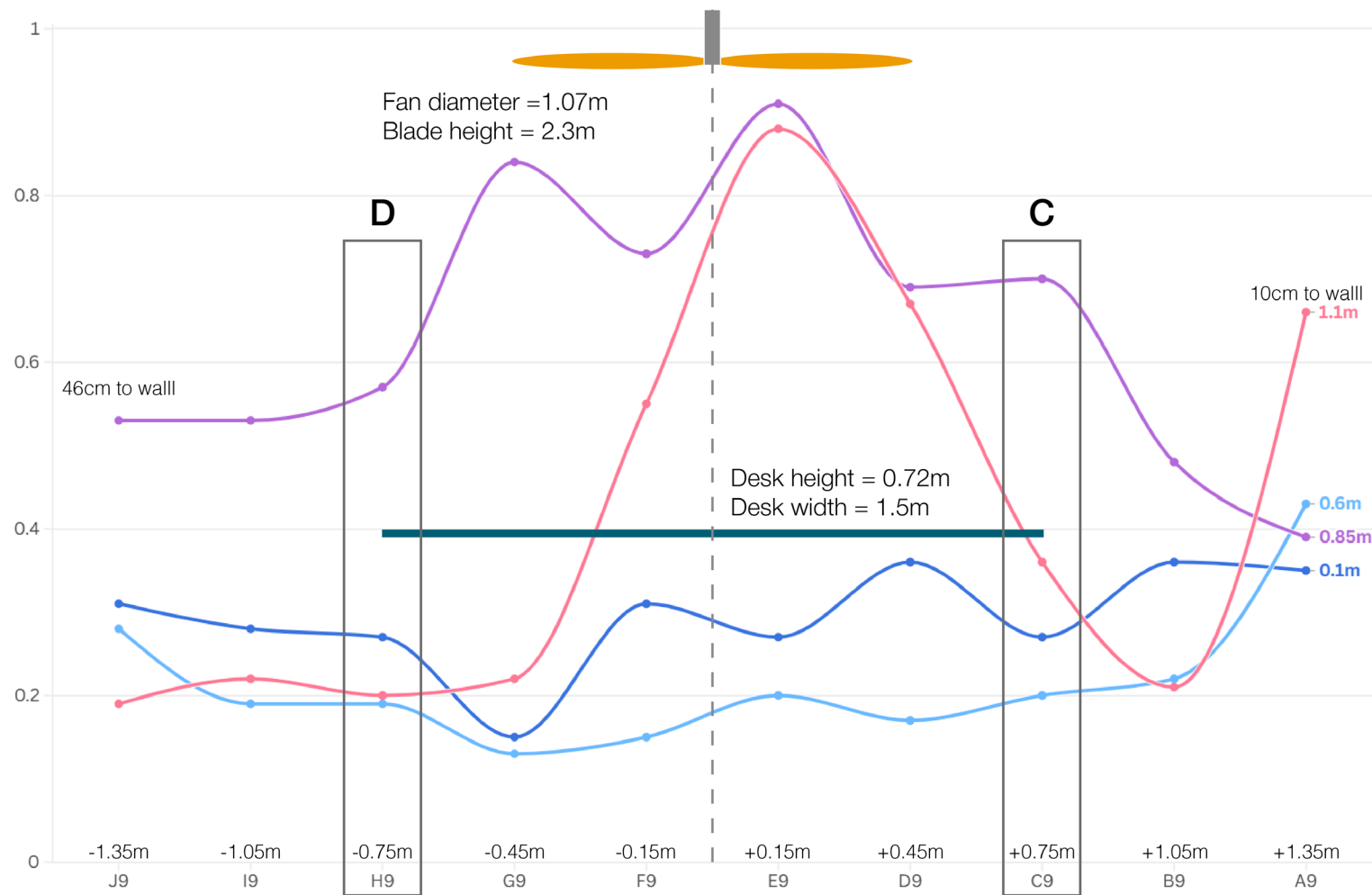


# Measurement of Air Speed (Fan Speed 1 - 9)





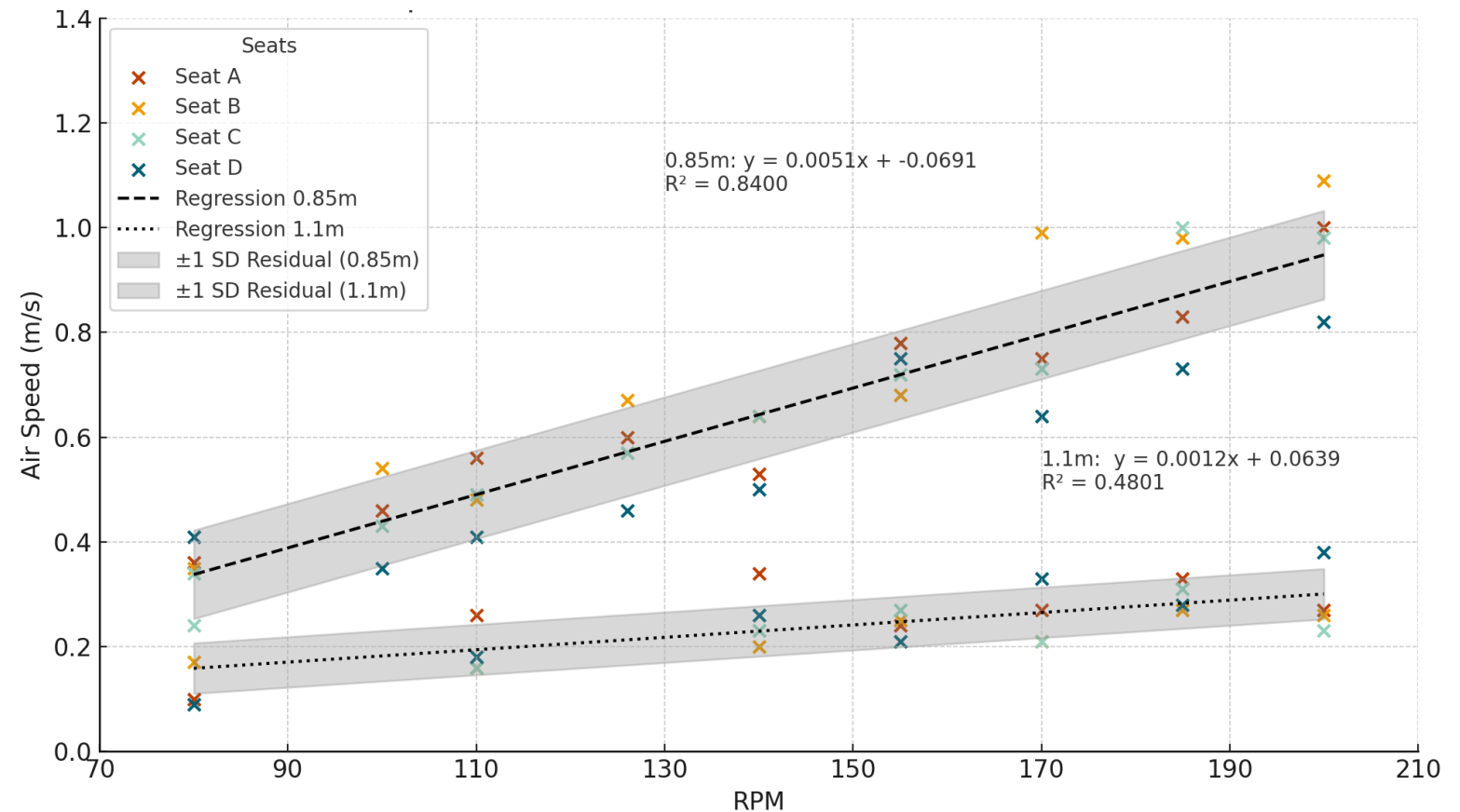
# Sectional Air Speed Distribution





# Seat Air Speed at 0.85m and 1.1m

- Positive linear correlation as RPM increases
- Air Speed at 0.85m is higher than at 1.1m
- Air speed at 0.85m shows higher deviation by seat
- No clear trend of which seat consistently receives the highest or lowest air speed. (Seat D has the lowest air speed at most fan speed)



Measurement height	Speed RPM	Speed_1 80	Speed_2 100	Speed_3 110	Speed_4 126	Speed_5 140	Speed_6 155	Speed_7 170	Speed_8 185	Speed_9 200
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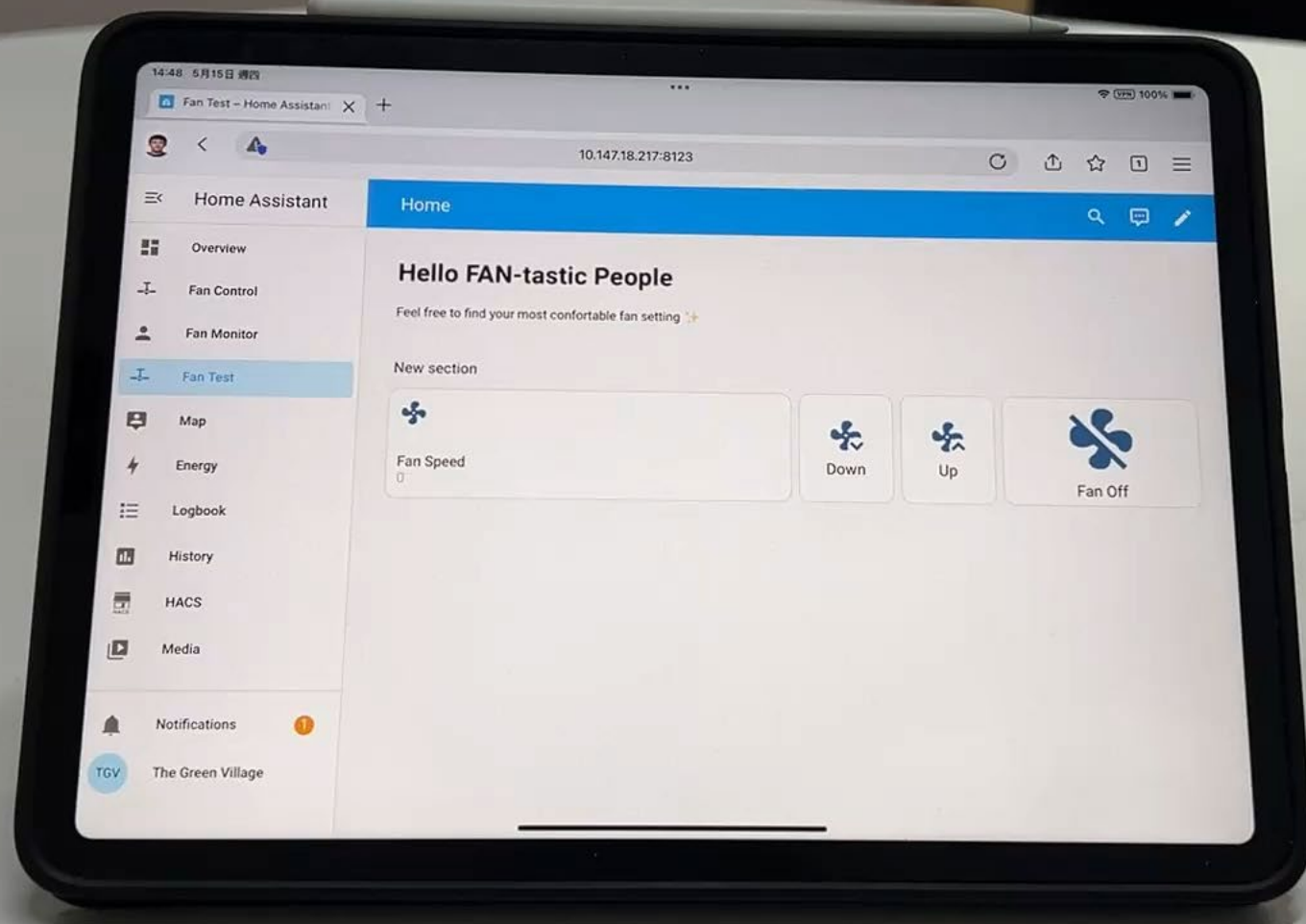
# Human Experiment

Thermal sensation, comfort level and preferred air speed







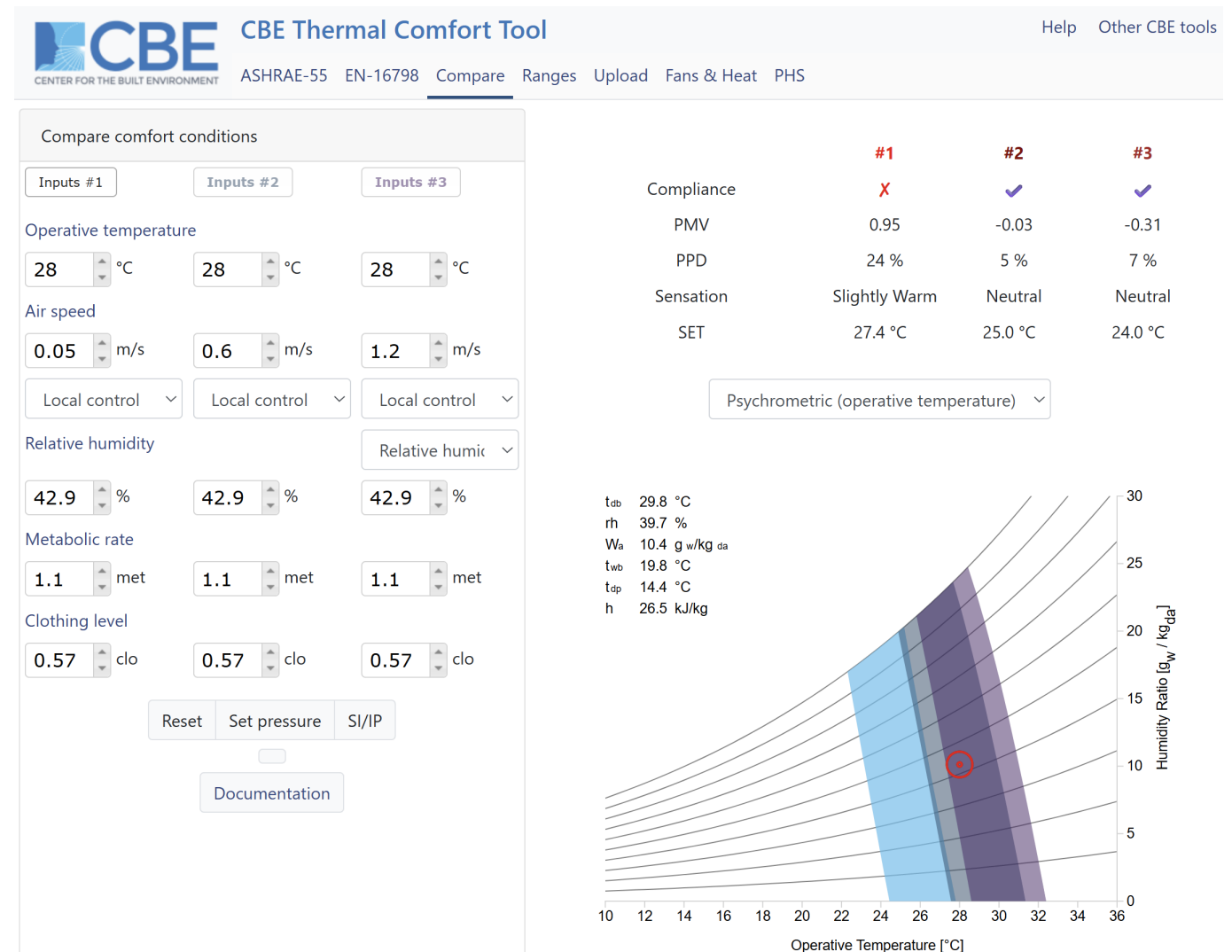




# Lab Condition

- Room Air temperature  $28^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$
- Relative Humidity = no control
- Experiments were only done in the morning to minimize the influence of solar radiation from west-facing façade.
- $28^{\circ}\text{C}$  was selected because the PMV is close to +1 (slightly warm) when there is no air movement, exceeding the comfort zone between -0.5 and +0.5
- Comparable with previous studies
- Outdoor temperature was not an “ideal” summer condition, but cold and rainy

Date	Outdoor_T	Rain	Air_T	RH	Globe_T	Participants
26-May	15.9	No	28.0	38.6	28.2	4
27-May	15.8	Yes	28.0	47.8	27.9	4
2-Jun	16.4	No	28.0	42.2	28.1	4
4-Jun	18.0	No	28.2	42.6	28.5	4
5-Jun	16.5	Yes	28.3	40.6	28.2	2
6-Jun	17.0	Yes	27.9	39.9	28.2	3
10-Jun	14.4	No	27.9	48.7	27.9	3
Average	16.3	--	28.0	42.9	28.1	--



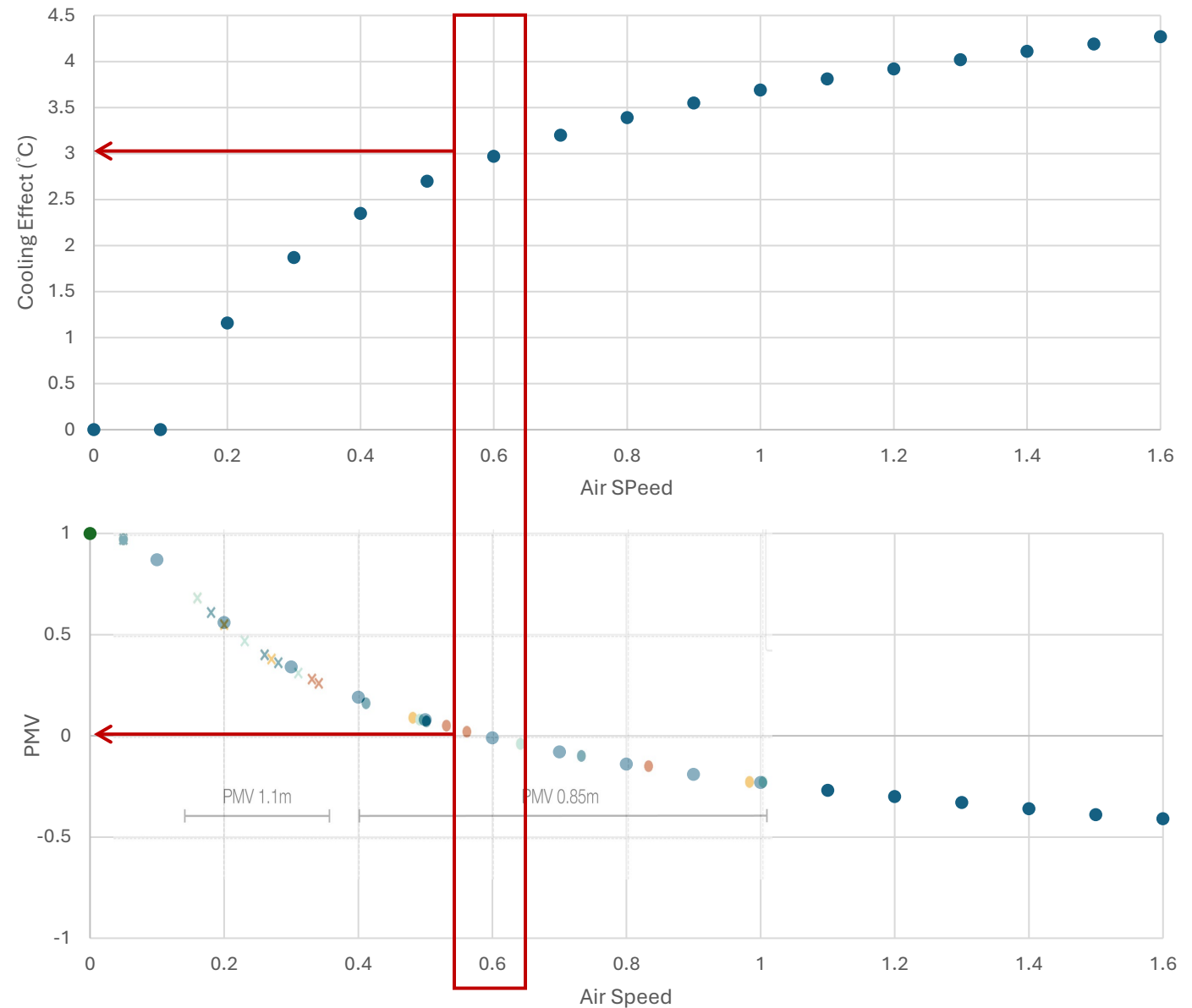




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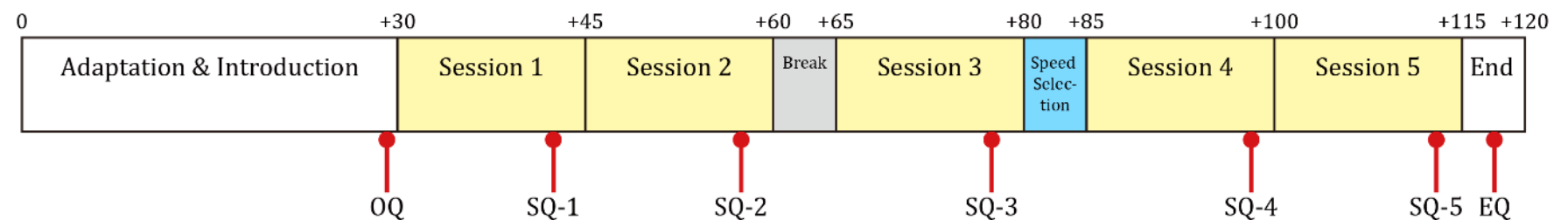




# Experiment Procedure

- 24 volunteers from 7 days
- Sex:
  - male = 12 persons
  - female = 12 persons
- Age:
  - 20-29 = 18 persons
  - 30-39 = 6 persons
- Only Case\_1A was tested
- Fan speed sessions in random order

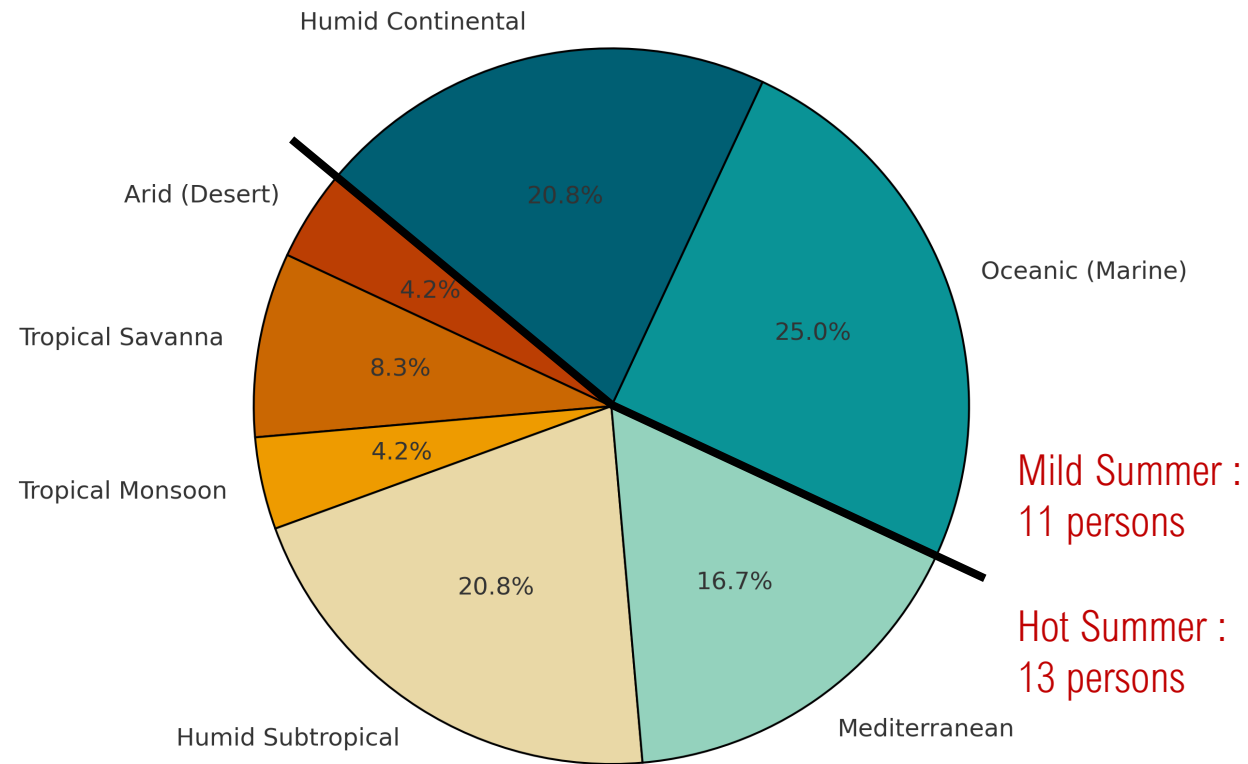
Date		26-May	27-May	2-Jun	4-Jun	5-Jun	6-Jun	10-Jun
		Monday	Tuesday	Monday	Wednesday	Thursday	Friday	Tuesday
Nr. Participants		4	4	4	4	2	3	3
Session	1	0	5	3	8	Selected-3	3	5
	2	5	Selected-3	0	5	3	8	Selected-4
	3	8	3	8	Selected-6	0	5	0
	4	3	8	Selected-6	0	5	0	8
	5	Selected-7	0	5	3	8	Selected-5	3



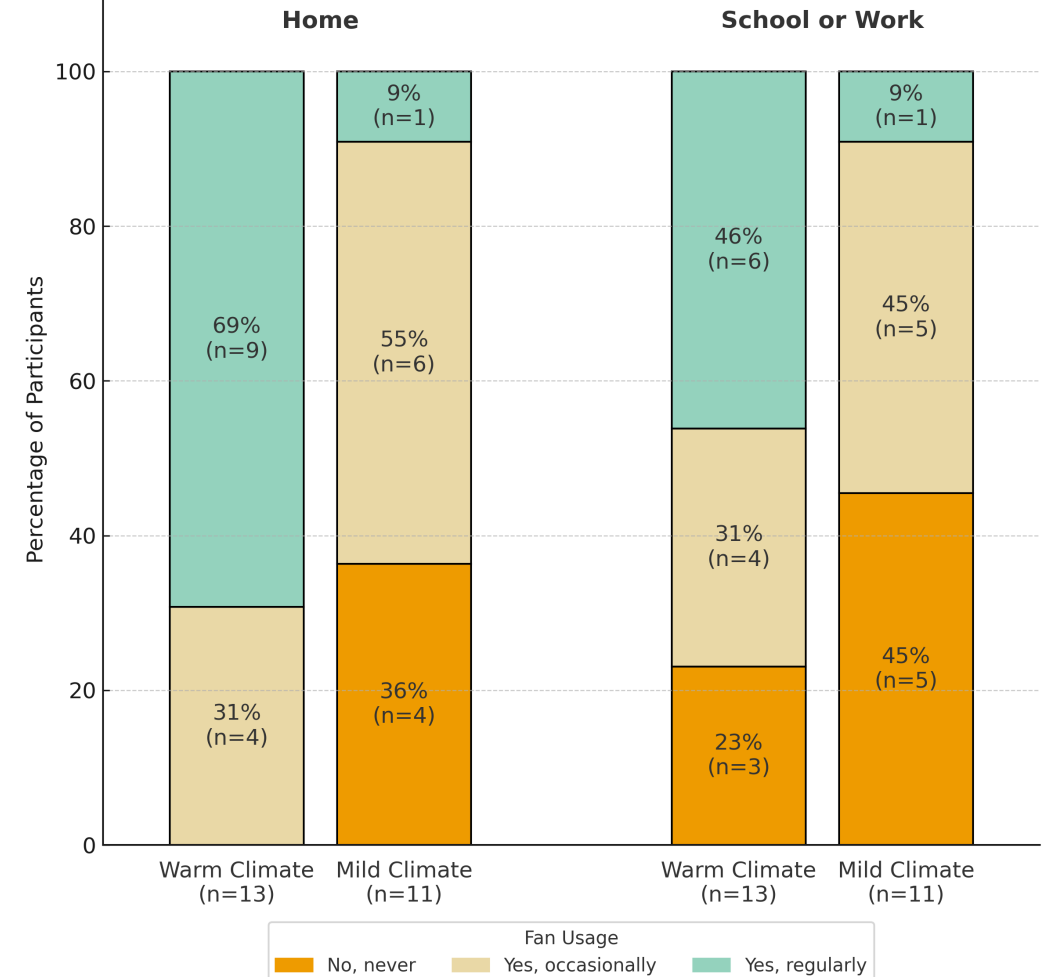


# Climate Background and Fan Usage for Cooling

Climate Zone Background Of Participants



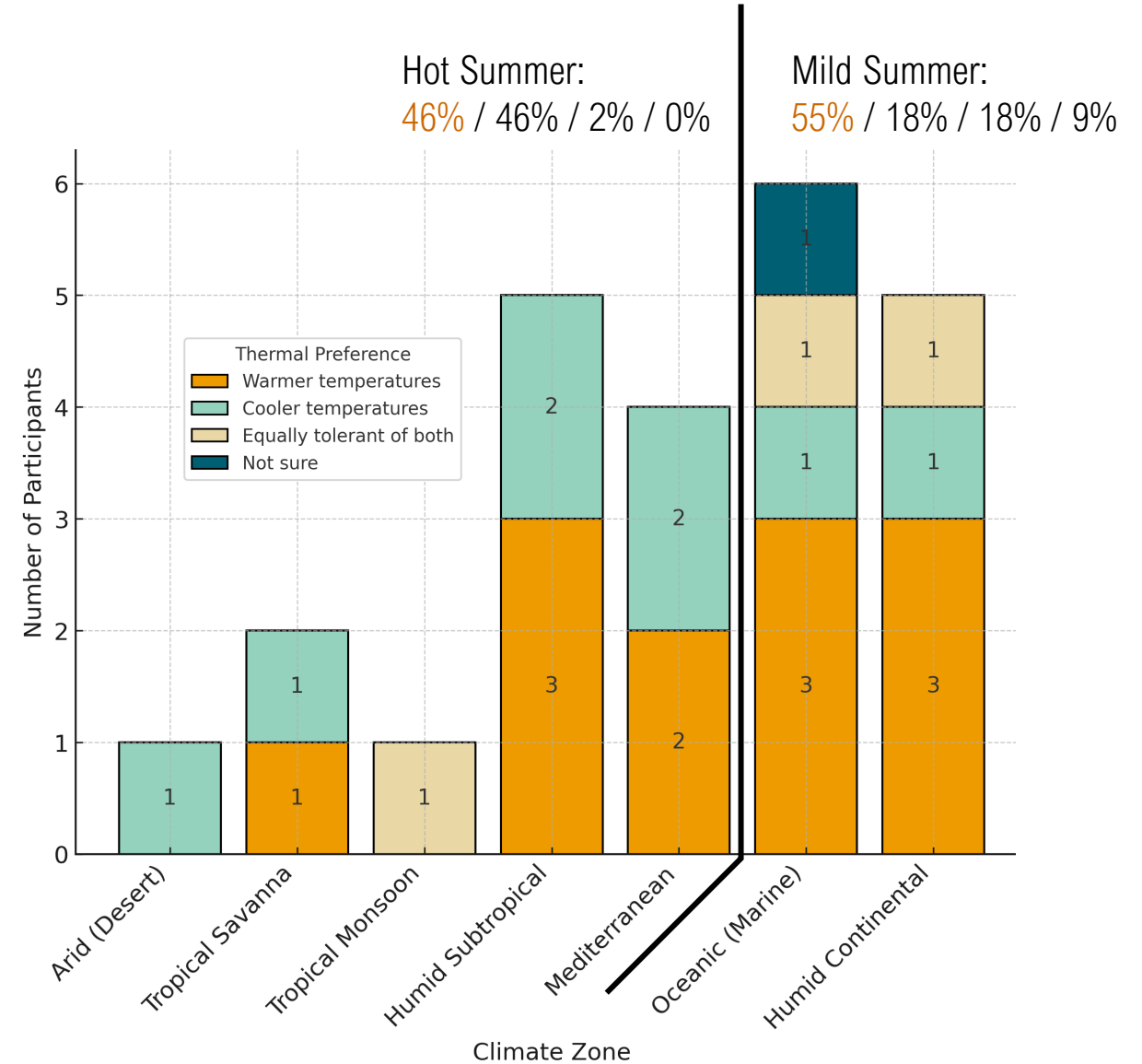
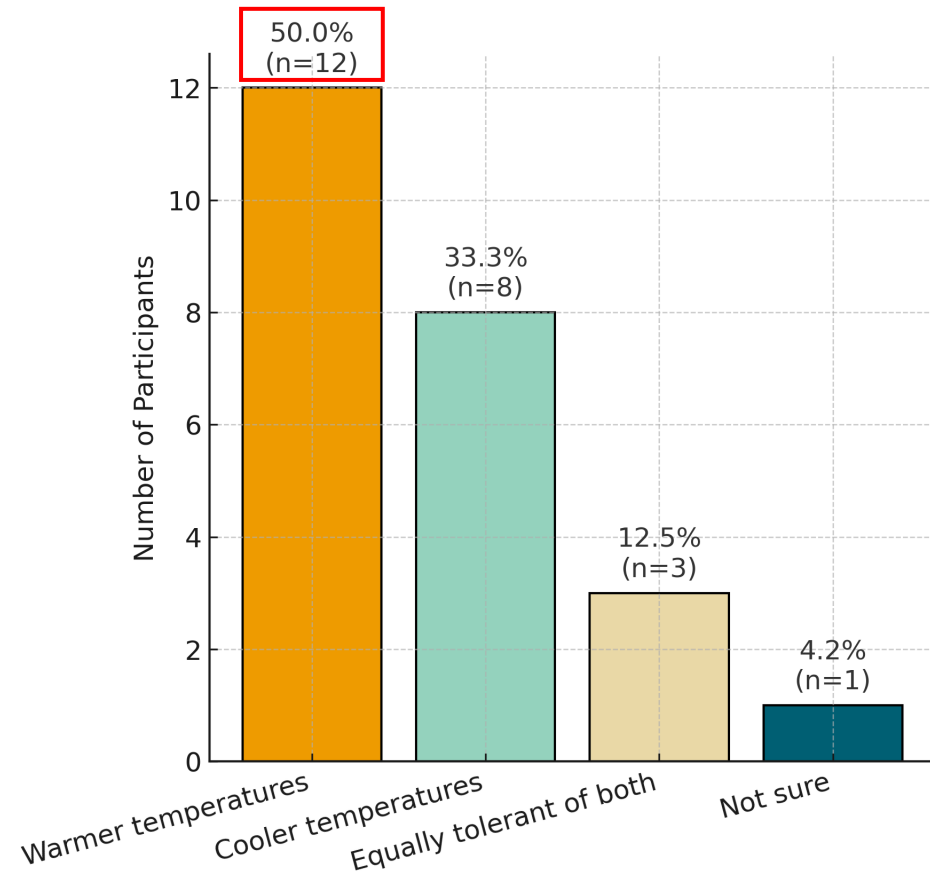
Fan Usage for Cooling





# Self-reported Thermal Tolerance

*Are you more tolerant of warmer or cooler temperature?*



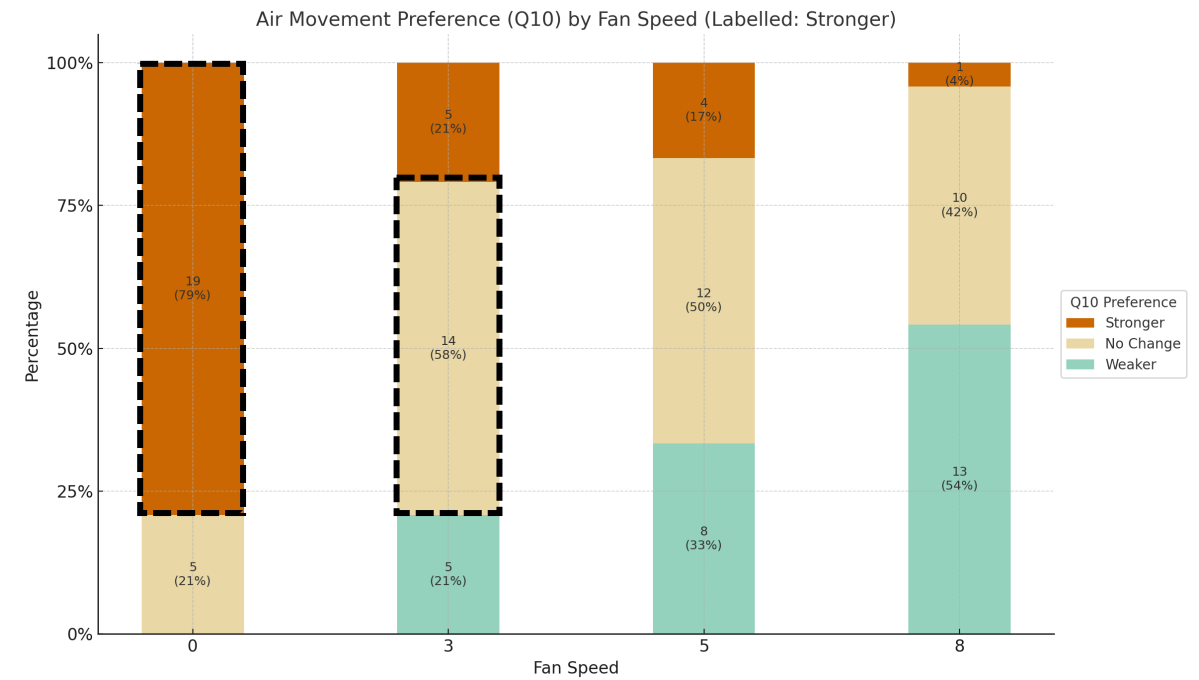
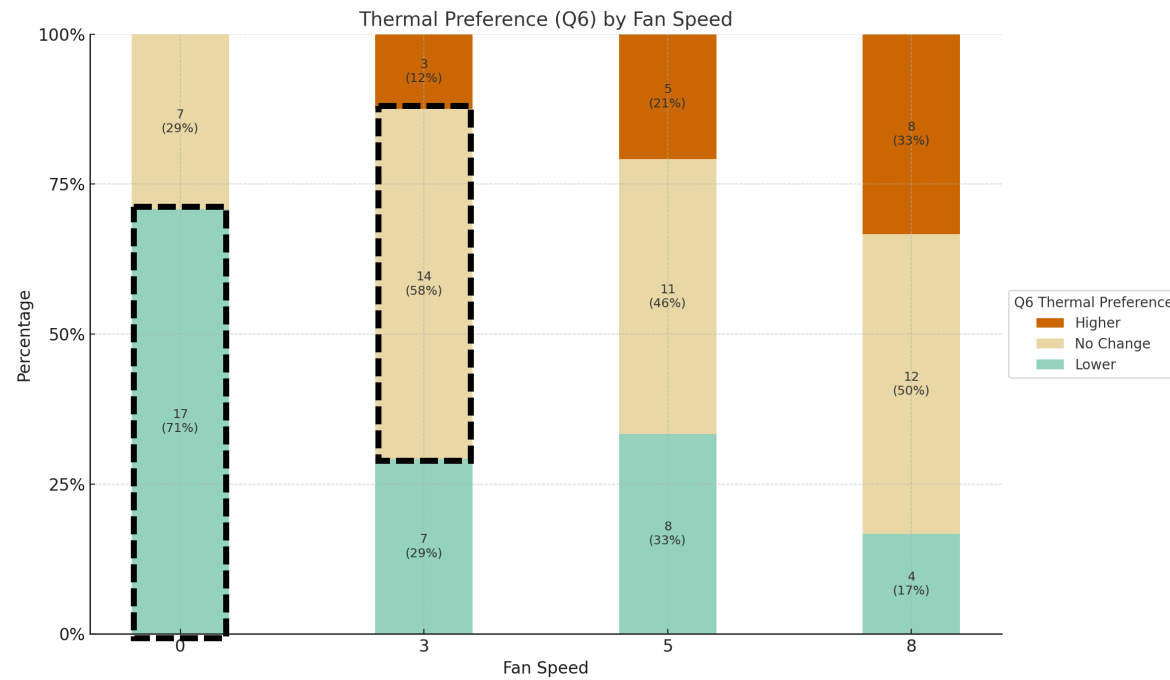


# Preferred Air Speed

For given and group-selected fan speed sessions

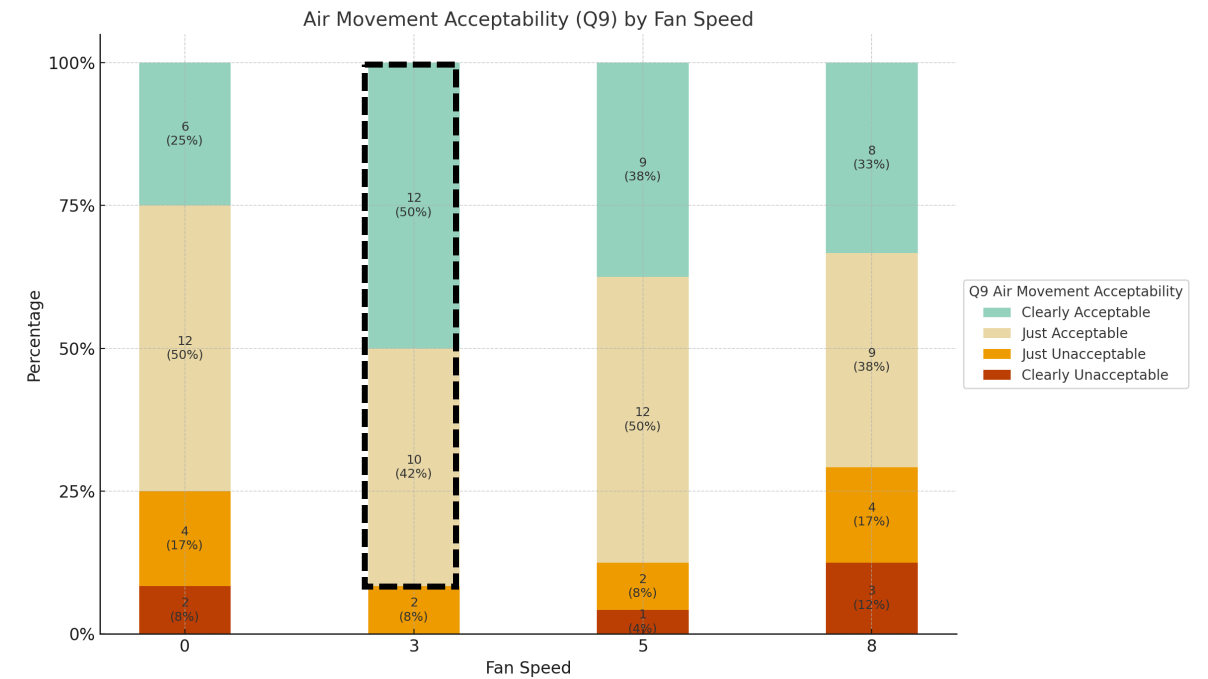
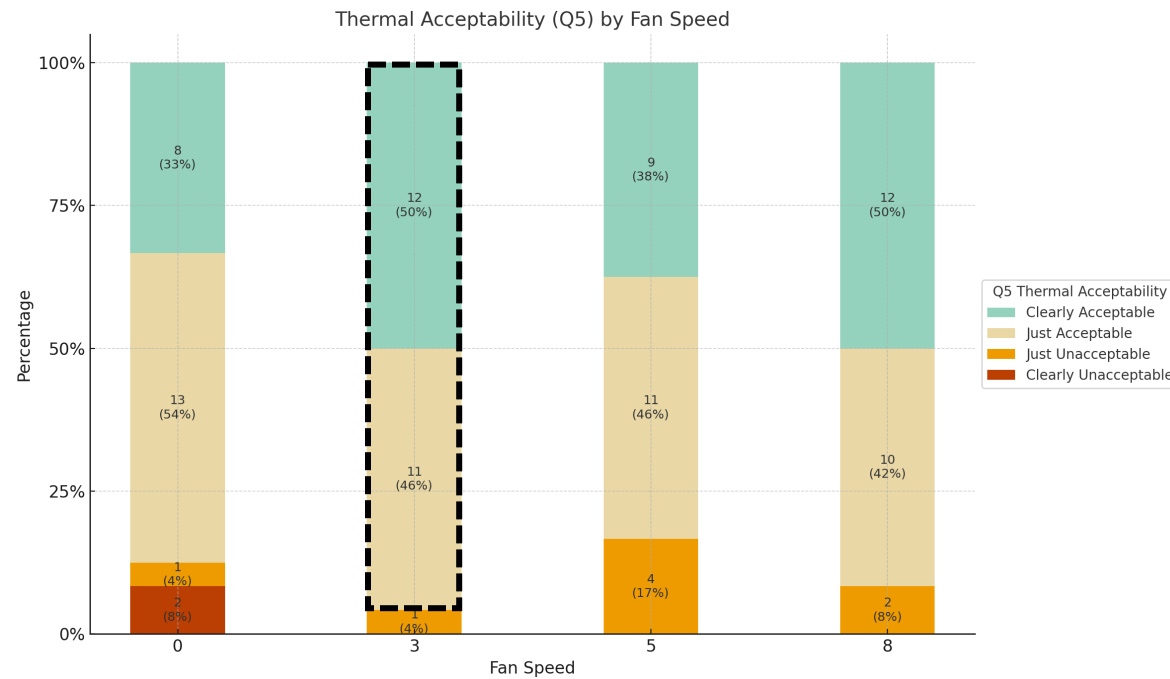


# Thermal & Air Movement Preference



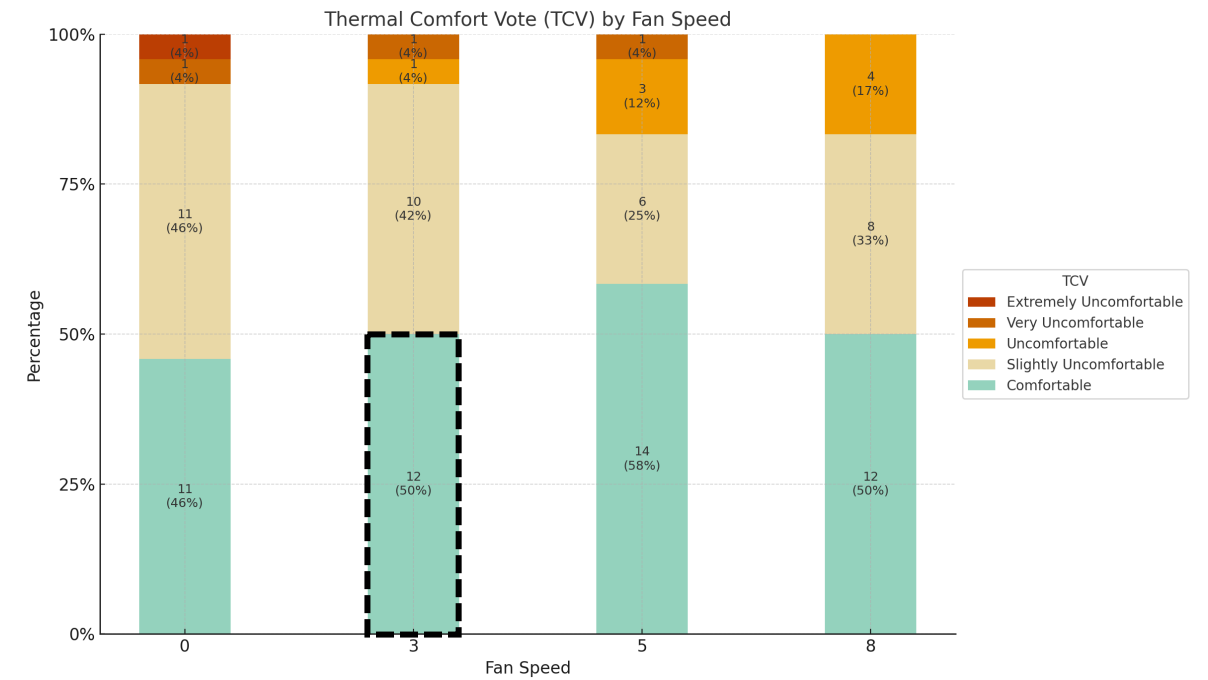
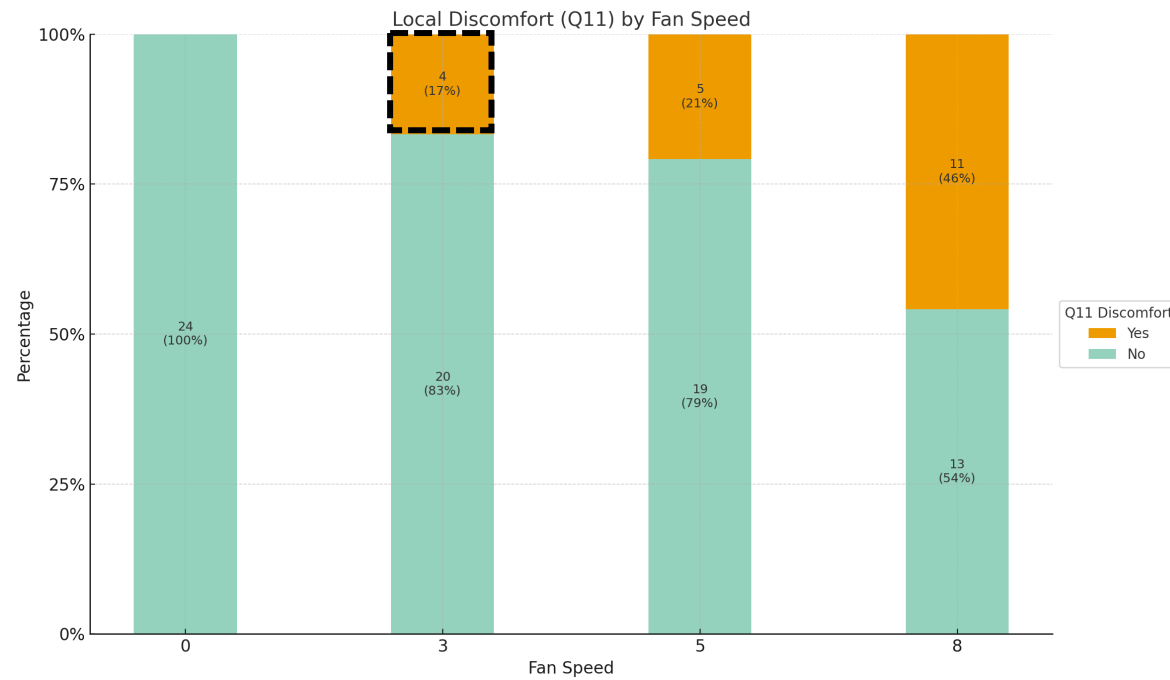


# Highest percentage of “Acceptable”





# Air Movement Acceptability and Feeling of Local Draft

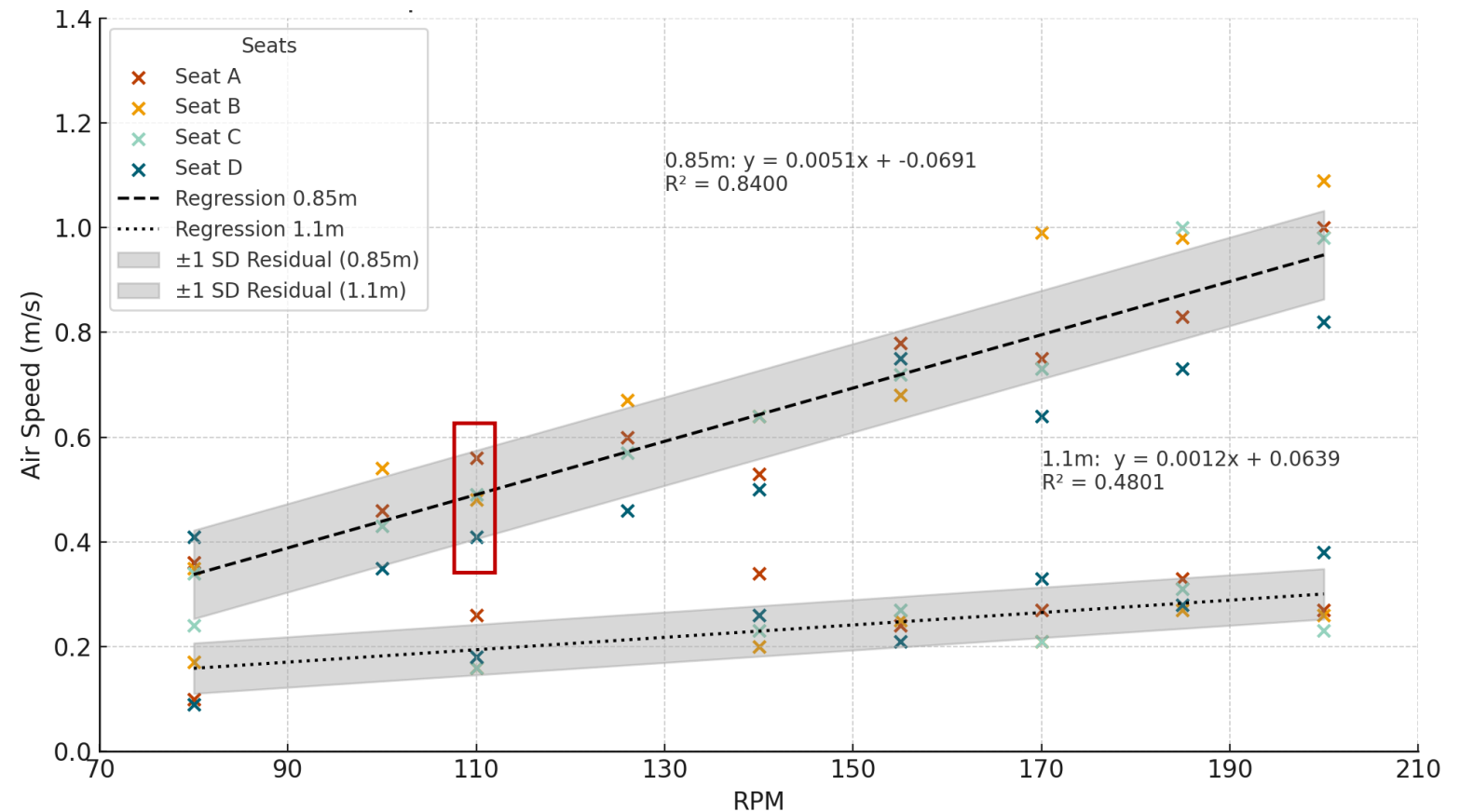






# Preferred Air Speed without group-control

- Seat air speed ranging from 0.41m/s to 0.56m/s
- Average seat air speed 0.49m/s
- Total power consumption 7.2W,
- 1.8W per person



Measurement	Speed	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5	Speed_6	Speed_7	Speed_8	Speed_9
height	RPM	80	100	110	126	140	155	170	185	200
0.85m	A	0.36	0.46	0.56	0.6	0.53	0.78	0.75	0.83	1
	B	0.35	0.54	0.48	0.67	0.64	0.68	0.99	0.98	1.09
	C	0.34	0.43	0.49	0.57	0.64	0.72	0.73	1	0.98
	D	0.41	0.35	0.41	0.46	0.5	0.75	0.64	0.73	0.82
	Avg_seat	0.37	0.45	0.49	0.58	0.58	0.73	0.78	0.89	0.97
	Avg_all	0.31	0.39	0.42	0.5	0.52	0.63	0.68	0.77	0.83

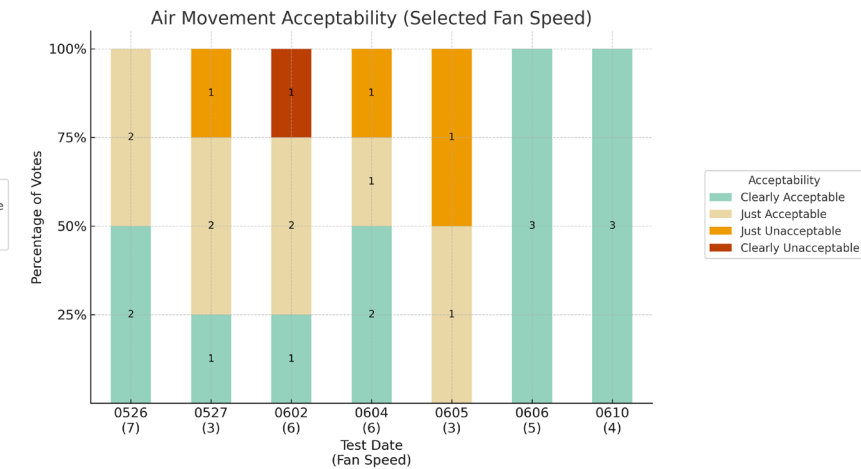
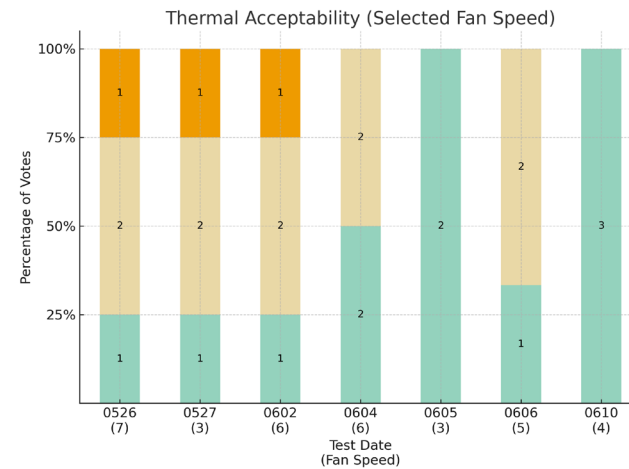
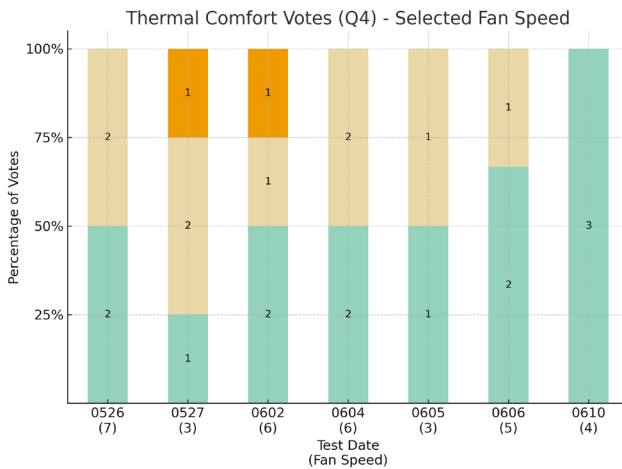


# Group-selected Fan Speeds

Date		26-May	27-May	2-Jun	4-Jun	5-Jun	6-Jun	10-Jun
		Monday	Tuesday	Monday	Wednesday	Thursday	Friday	Tuesday
Nr. Participants		4	4	4	4	2	3	3
Session	1	0	5	3	8	Selected-3	3	5
	2	5	Selected-3	0	5	3	8	Selected-4
	3	8	3	8	Selected-6	0	5	0
	4	3	8	Selected-6	0	5	0	8
	5	Selected-7	0	5	3	8	Selected-5	3



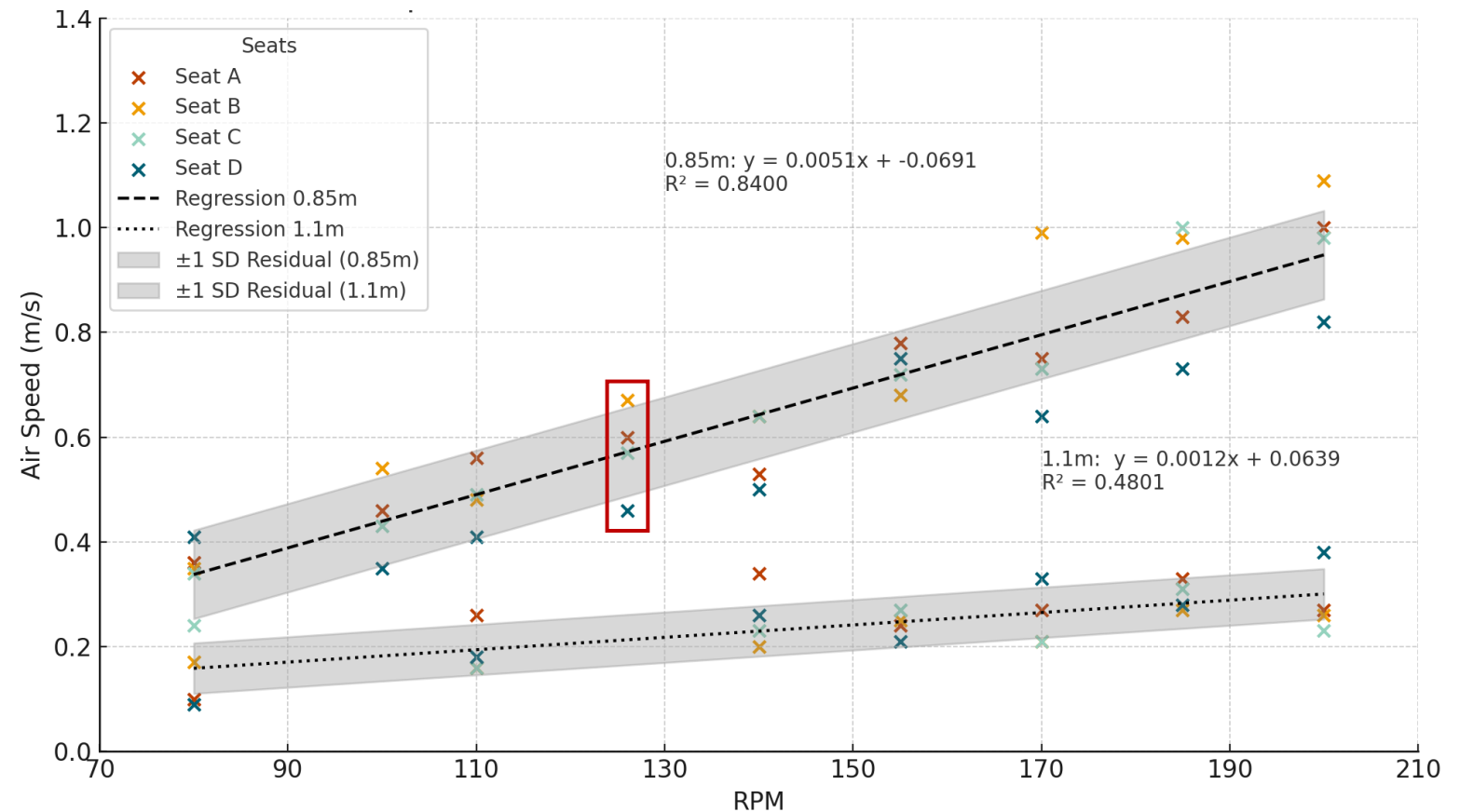
# Preferred Air Speed with Group Control





# Preferred Air Speed without group-control

- Seat air speed ranging from 0.41m/s to 0.56m/s
- Average seat air speed 0.49m/s
- Total power consumption 7.2W,
- 1.8W per person

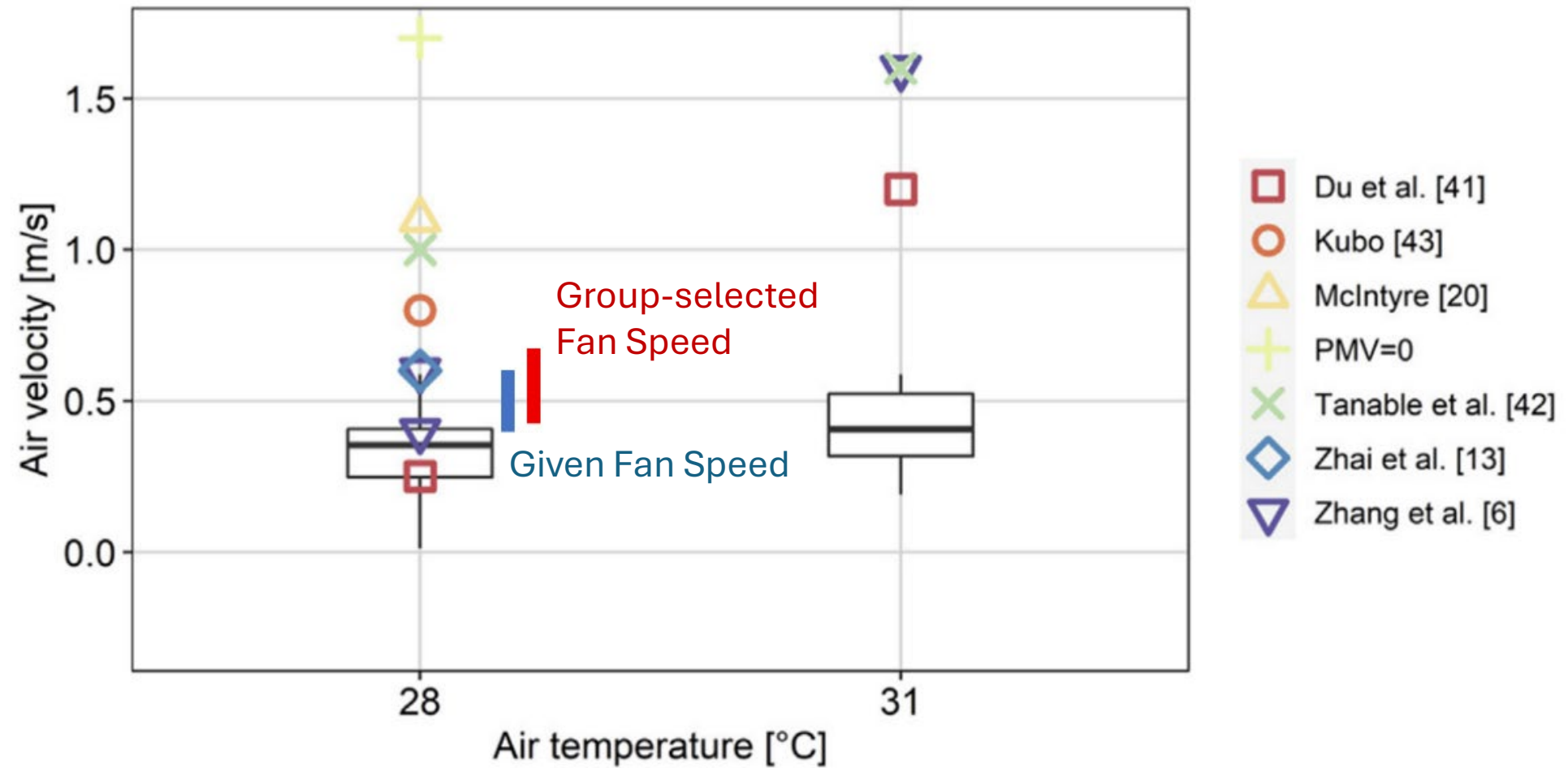


Measurement	Speed	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5	Speed_6	Speed_7	Speed_8	Speed_9
height	RPM	80	100	110	126	140	155	170	185	200
0.85m	A	0.36	0.46	0.56	0.6	0.53	0.78	0.75	0.83	1
	B	0.35	0.54	0.48	0.67	0.64	0.68	0.99	0.98	1.09
	C	0.34	0.43	0.49	0.57	0.64	0.72	0.73	1	0.98
	D	0.41	0.35	0.41	0.46	0.5	0.75	0.64	0.73	0.82
	Avg_seat	0.37	0.45	0.49	0.58	0.58	0.73	0.78	0.89	0.97
	Avg_all	0.31	0.39	0.42	0.5	0.52	0.63	0.68	0.77	0.83



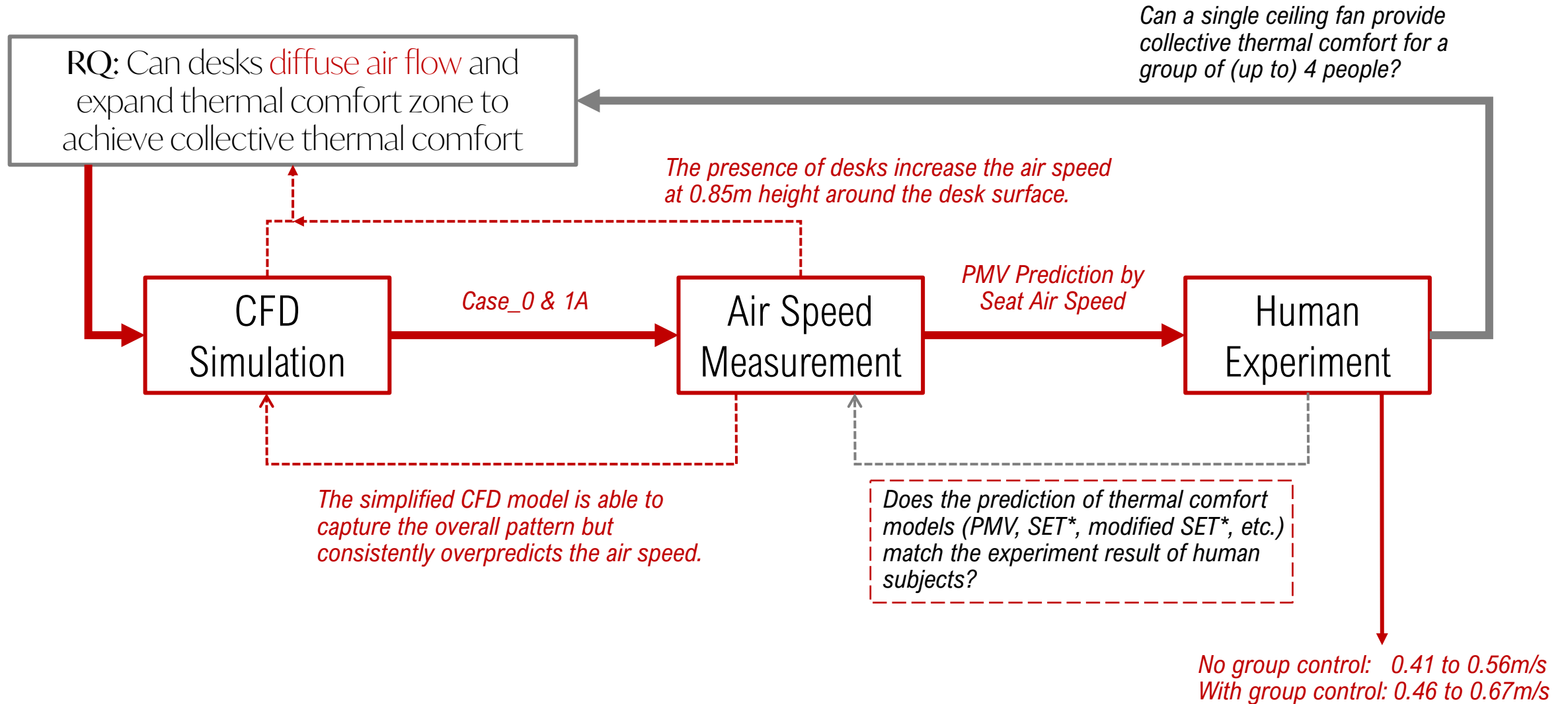


# Comparison with Previous Studies



Riseto et al. (2021)

# Multi-loop Validation



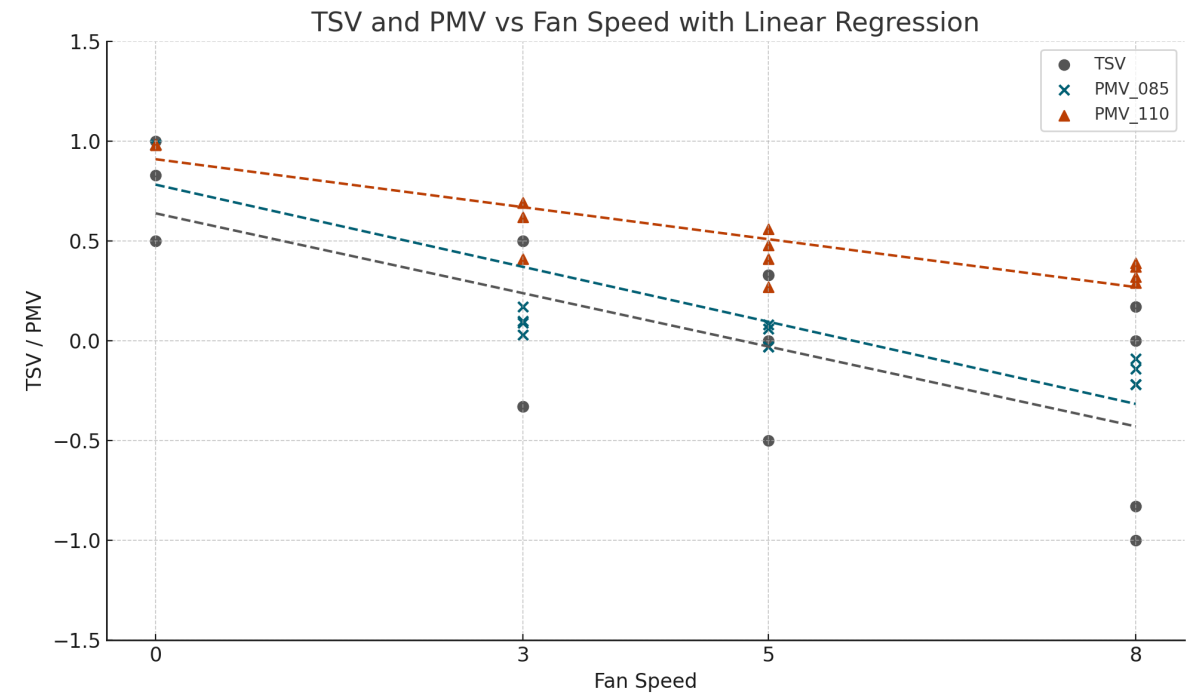
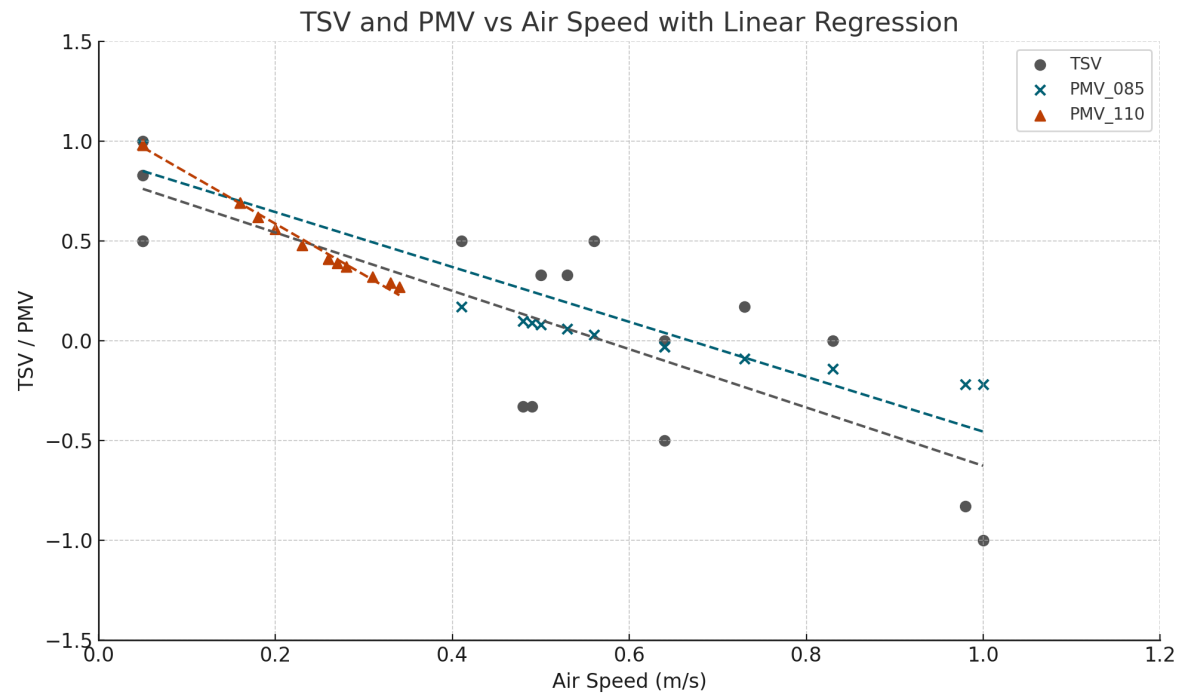


# PMV vs TSV

Prediction vs Actual Thermal Sensation

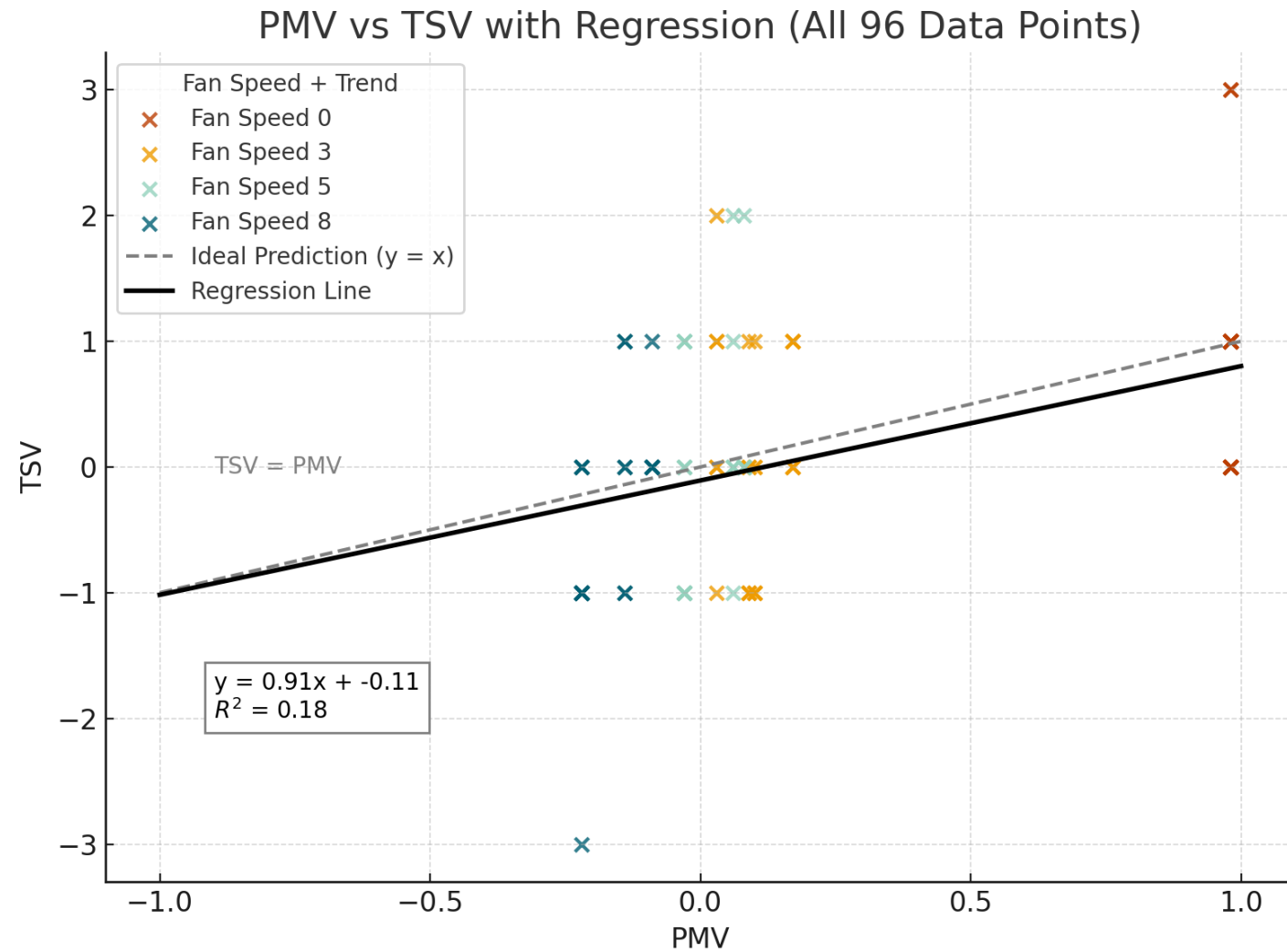


# TSV / PMV Comparison





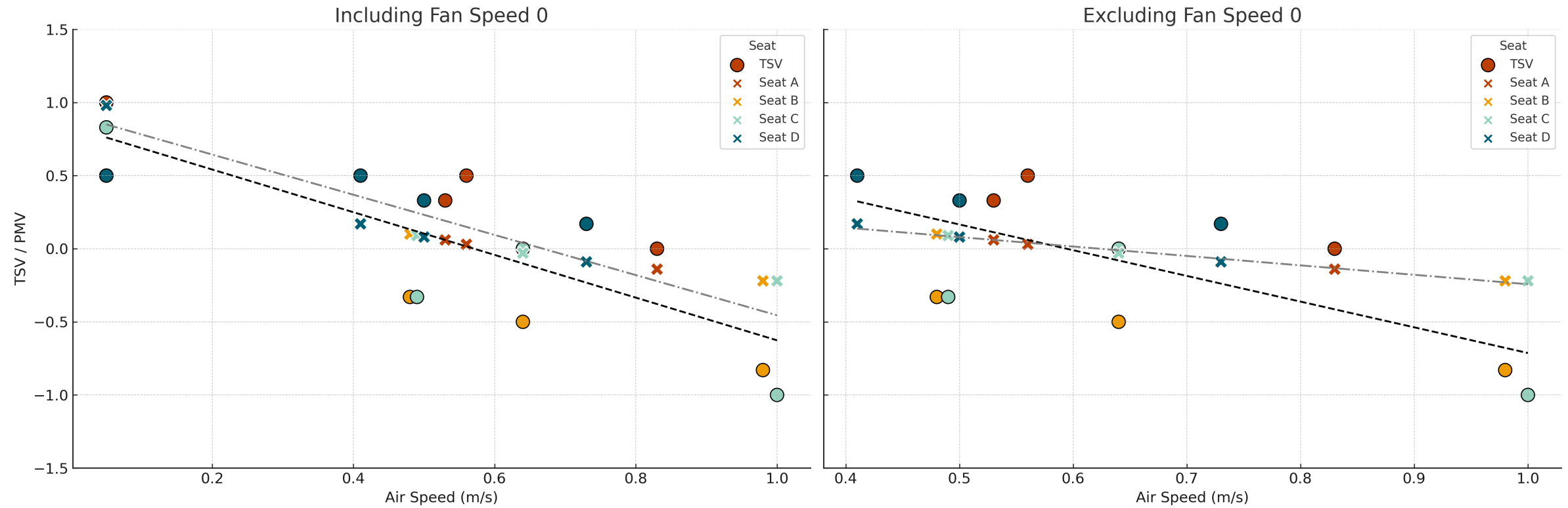
# Individual TSV / PMV Comparison by Fan Speed





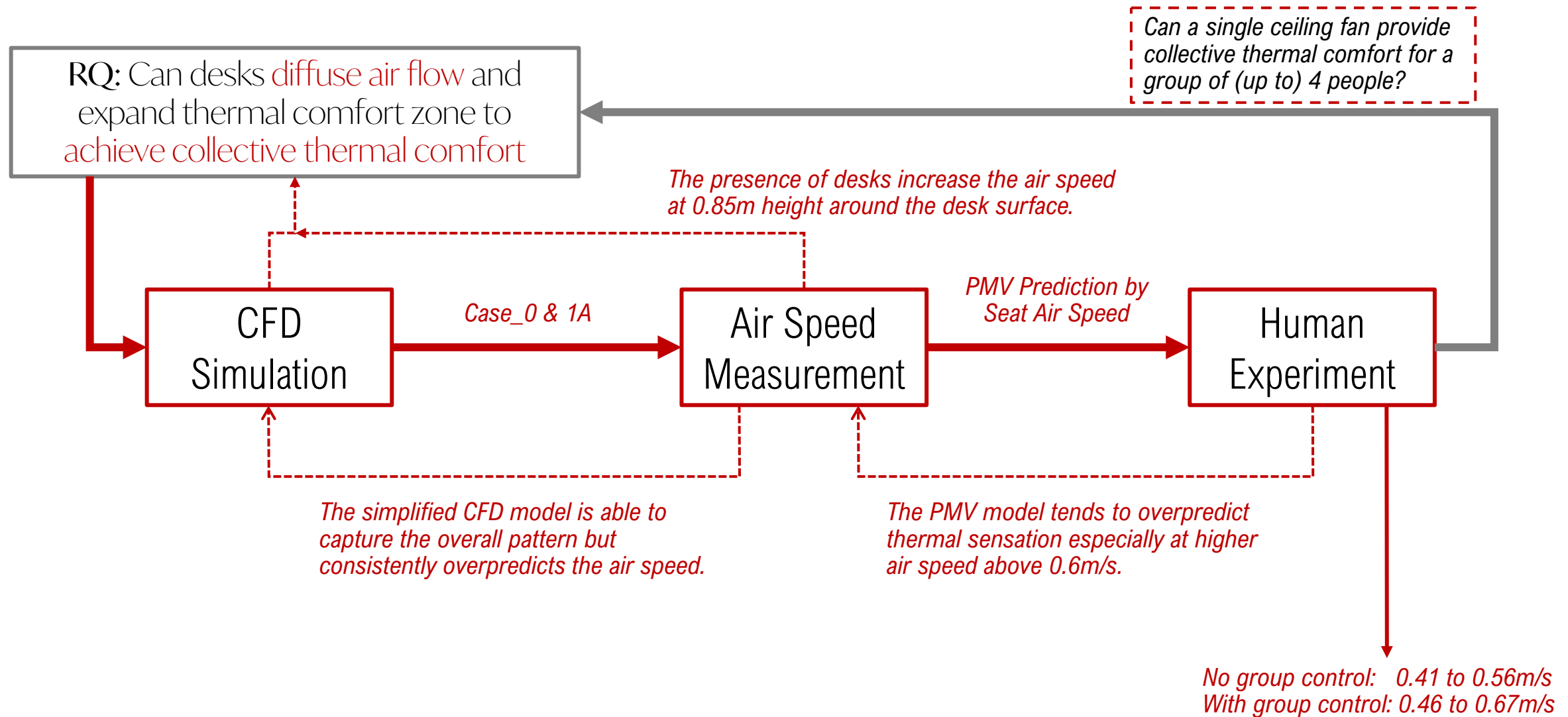


# Seat-average TSV vs PMV





# Multi-loop Validation

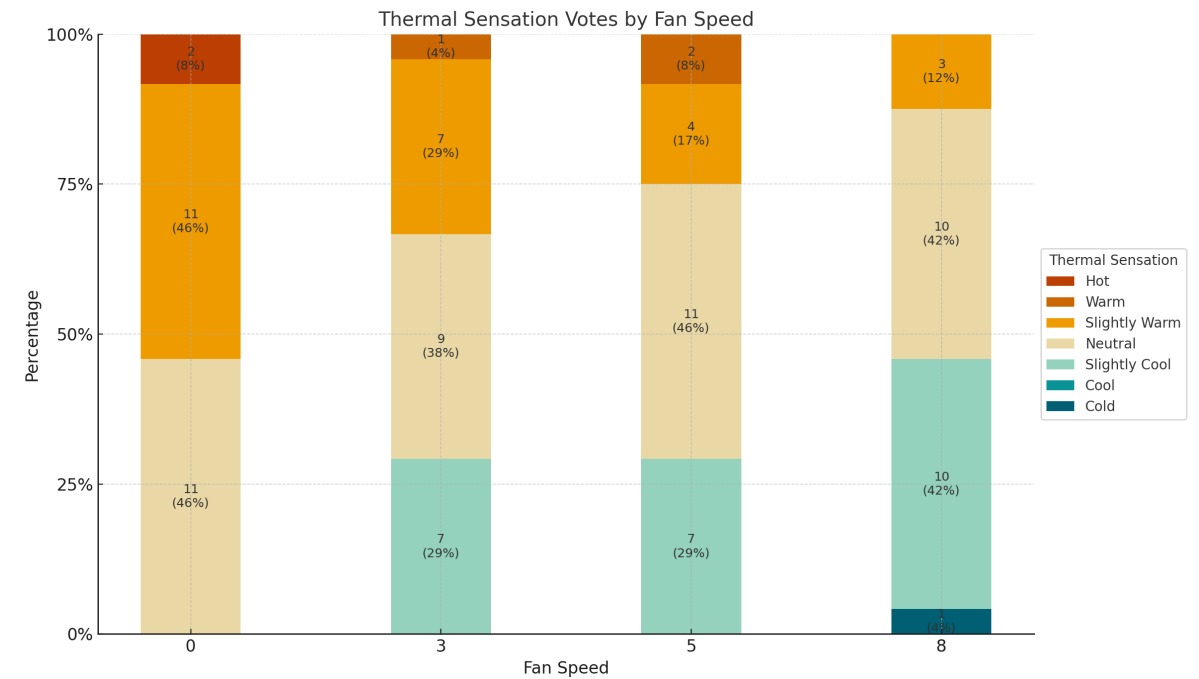
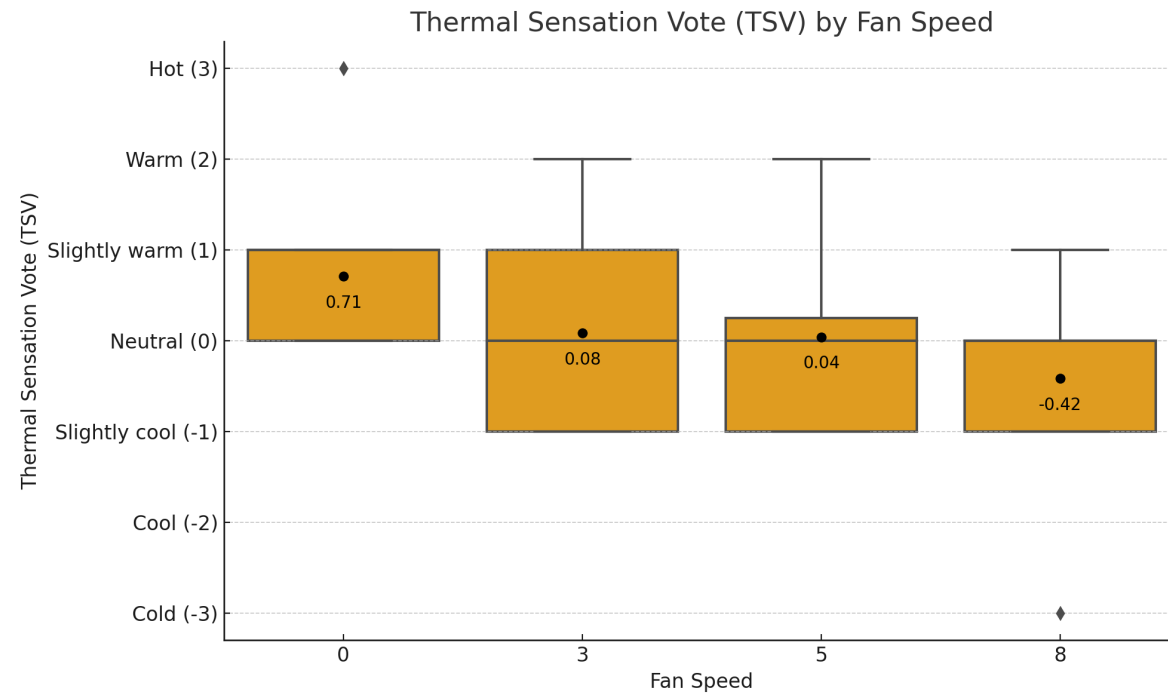




# Did Comfort Vote Improve?



# TSV did decrease as the air speed increased

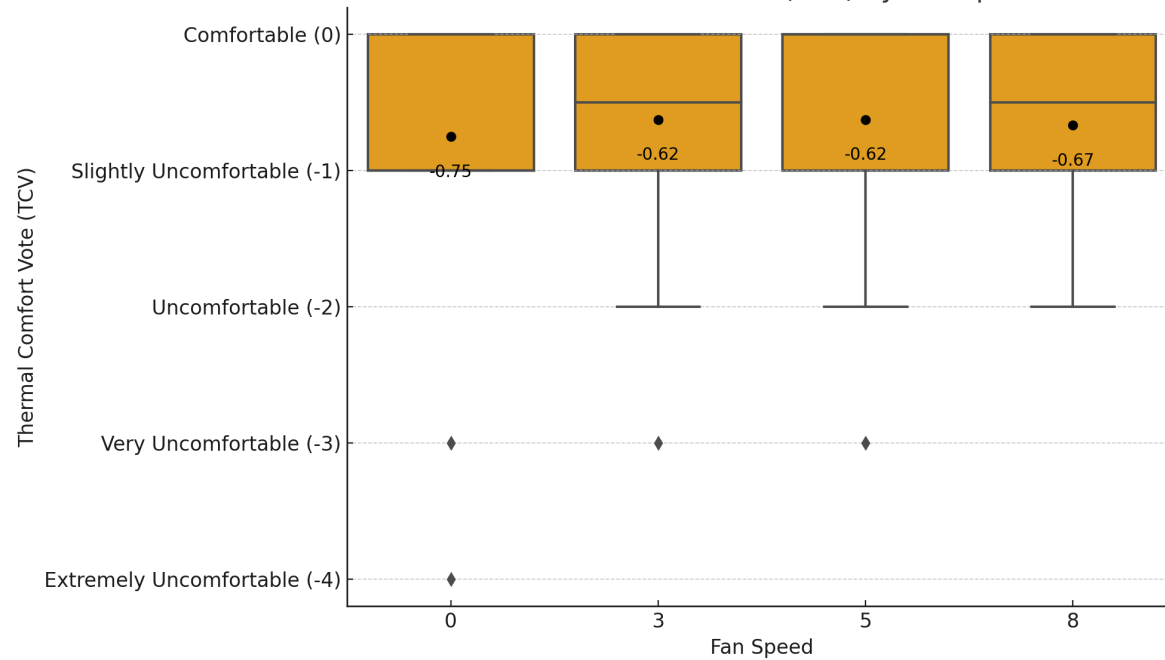




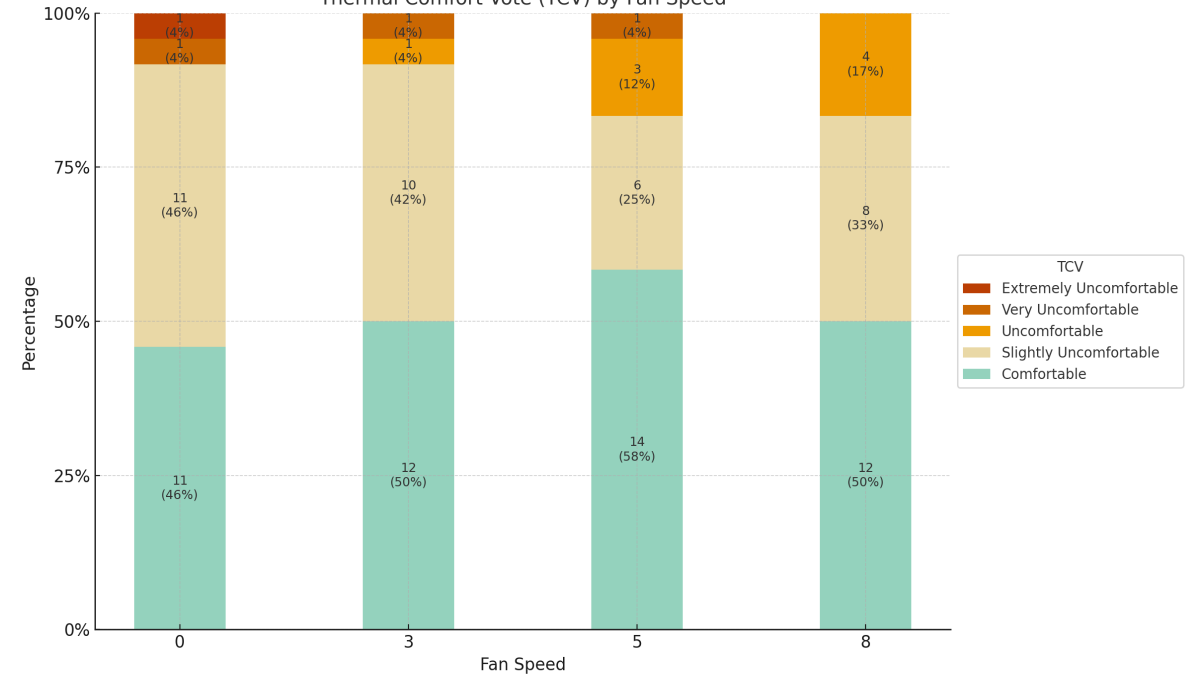
# But did the people feel more comfortable?

TCV	Count	Total Counts	%
Comfortable	8	11	72.7%

Thermal Comfort Vote (TCV) by Fan Speed



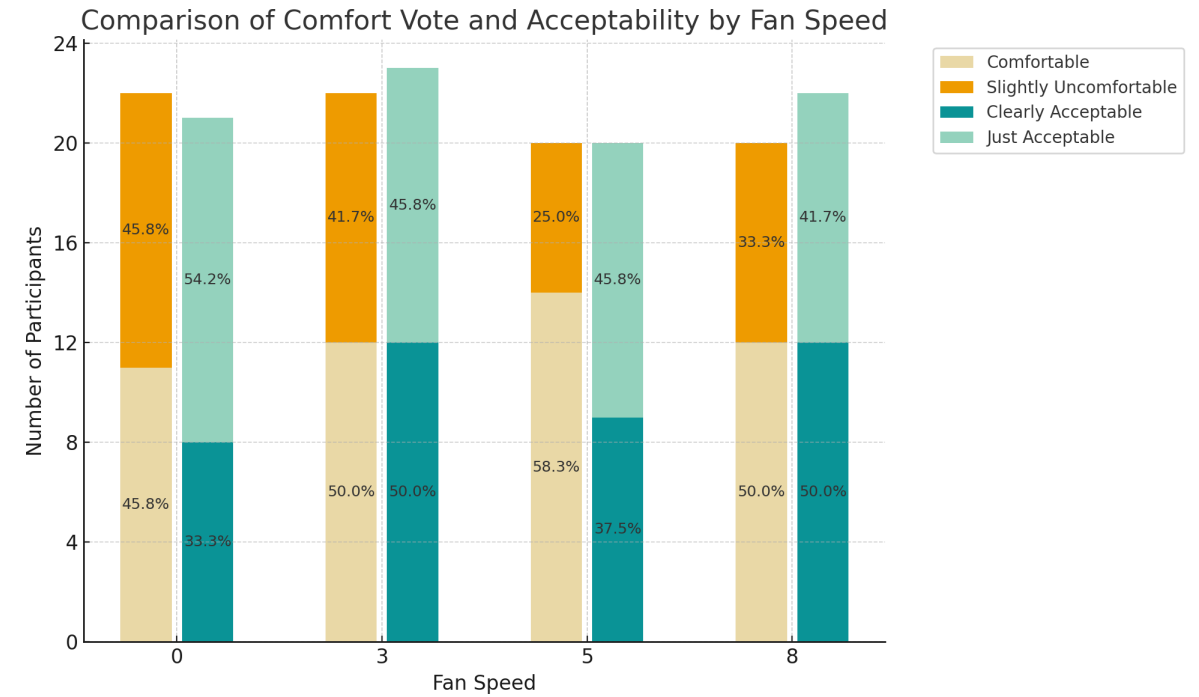
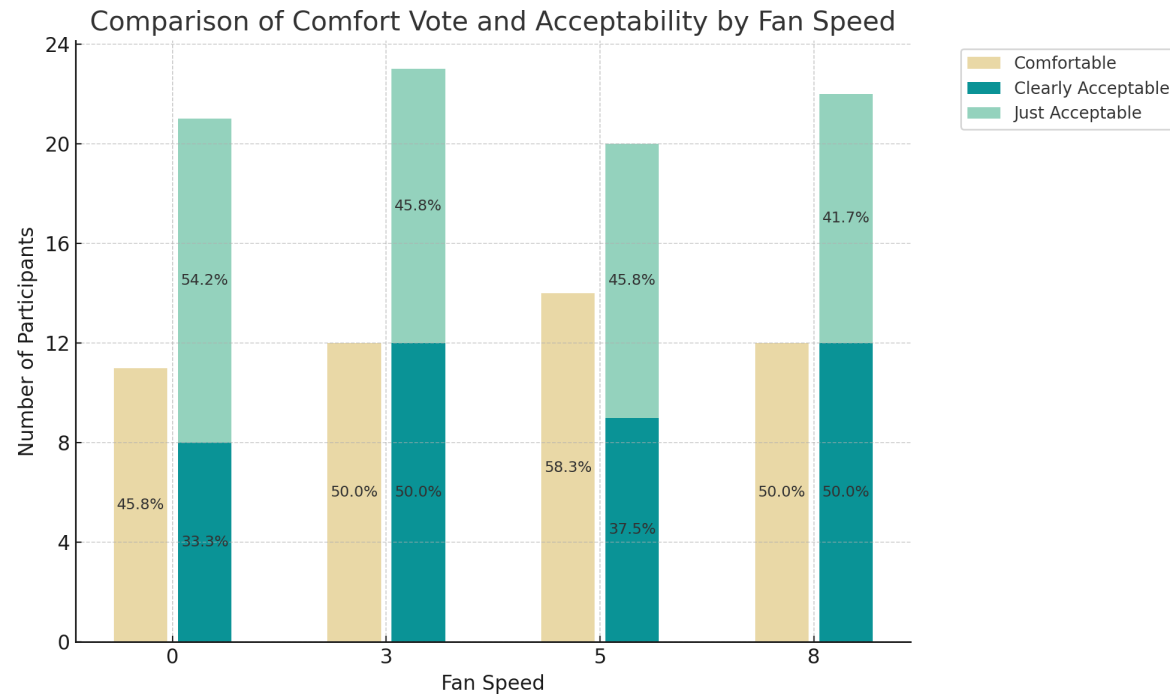
Thermal Comfort Vote (TCV) by Fan Speed





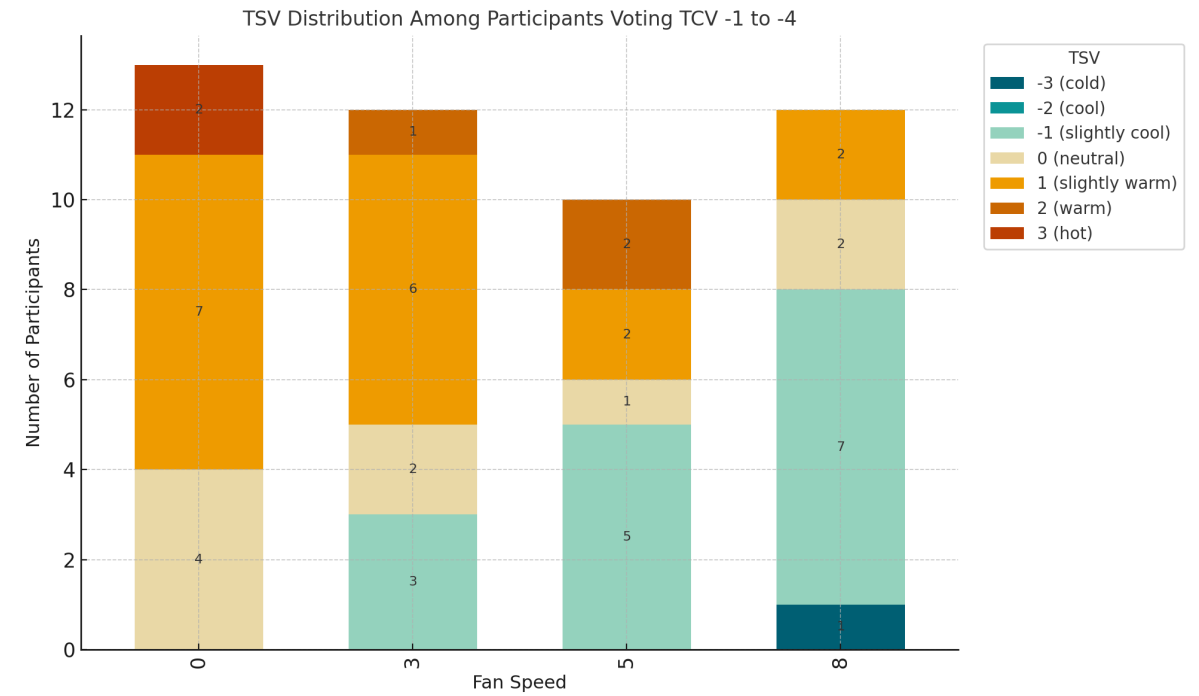
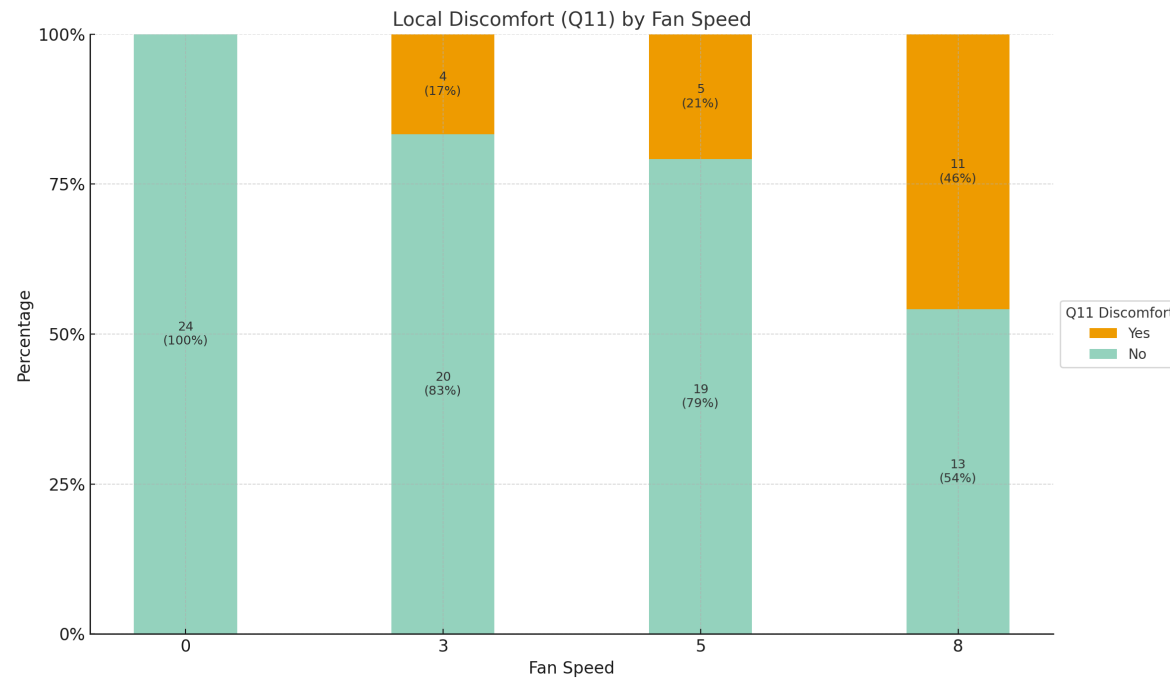


# Comfort Vote & Acceptability

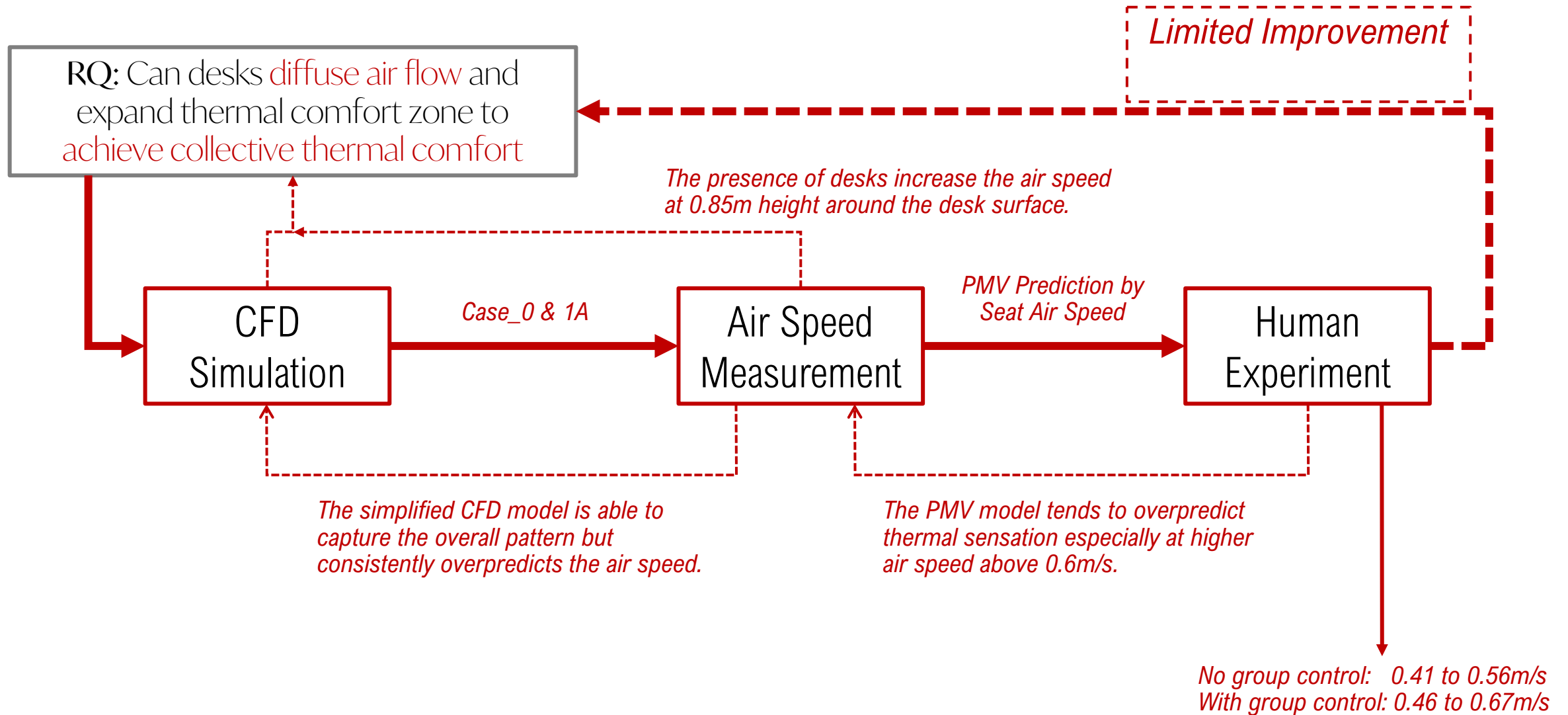




# Cause of Discomfort



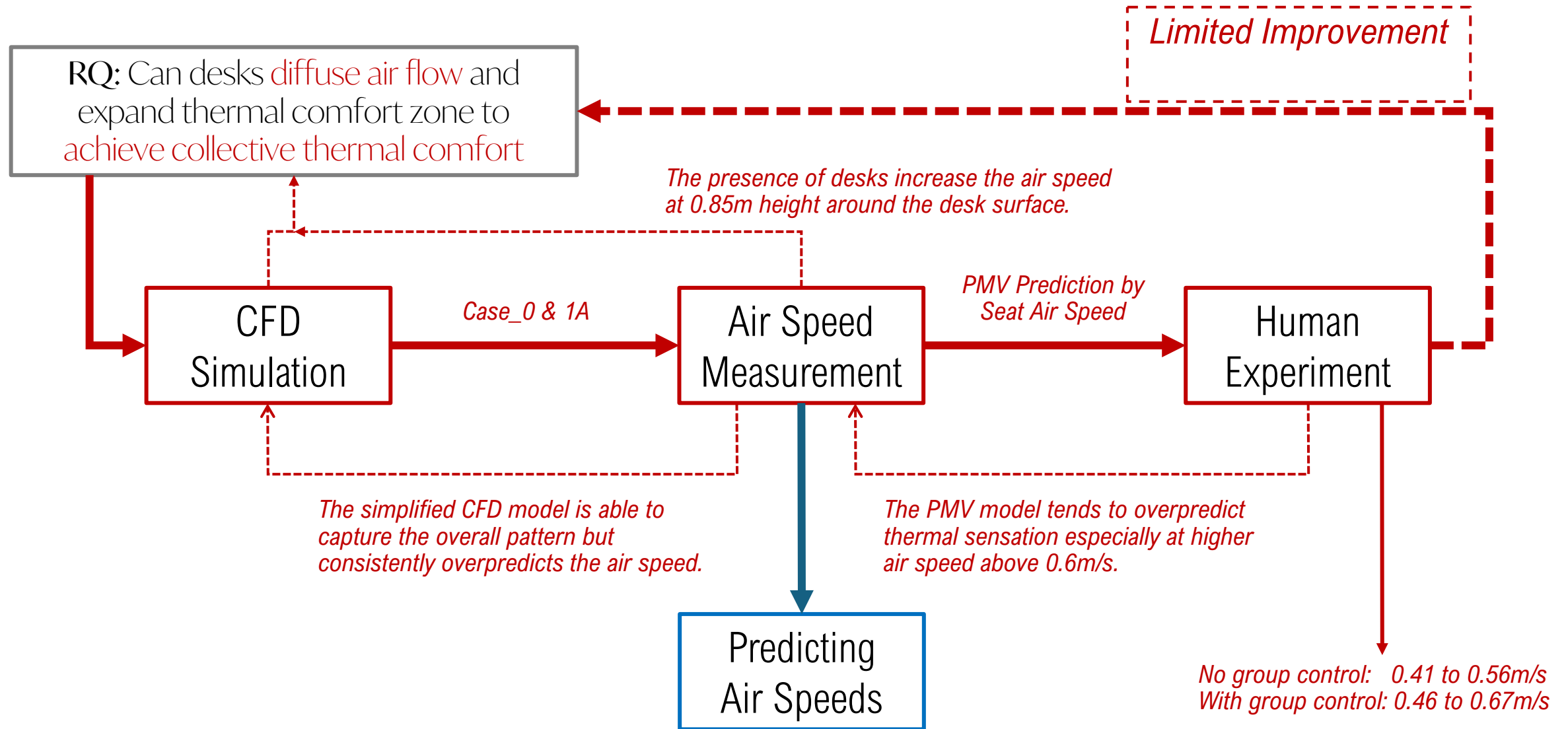
# Multi-loop Validation





One more thing...

# Multi-loop Validation





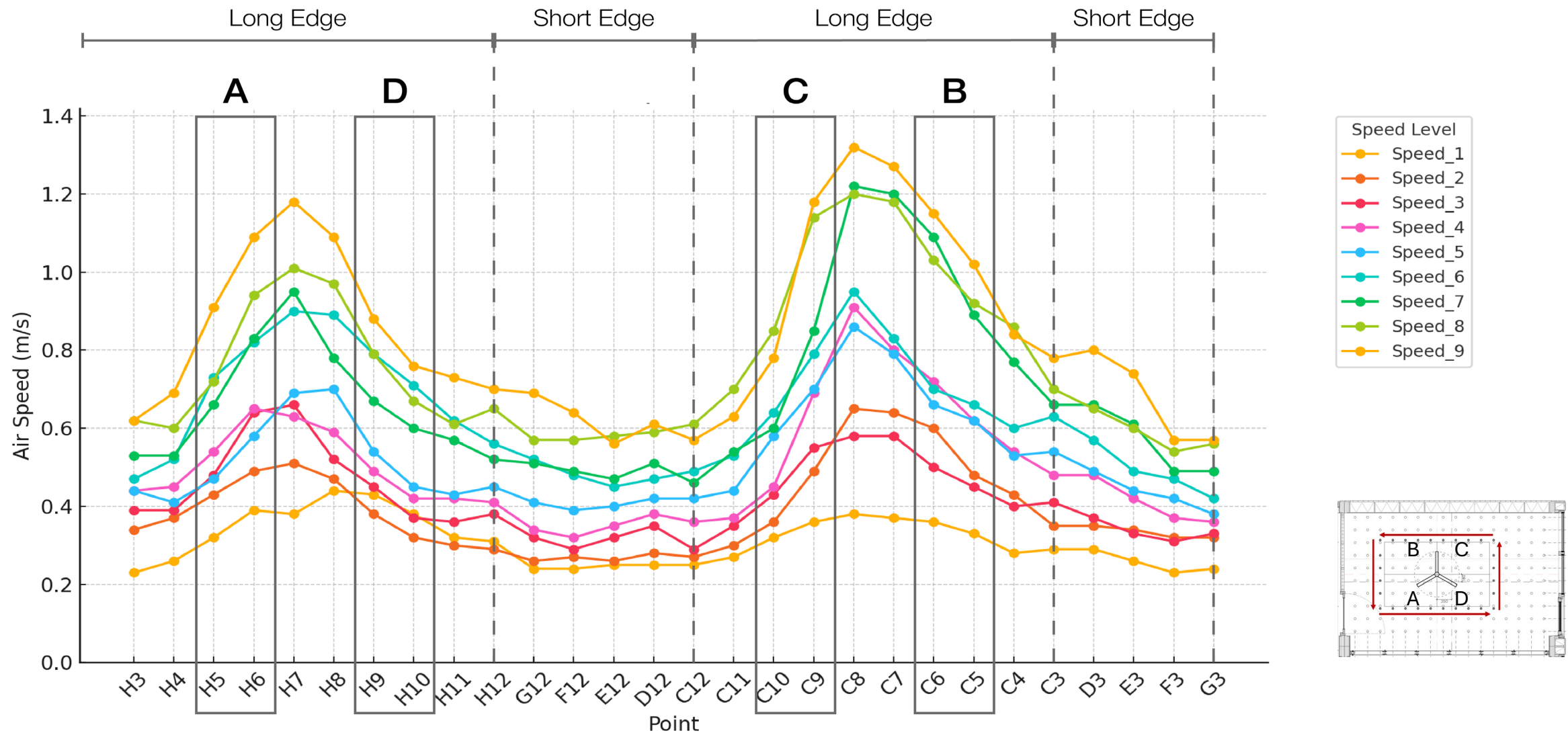
# Diffusion Power

Prediction with normalized pattern



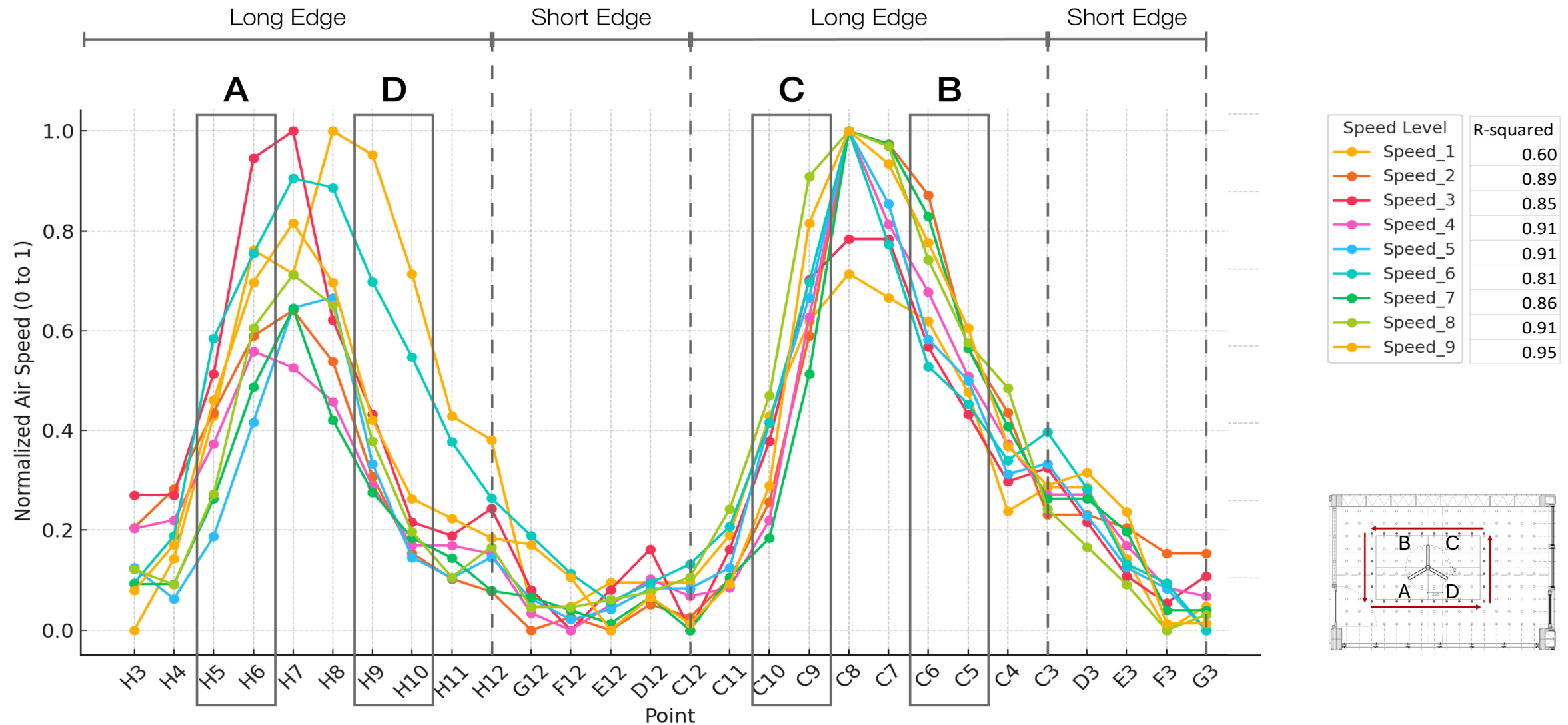


# Measurement of Air Speed (Fan Speed 1 - 9)





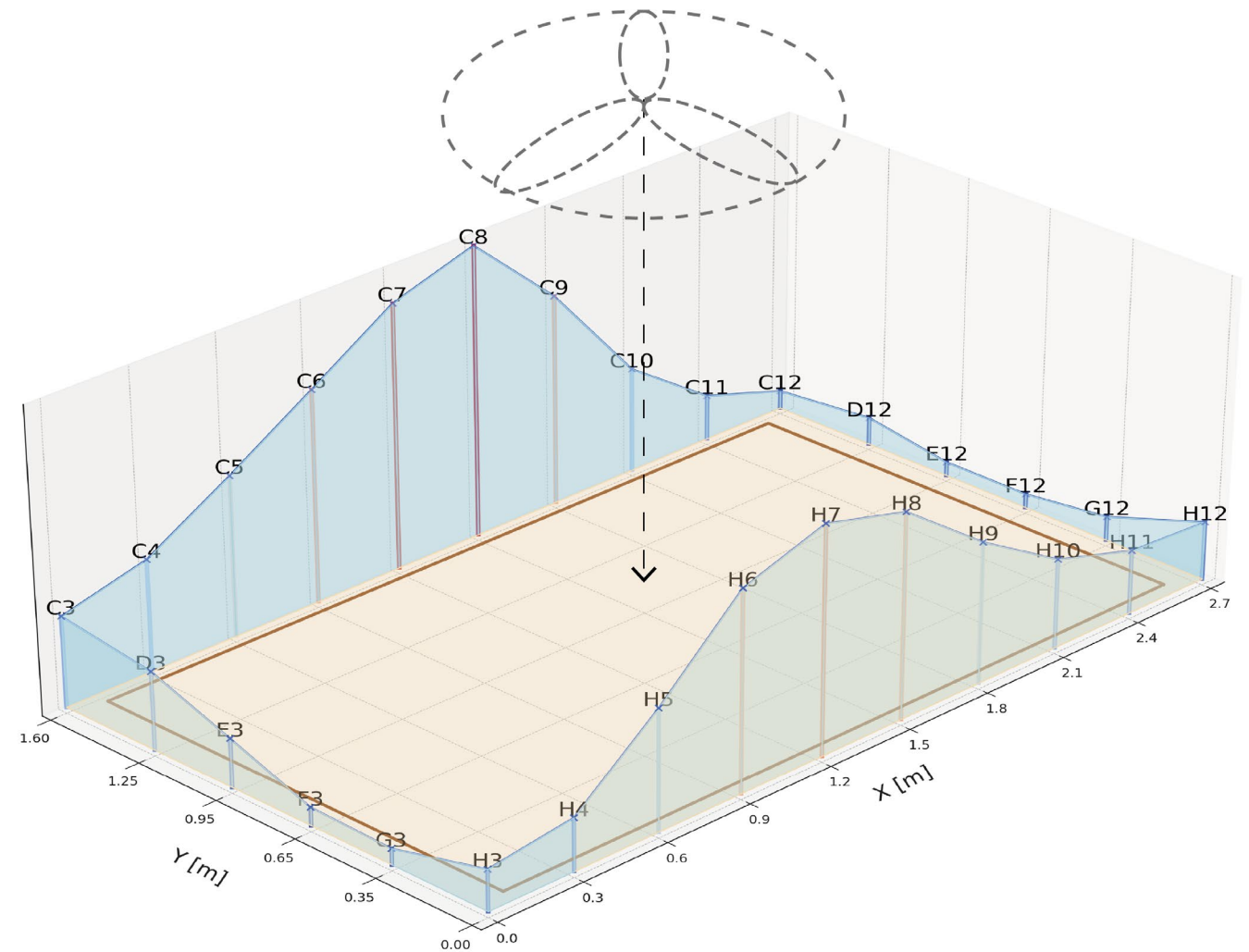
# Measurement of Air Speed (Fan Speed 1 - 9)





# Normalized Air Speed Pattern

- Peak at the center point of the long edges and air speed decreases gradually towards the far end.
- Difference of air speed along the short edges is neglectable.
- The peak is slightly higher on the side with shorter distance to the wall.



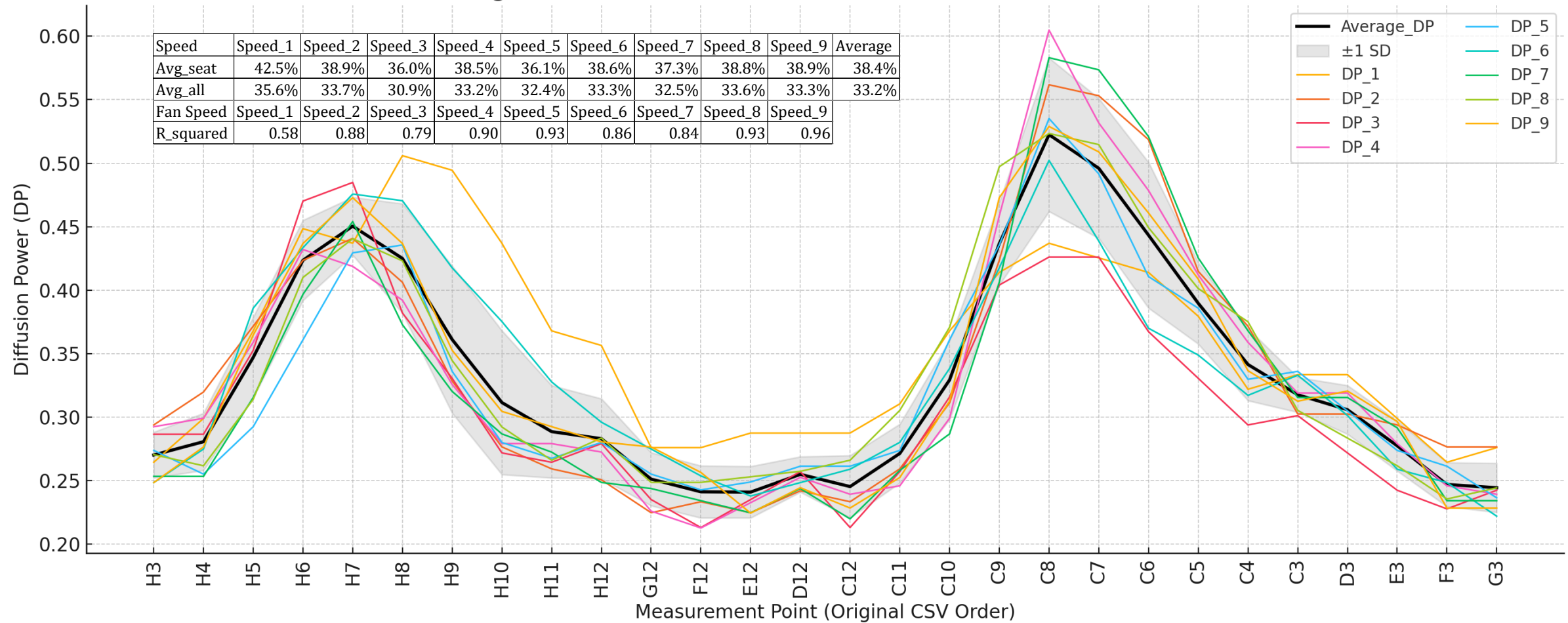


# Diffusion Power

$$FAS(m/s) = \frac{\text{Air Flow (m}^3/h\text{)}}{\text{Fan Blade Area (m}^2\text{)} * 3600}$$

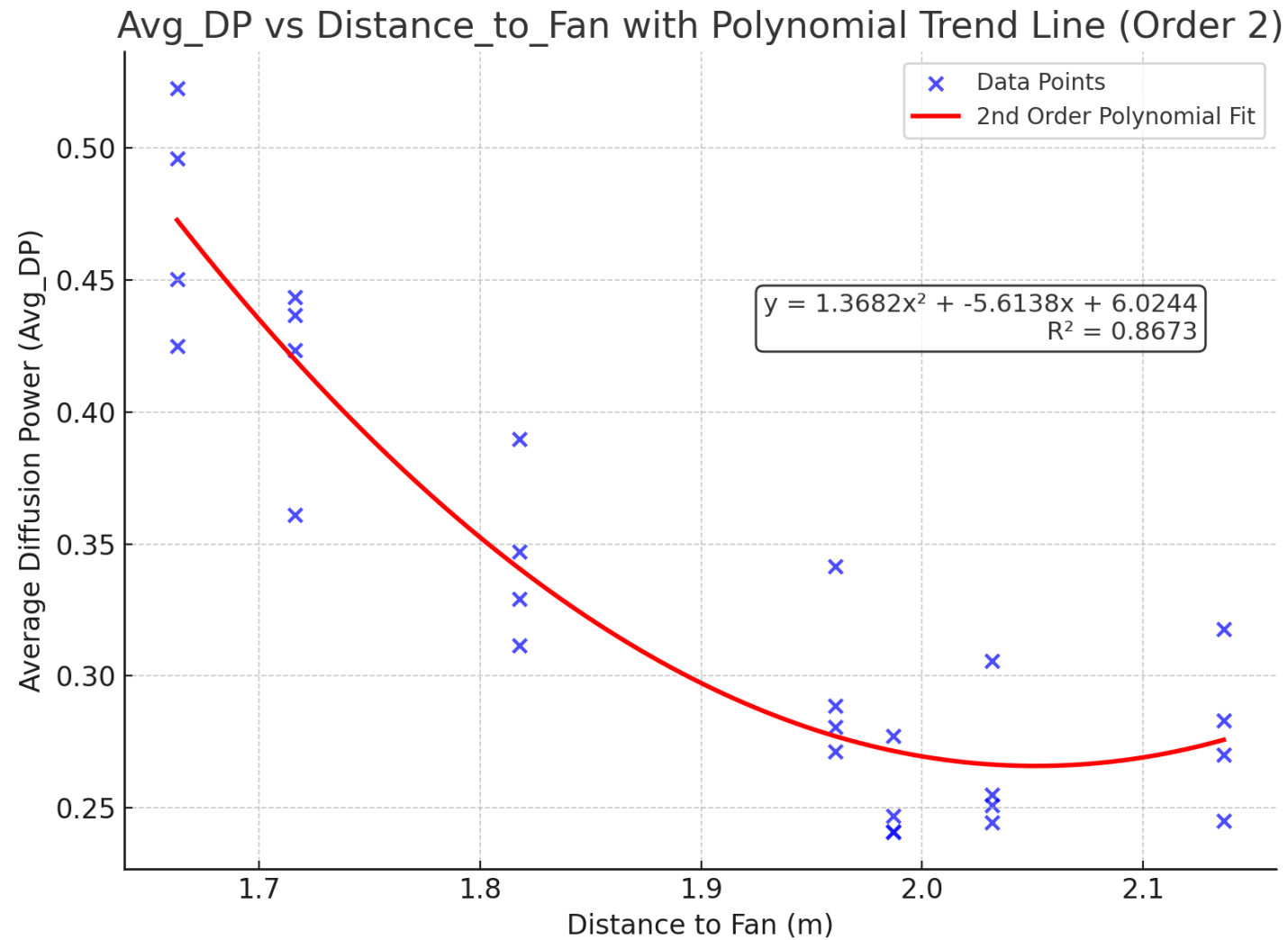
$$DP = \frac{\text{Measured Air Speed (AS)}}{\text{Fan Air Speed (FAS)}} \times 100\%$$

Average Diffusion Power with Standard Deviation Bands ( $\pm 1$  SD)





# Air Speed prediction with Diffusion Power





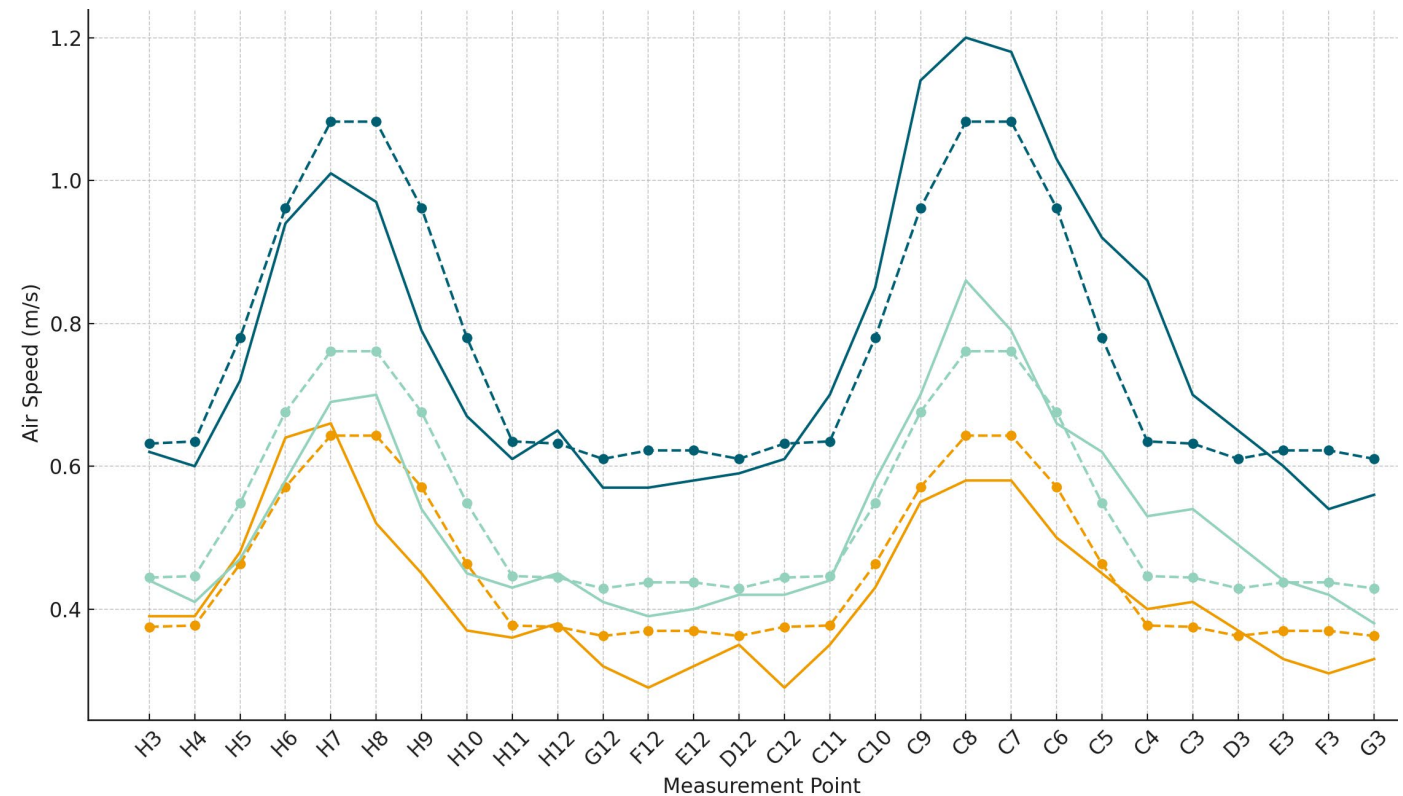


# Prediction with FAS and Distance to Fan Center

- X is the distance to fan center
- DP can be calculated as a function of distance to fan center
- FAS can often be derived from the spec sheet
- The predicted air speed (PAS) can be calculated from the 2 equations:

$$DP = 1.3682x^2 - 5.6138x + 6.0244$$

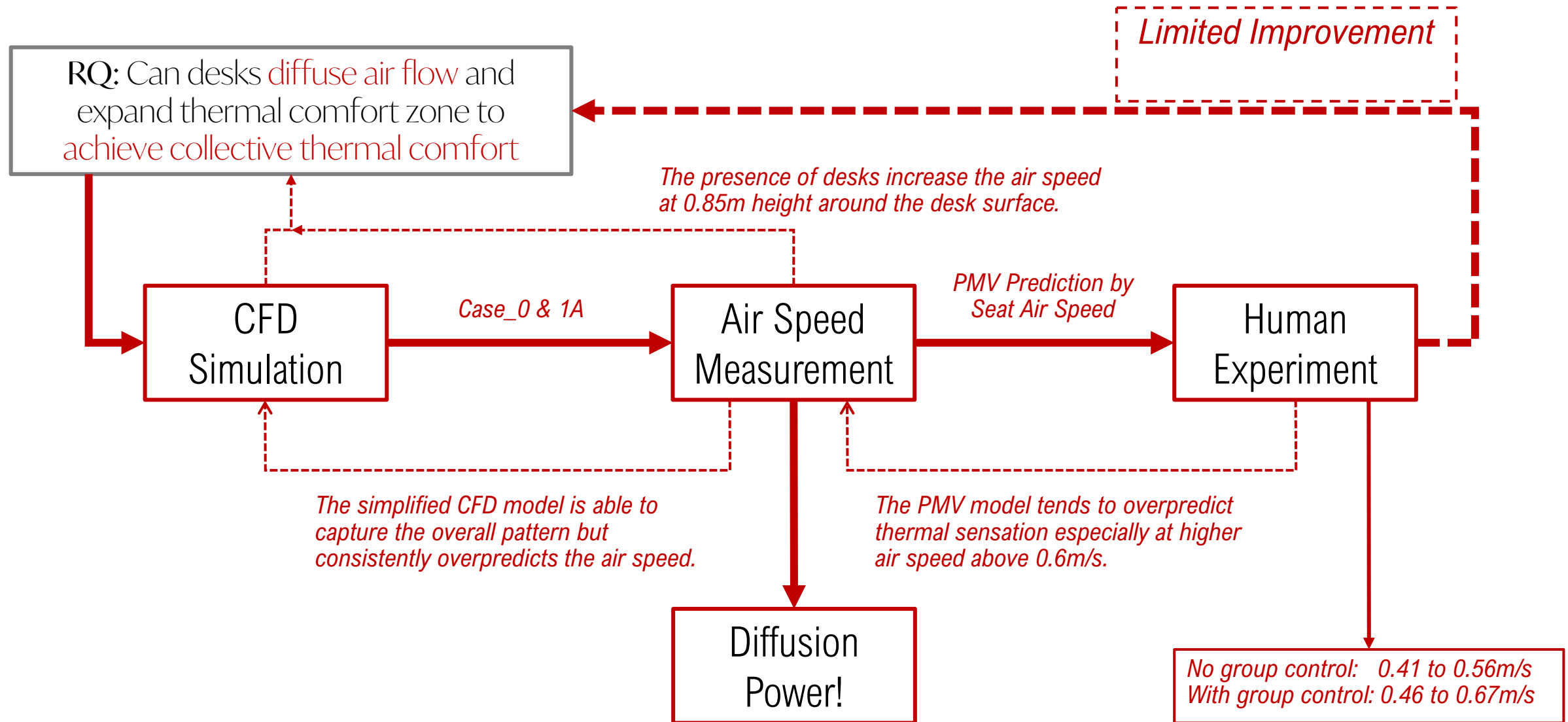
$$PAS = FAS * DP$$







# Multi-loop Validation





# Conclusion

and suggestion for practitioner



# Conclusion

1. Simplified CFD models can predict overall airflow pattern, but consistently overpredicts the absolute airspeed magnitudes.
2. The existence of desks increased the average air speed at chest level (0.85m) .
3. The average of diffused air speed is able to maintain over 30% from the initial FAS.
4. PMV tends to overpredict actual thermal sensation, in this case, even at no-air-movement condition.
5. At 28°C / 42.9% RH, air speed between 0.41m/s to 0.56m/s (seat-average of 0.49m/s) with power consumption of 1.8W per person can make 50% of the participants feel comfortable and over 90% of the participants feel the thermal condition to be acceptable even without group control.
6. At 28°C / 42.9% RH with elevated air speed, the comfort level improvement is limited.



# Suggestions for Practitioner

1. Simplified CFD can provide preliminary understanding of air flow pattern in early design stage.
2. Collective comfort zones can be designed by carefully arranging the placement of ceiling fan and desks
3. Personal or group control enables the occupants to adjust the air speed according to their preference more instantly.





MultiFANS





OnlyFAN

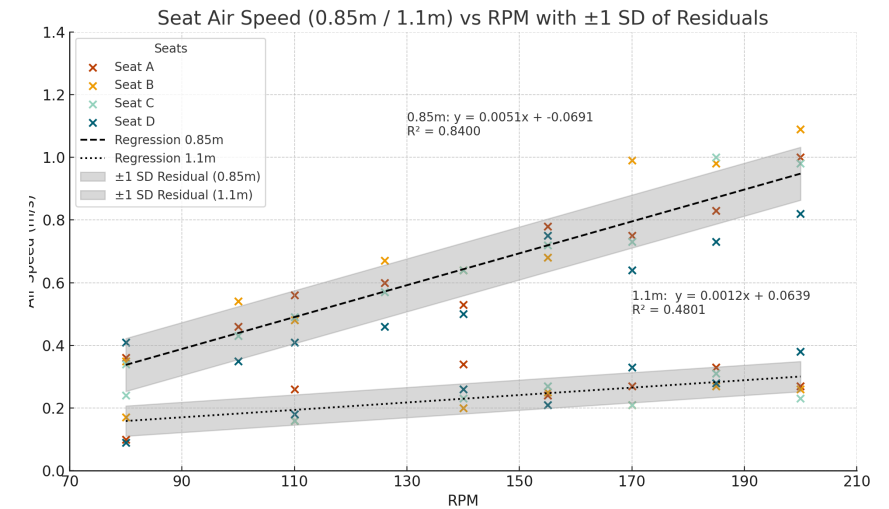
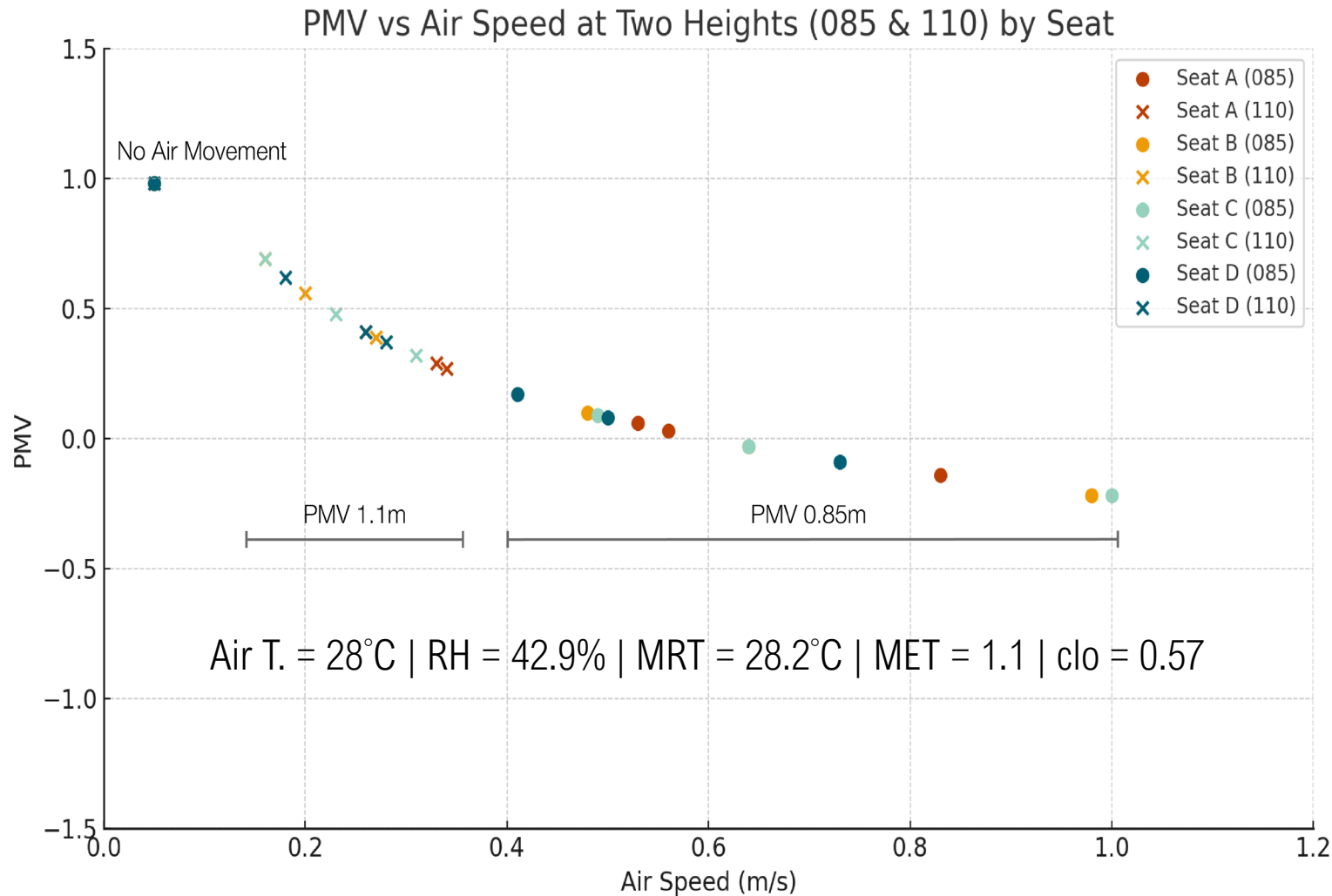
*Thanks for listening!*



# Annex



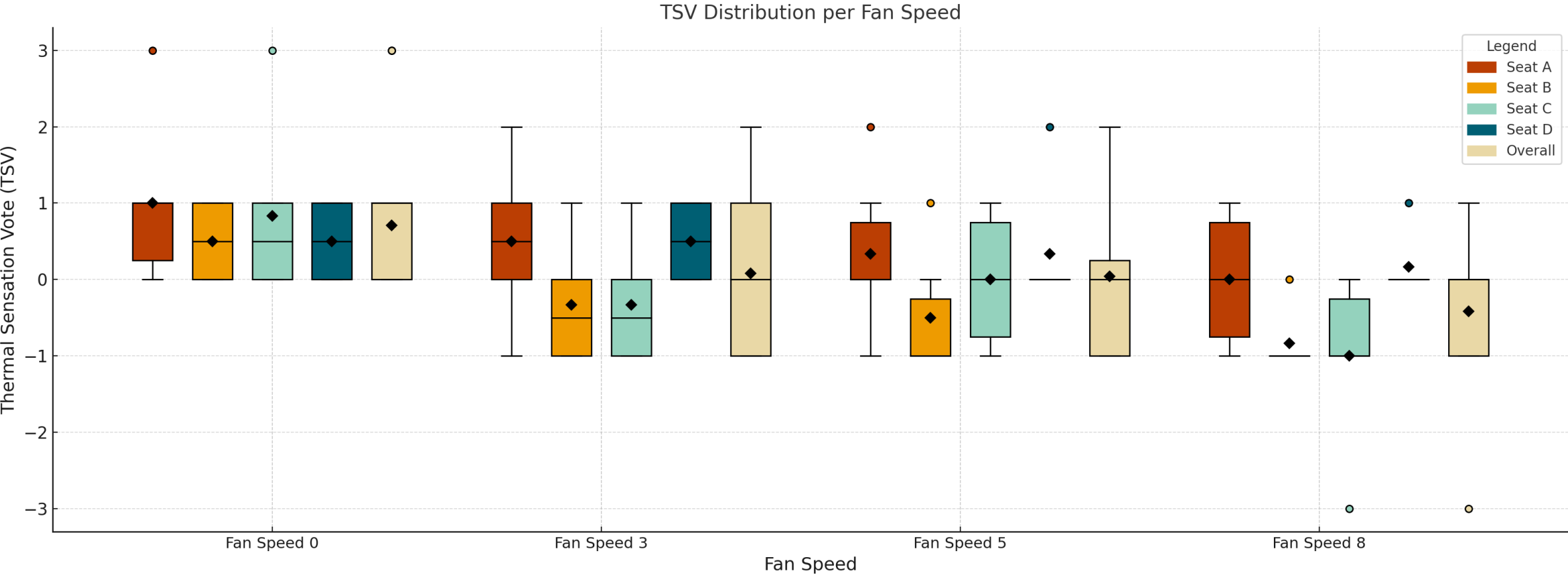
# PMV Prediction by Seat Air Speed



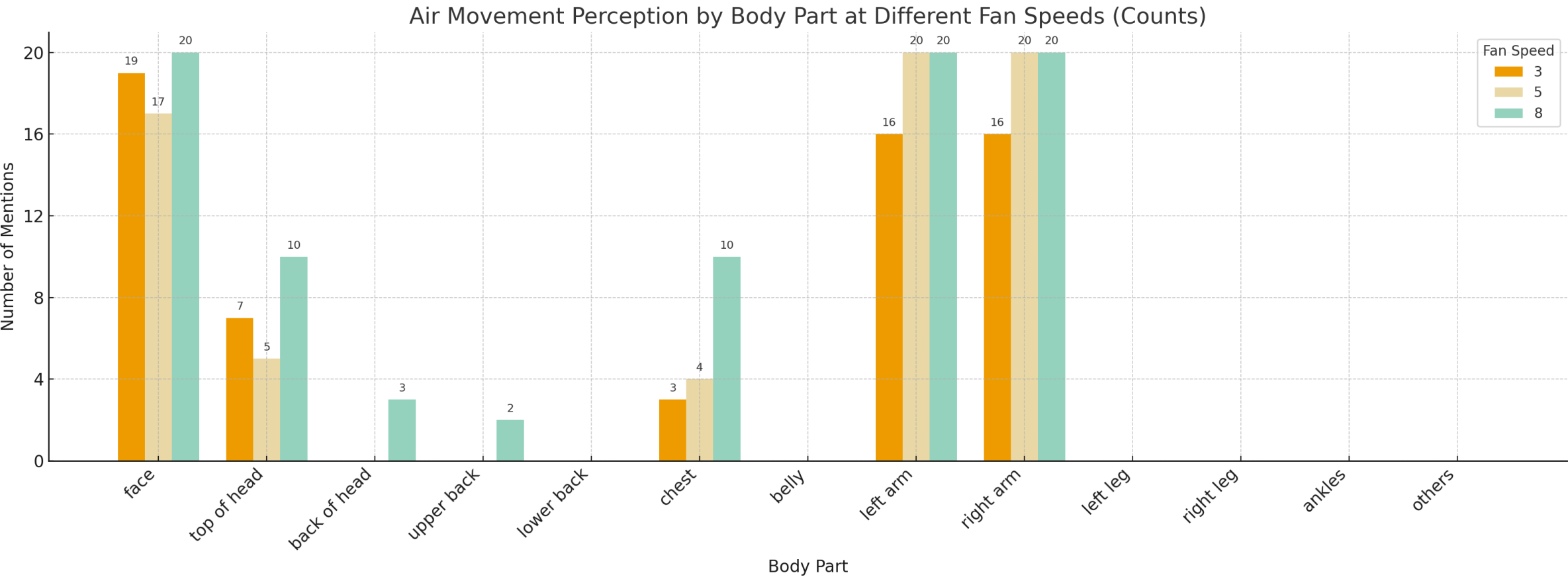
Measurement	Speed	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5	Speed_6	Speed_7	Speed_8	Speed_9
height	RPM	80	100	110	126	140	155	170	185	200
0.85m	A	0.36	0.46	0.56	0.6	0.53	0.78	0.75	0.83	1
	B	0.35	0.54	0.48	0.67	0.64	0.68	0.99	0.98	1.09
	C	0.34	0.43	0.49	0.57	0.64	0.72	0.73	1	0.98
	D	0.41	0.35	0.41	0.46	0.5	0.75	0.64	0.73	0.82
	Avg_seat	0.37	0.45	0.49	0.58	0.58	0.73	0.78	0.89	0.97
	Avg_all	0.31	0.39	0.42	0.5	0.52	0.63	0.68	0.77	0.83
1.1m	A	0.1	N/A	0.26	N/A	0.34	0.24	0.27	0.33	0.27
	B	0.17		0.16		0.2	0.25	0.21	0.27	0.26
	C	0.24		0.16		0.23	0.27	0.21	0.31	0.23
	D	0.09		0.18		0.26	0.21	0.33	0.28	0.38
	Avg_seat	0.15		0.19		0.26	0.24	0.26	0.30	0.29



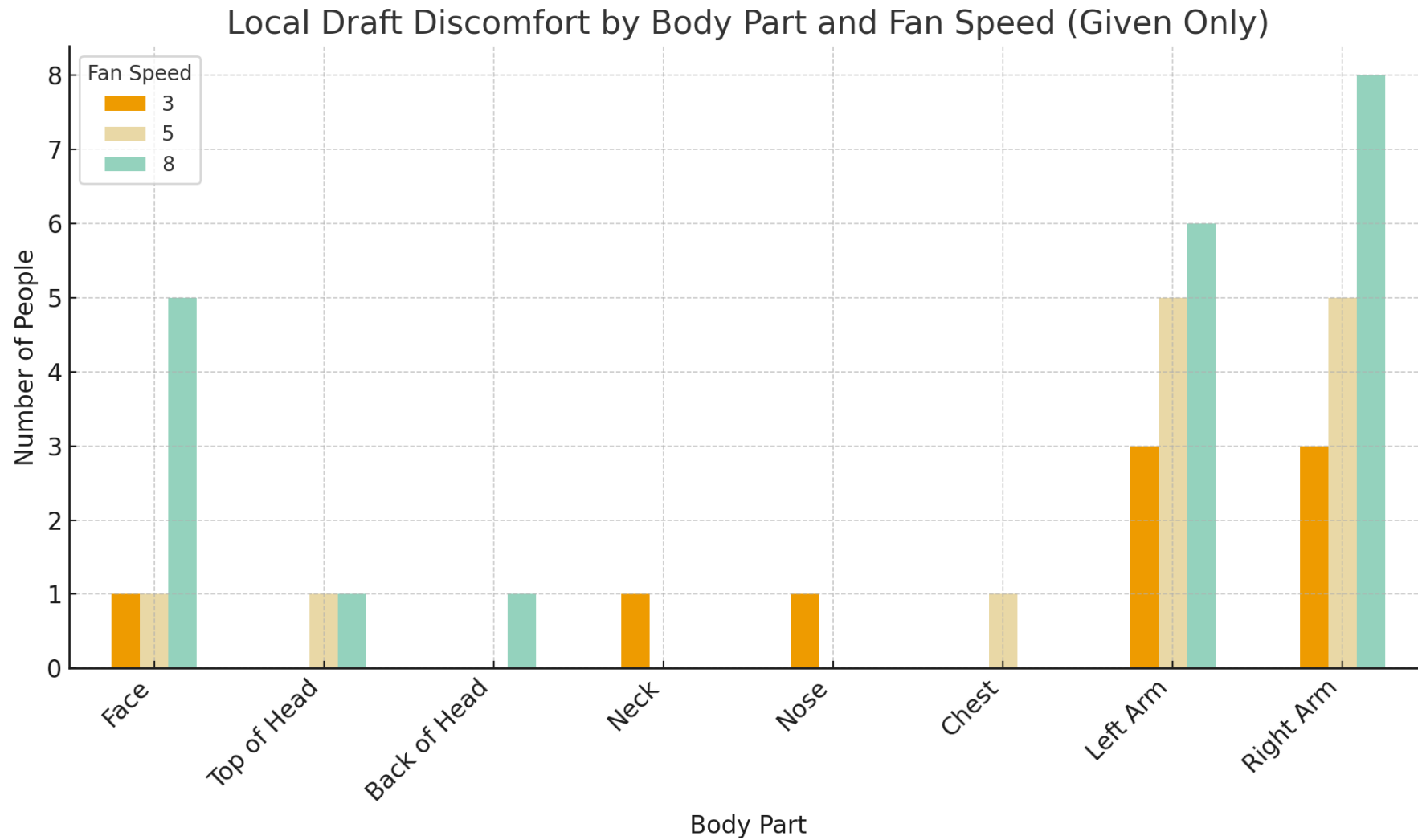
# Seat-average TSV by Given Fan Speed



# Air Movement Sensation by Body Parts



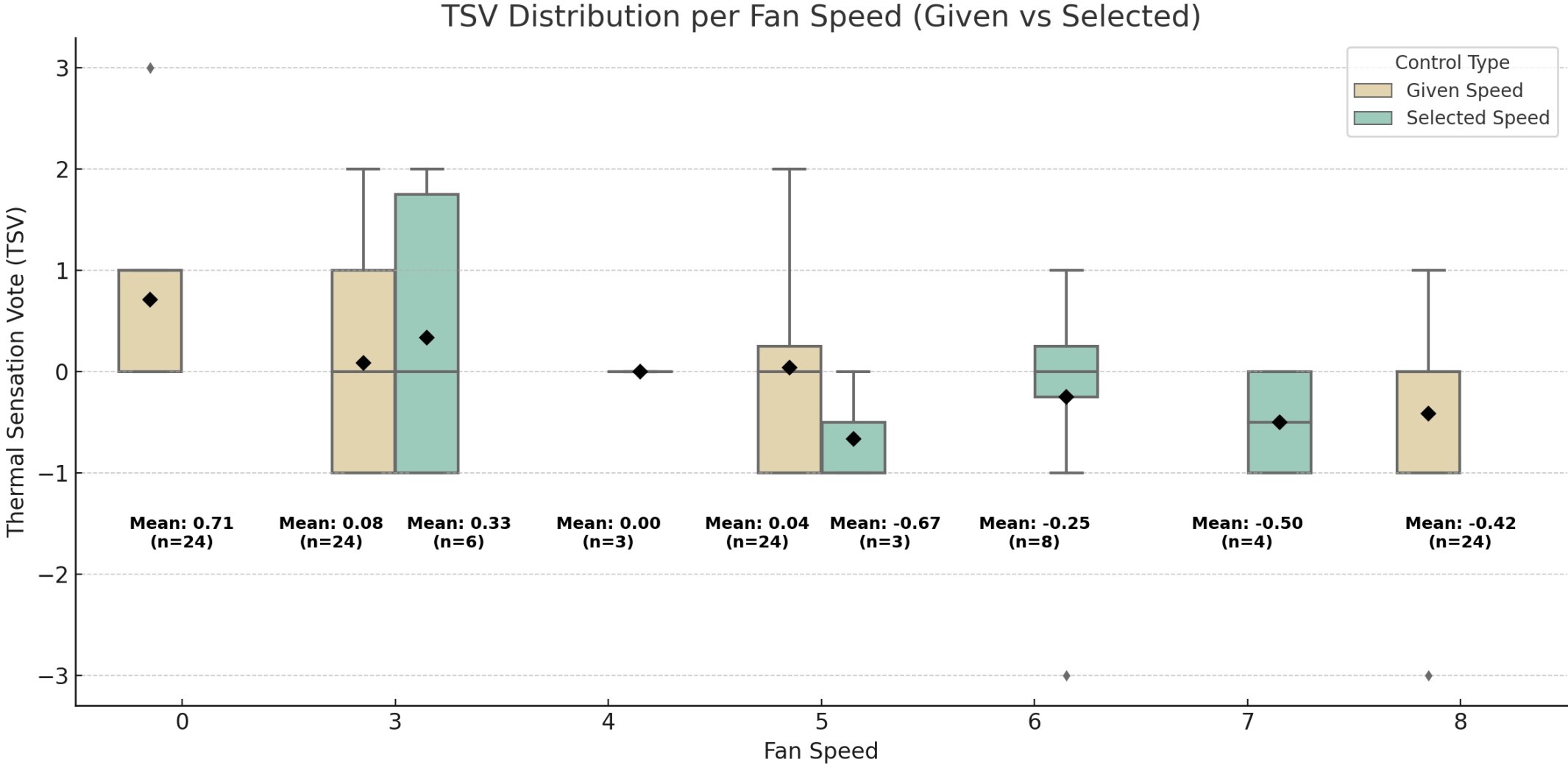
# Local Draft Discomfort by Body Parts





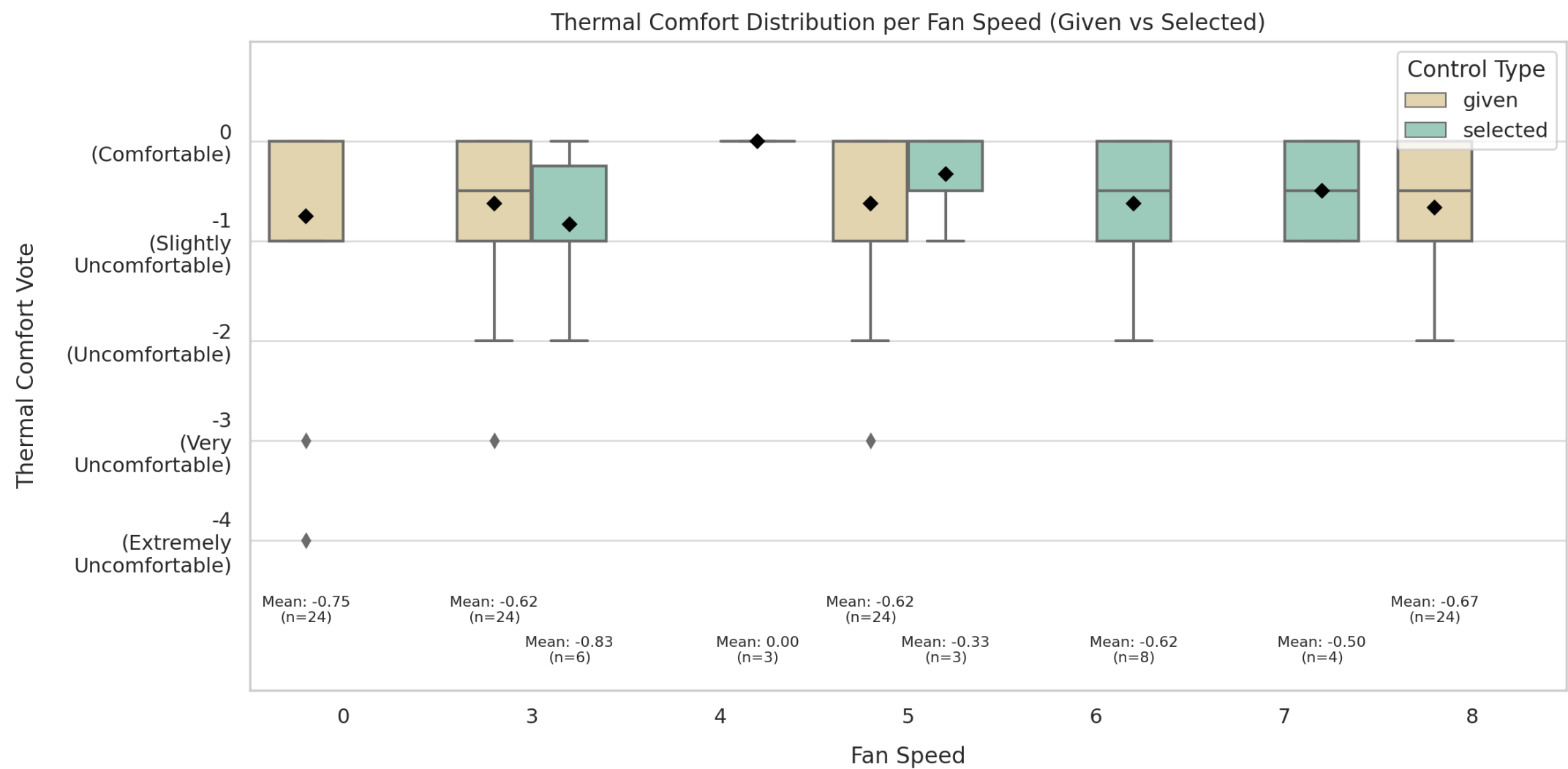


# TSV of Group-selected Fan Speed





# TCV of Group-selected Fan Speed



# Group-selection Process & Overall Experience

