

# Prediction of ventilation performance in urban area with CFD simulation and generative adversarial networks

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# Outline

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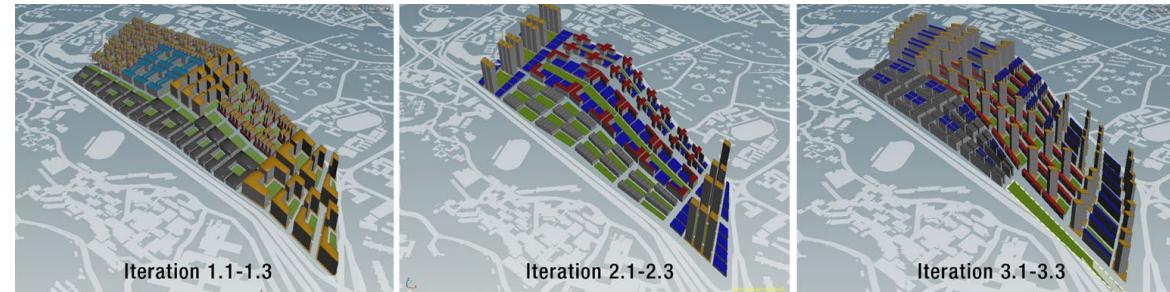
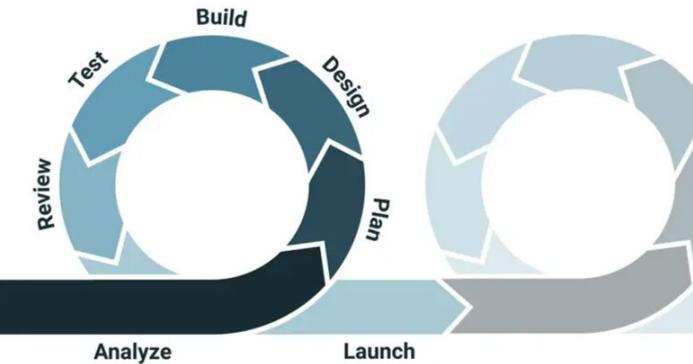
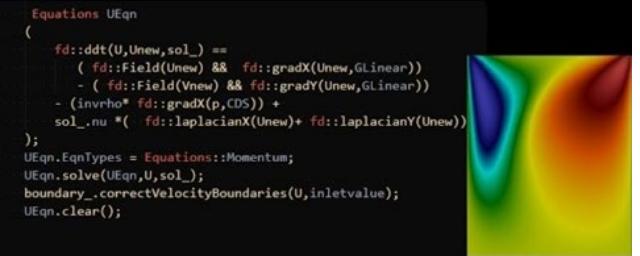
- Background and objectives
- Methodology
  - CFD simulation with OpenFOAM
  - CFD prediction with conditional GAN
- Results
  - Predicted ventilation map
  - Prediction accuracy
- Discussion
- Conclusions

# Background



- Ventilation in urban canyons

# Background



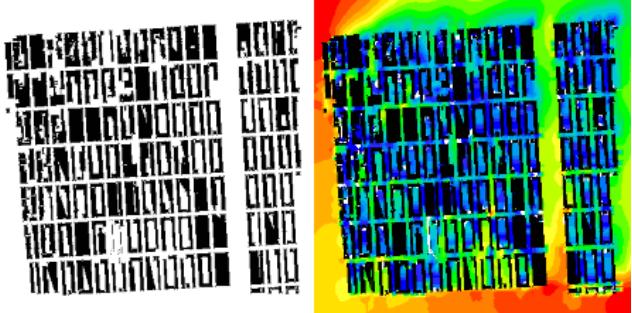
Design Automation Lab, NUS

- Gap between design and simulation

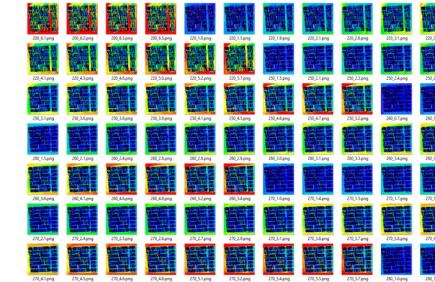
# Objectives



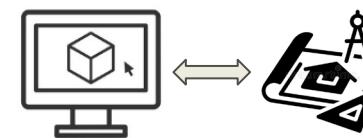
2D urban height map



Ventilation prediction



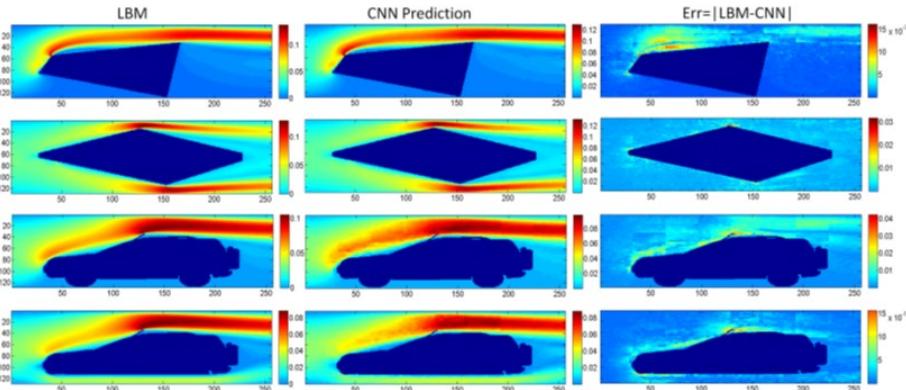
Ventilation dataset in urban scale



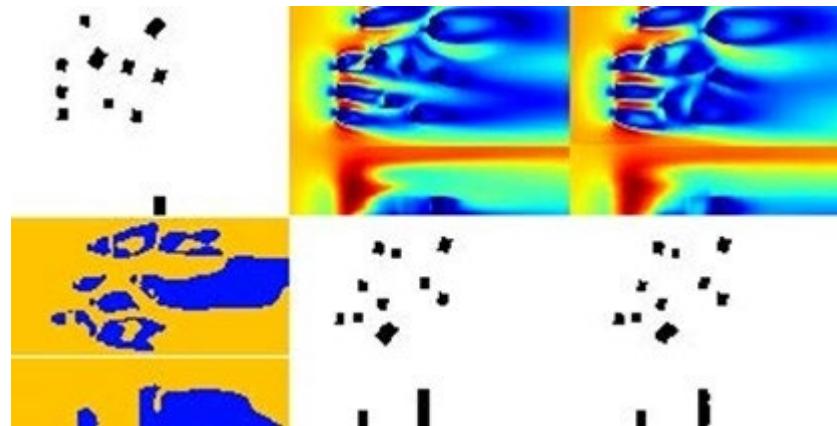
Remove the gap between design and simulation

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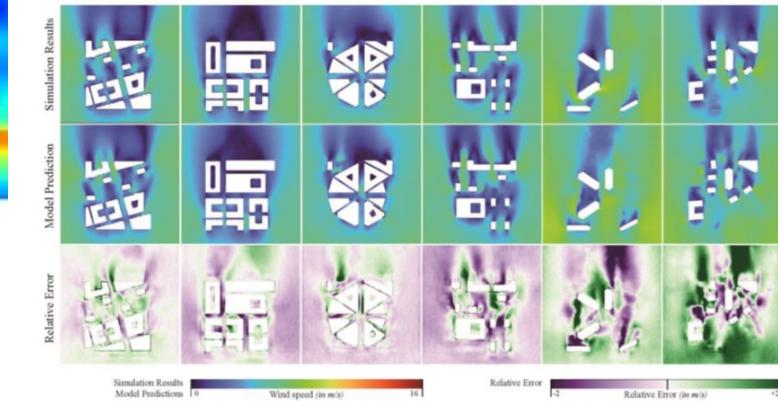
# Related studies



Guo et al. (2016)  
UMich

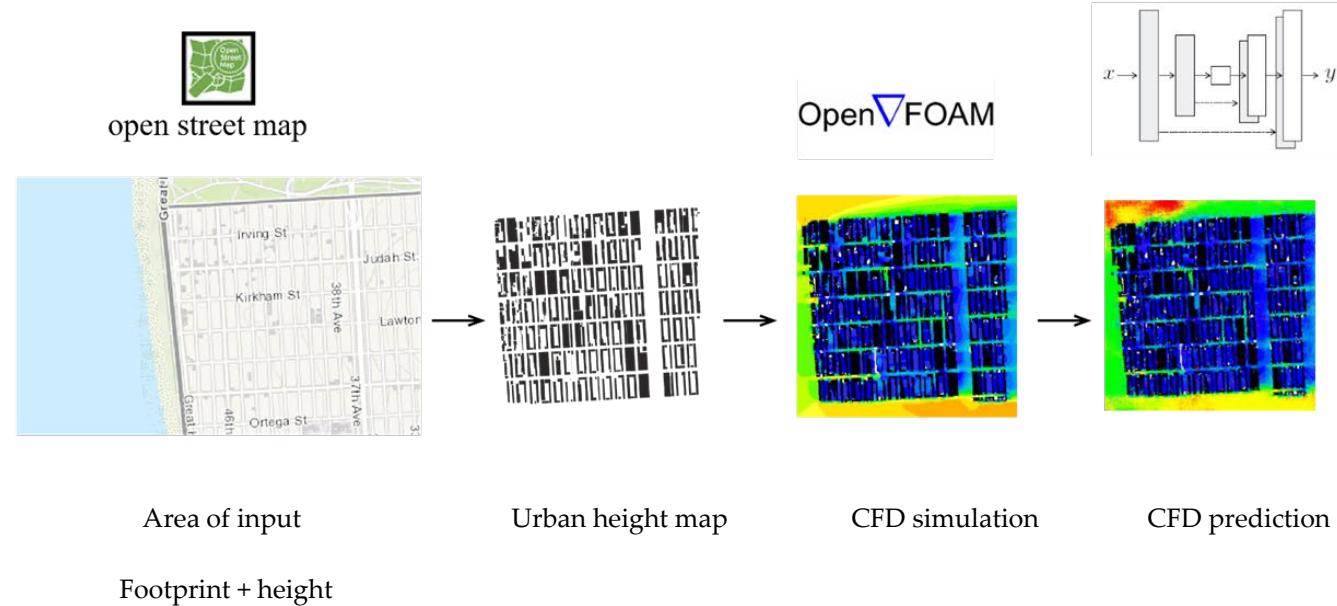


Musil et al. (2019)  
Foster + Partners



Mokhtar et al. (2020)  
KPF

# Pipeline



# Height map



# CFD simulation settings

## Site

- Location: west coast of San Francisco
- Area: 2,250,000 m<sup>2</sup> (~1500 m x 1500m)



## Assumptions

- Inlet wind profile:  $U(z) = \frac{U_*}{\kappa} \ln \frac{z}{z_0}$
- turbulence model: standard k-  $\varepsilon$  model
- roughness length  $z_0 = 0.0002$  (open sea)
- reference velocity: 0 m/s to 6.5 m/s
- reference height of 10m

# CFD simulation settings

## Average block size

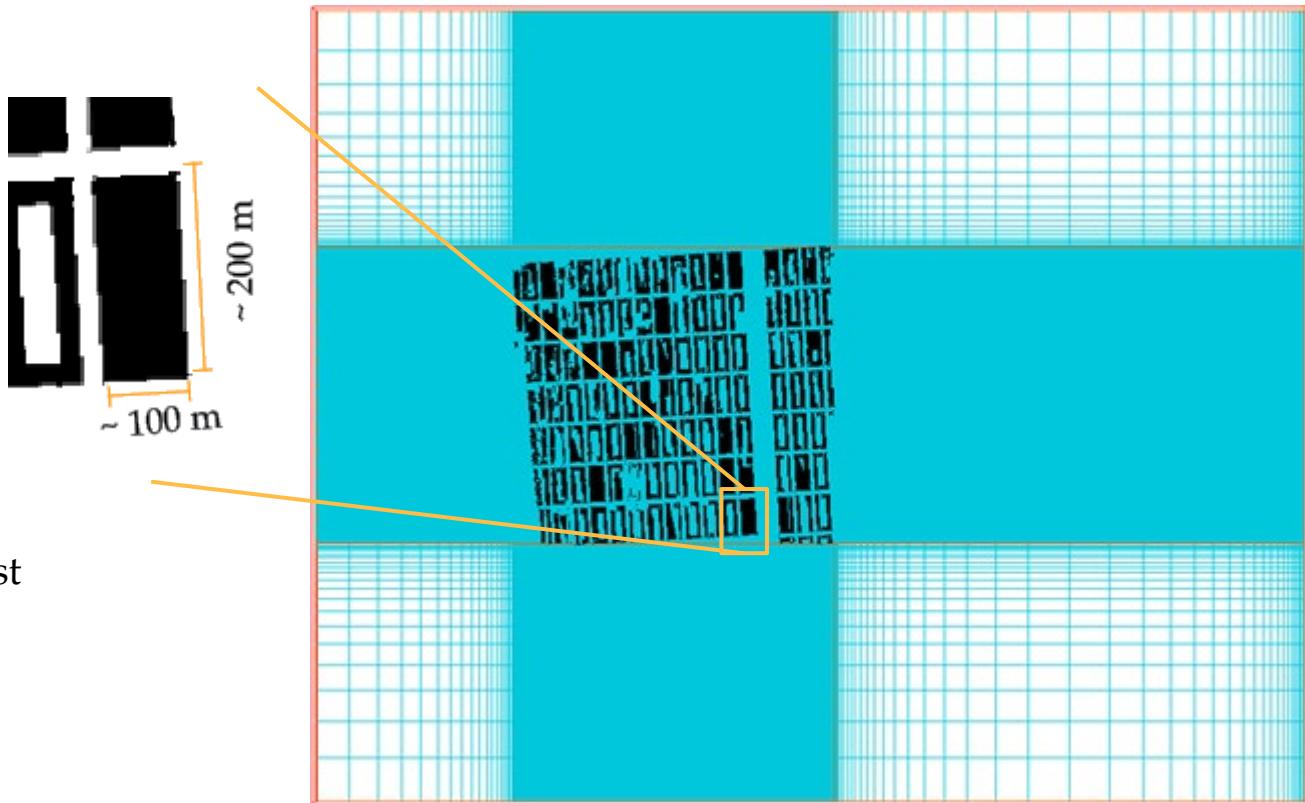
- 100 m x 200 m

## Grids

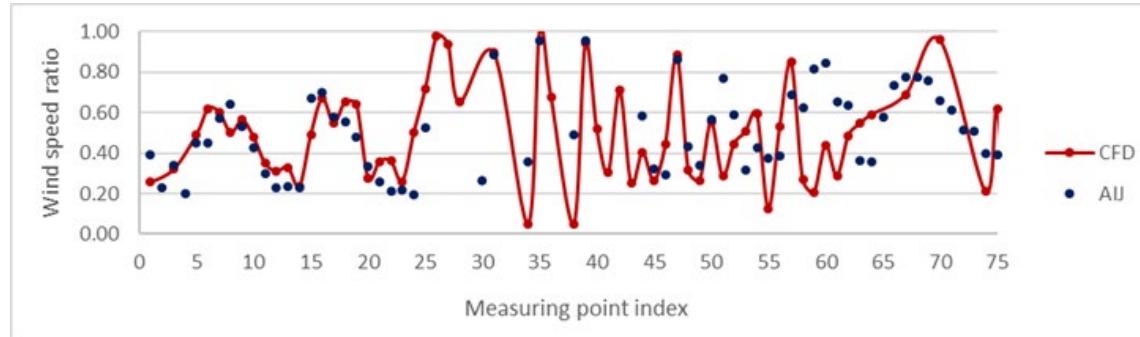
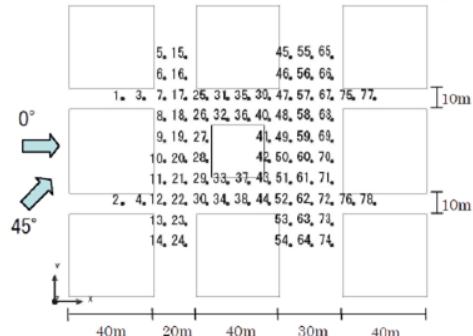
- Finest resolution: 10 m x 10 m
- Expansion ratio: maximum 1.2 times

## Wind tunnel

- Nine subregions
- Height: 30 m
- Leeward: 15 times of the height of the highest analysis volumes
- Windward & side: 5 times of the highest analysis volumes



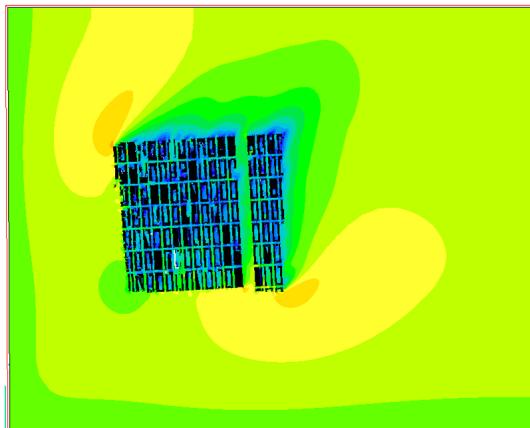
# CFD simulation validation



CFD simulation with  
AIJ benchmark



5m x 5m



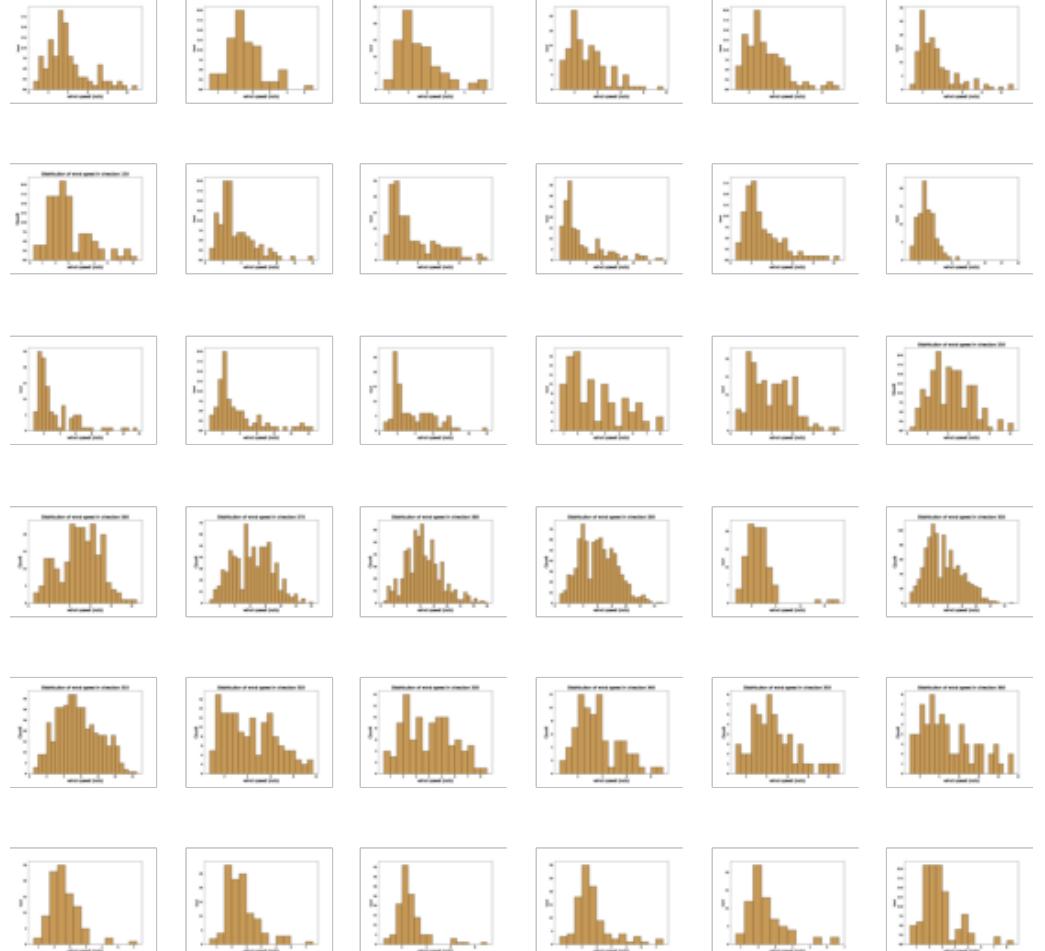
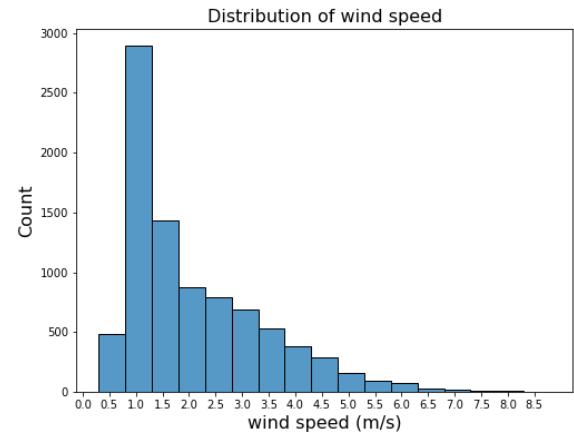
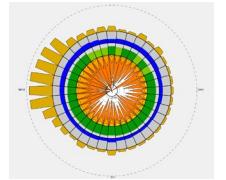
10m x 10m



15m x 15m

Grid resolution study

# CFD simulation wind profile distribution

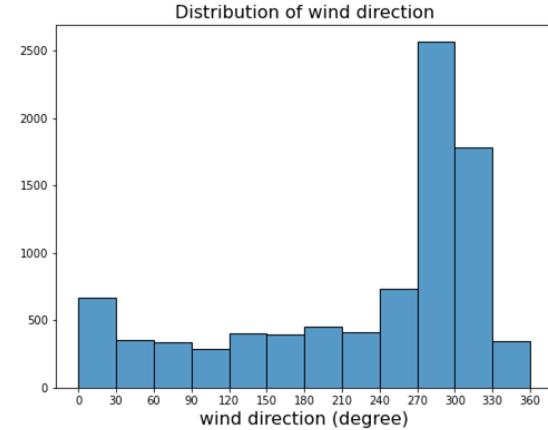


**wind velocity**

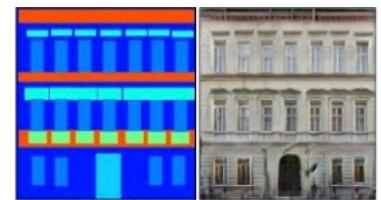
0 - 5.5 m/s spaced at 0.1

**wind direction**

0-360 degree spaced at 10



# CFD simulation dataset

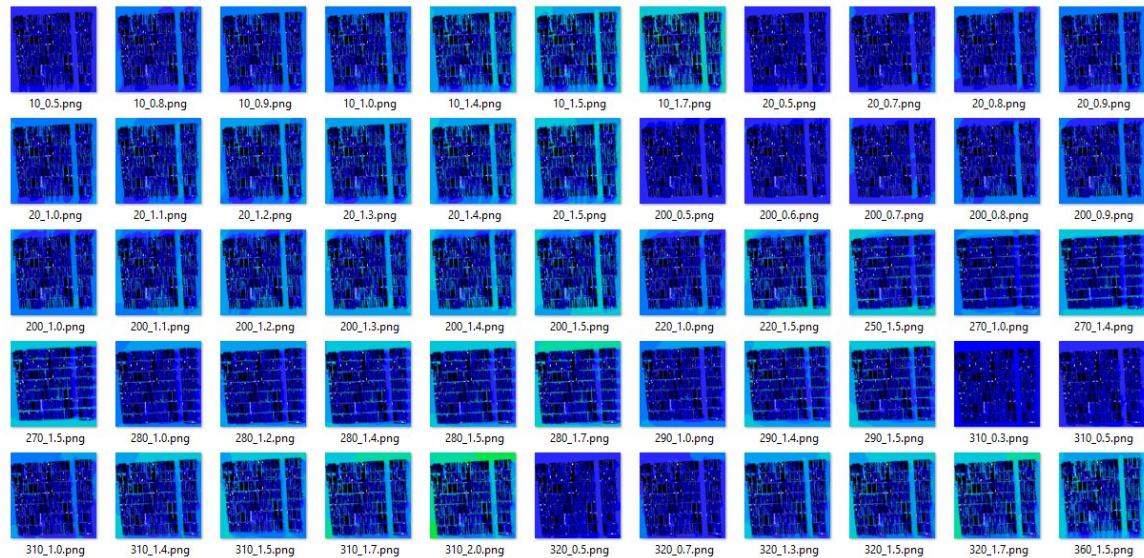


400 training data (Isola et al, 2017)

401 simulations in

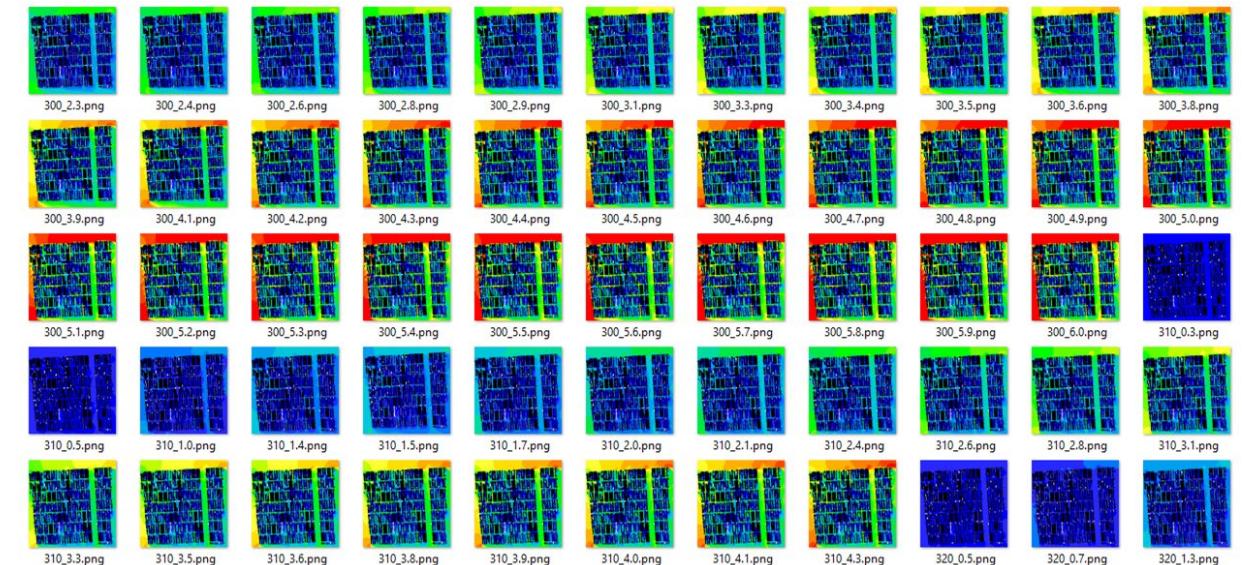
wind direction

0-360 degree spaced at 10

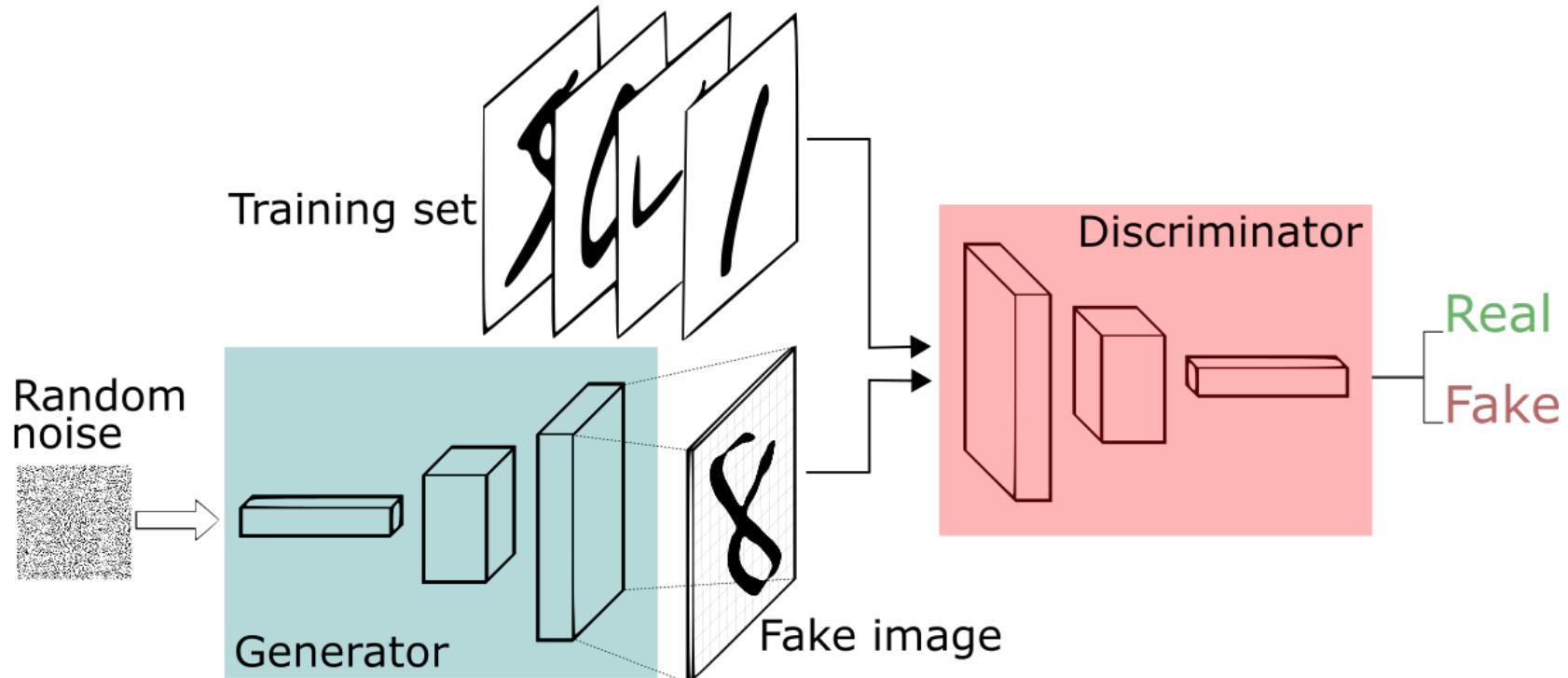


wind velocity

0 - 5.5 m/s spaced at 0.1

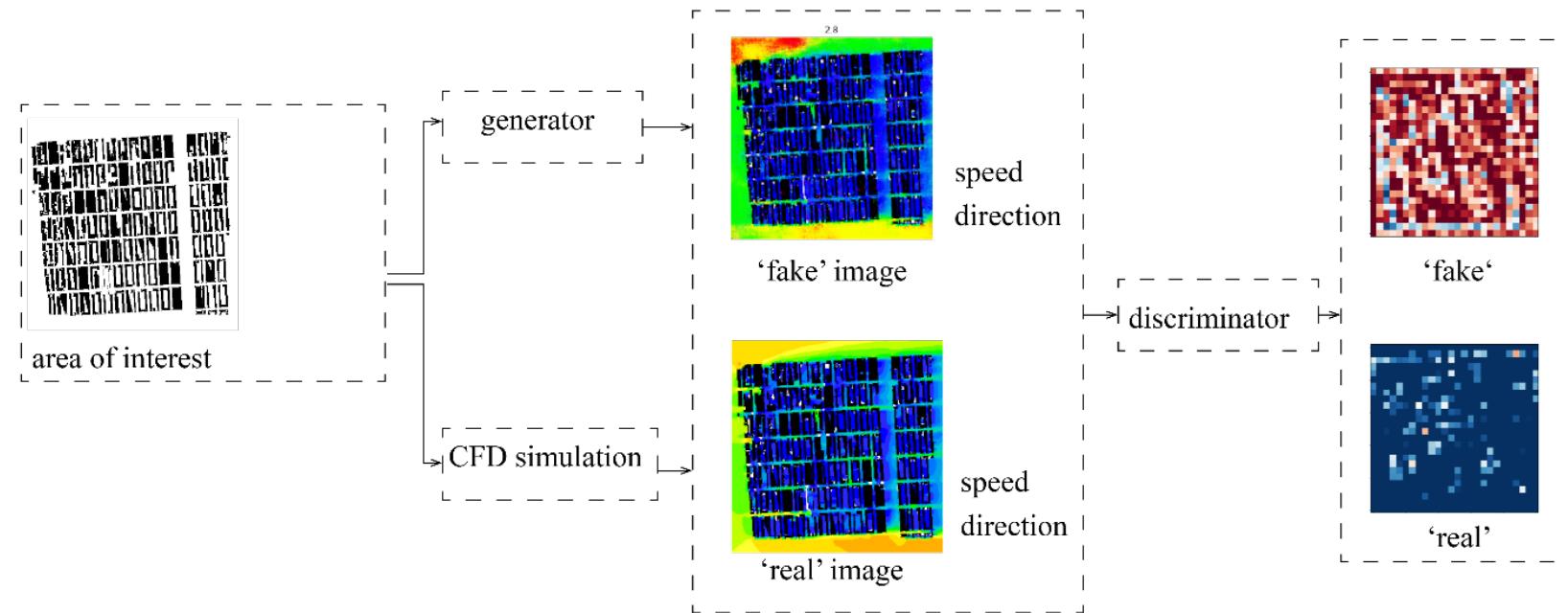


# Generative model generative adversarial neural networks

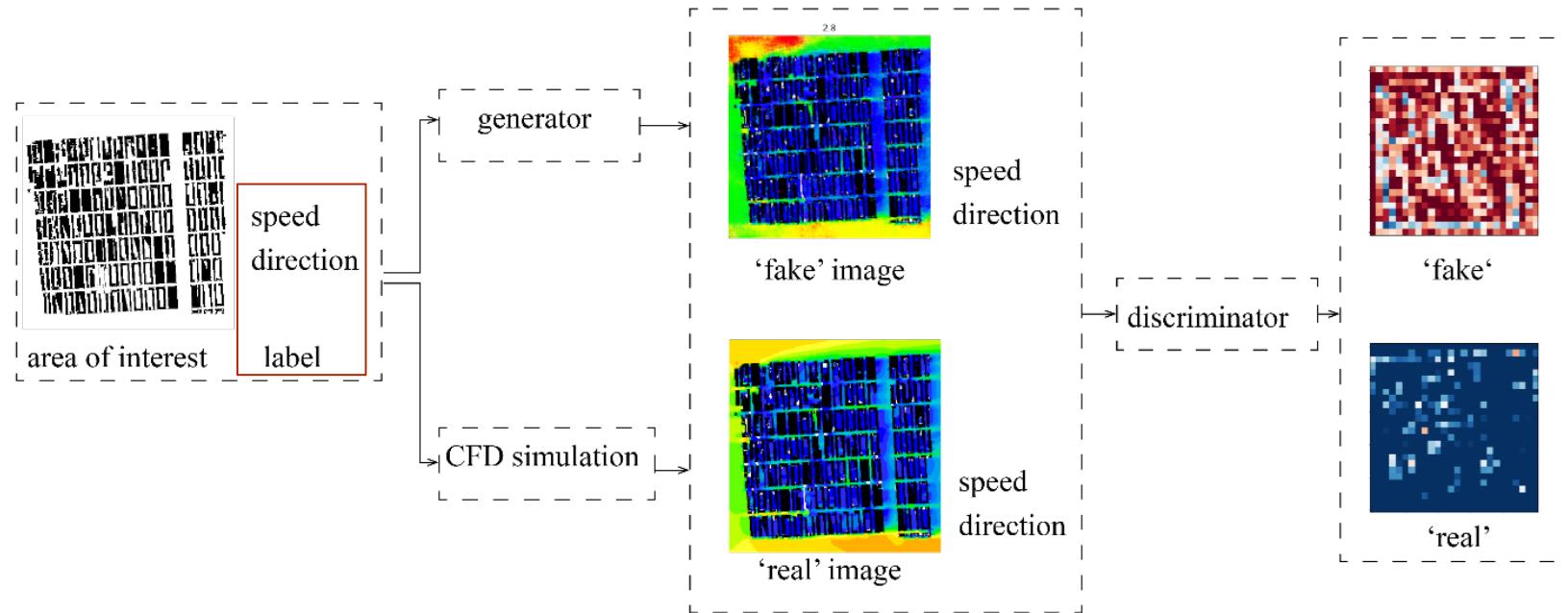


Radford et al. (2015)

# Generative model generative adversarial neural network (GAN)

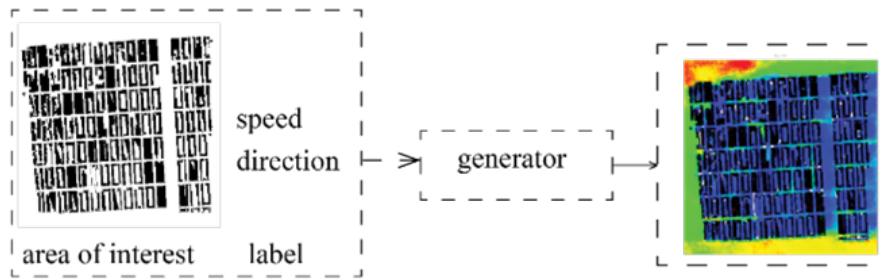


# Generative model conditional GAN - training



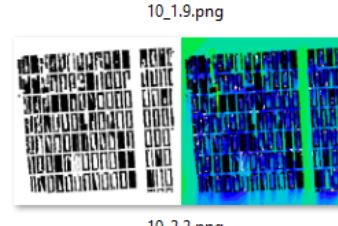
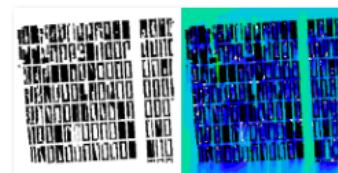
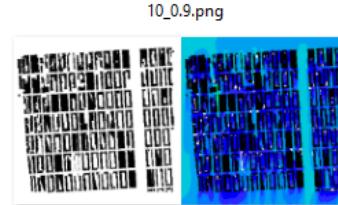
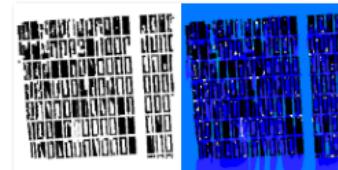
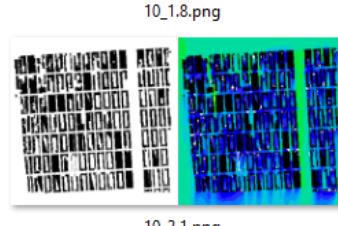
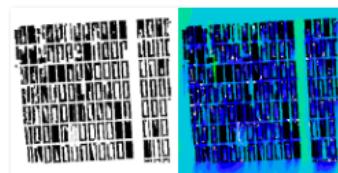
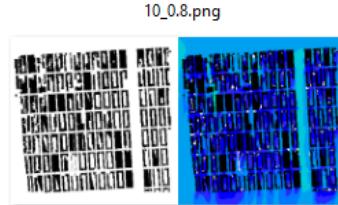
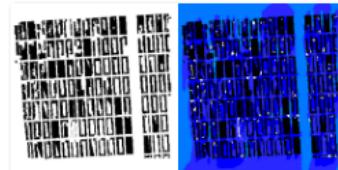
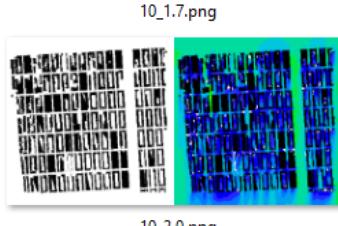
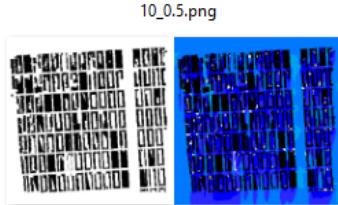
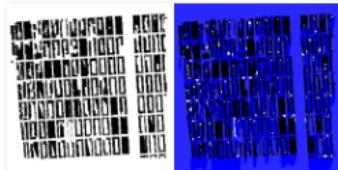
# Generative model conditional GAN - prediction

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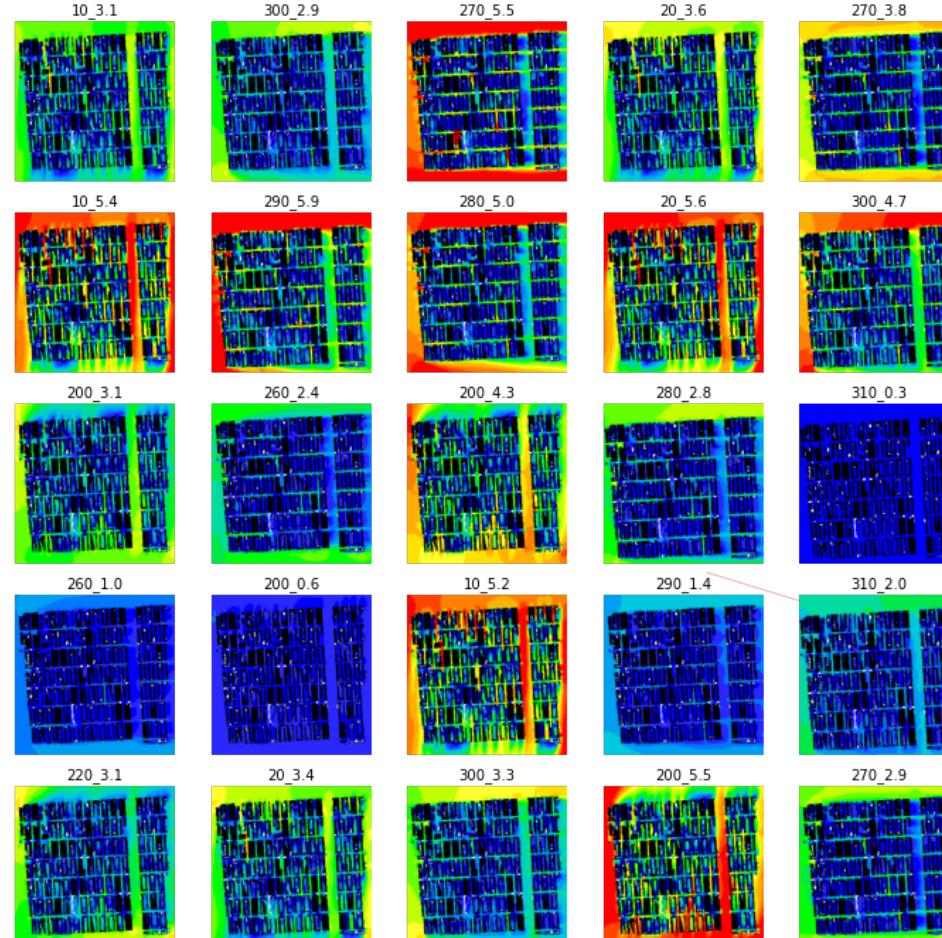
# Results

## Training data



# Results

## Predicted ventilation map

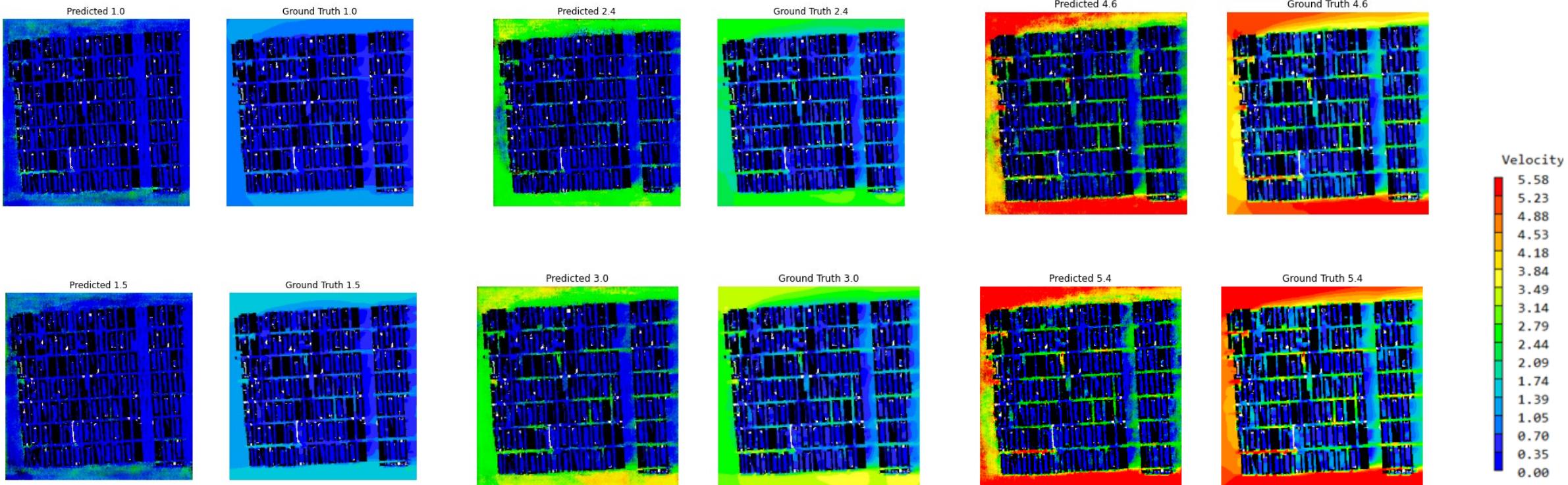


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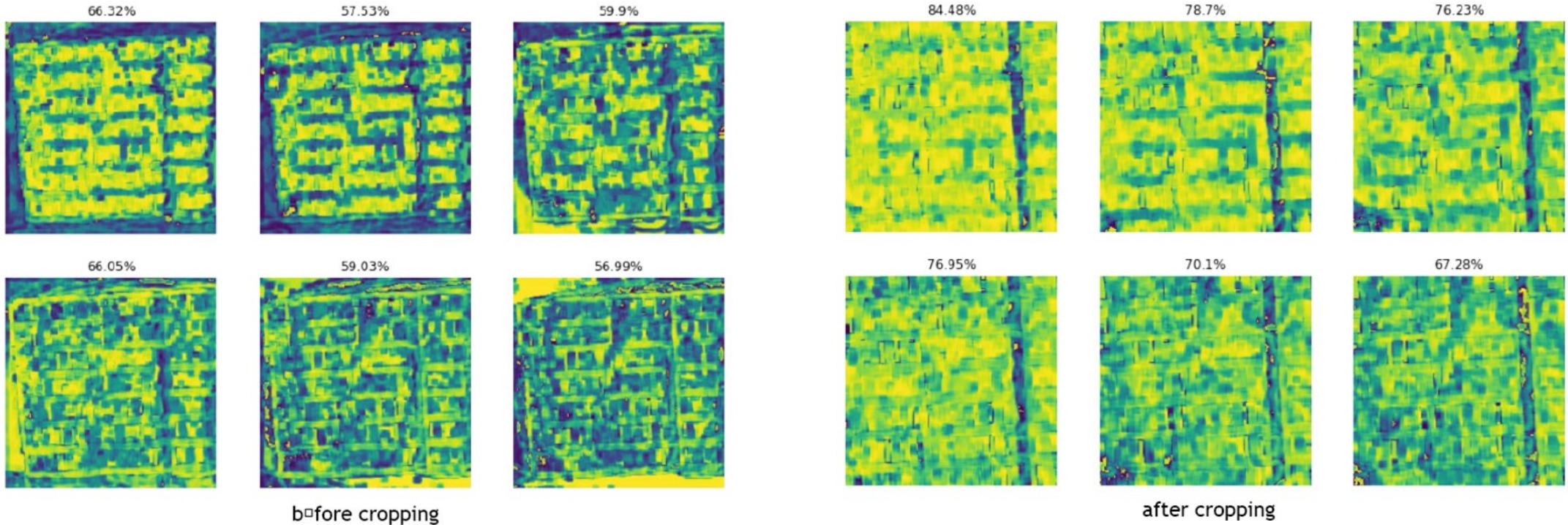
# Results

## Prediction accuracy

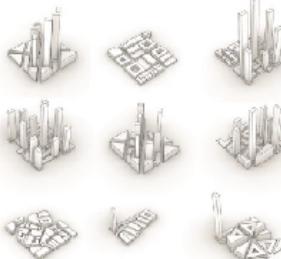


# Results

## Prediction accuracy



# Discussion

	model	wind setting	error%
Guo et al. [9]		NA (looks like single fac- ing & single speed)	99-11%
Mokhtar et al. [15]		6m/s facing south	MAE 50% data has a 0.6m/s-0.75m/s discrepancy
ours		multiple	~25%



# Conclusion

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- A framework of using conditional GAN for **instant ventilation visualization** in dense urban area
  - Allows architects and urban designers to get instant evaluation for ventilation performance in the early design stage
  - The average accuracy of the generated ventilation condition is 75%
- Limitation: constrained data size for model fitting
  - Limited universality for different location

## Next step

- constructing a more comprehensive dataset, mixing existing and retrofitted urban morphology to make the model generalizable.
- integrated into other performance indicator such as UTCI

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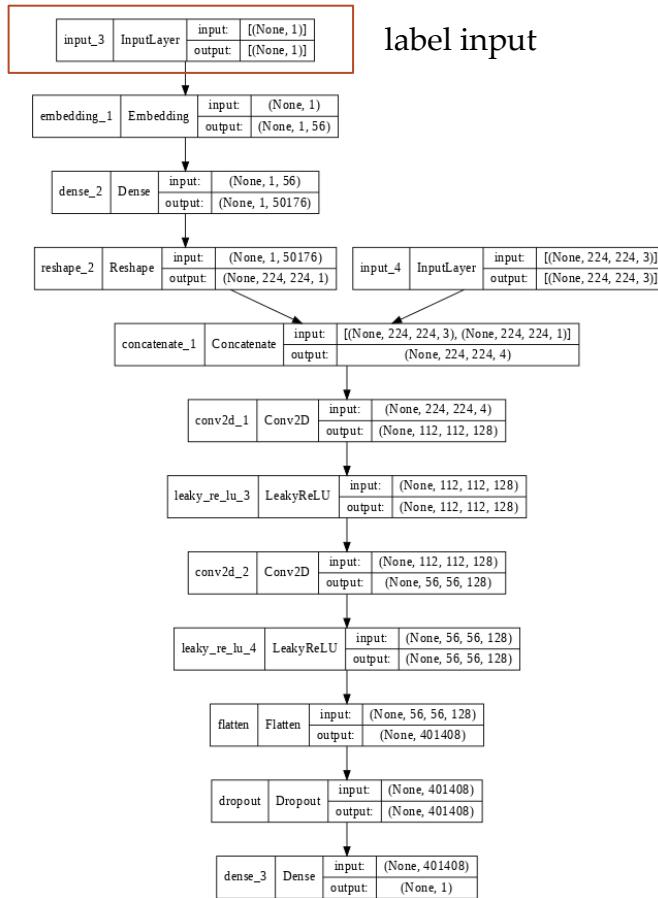
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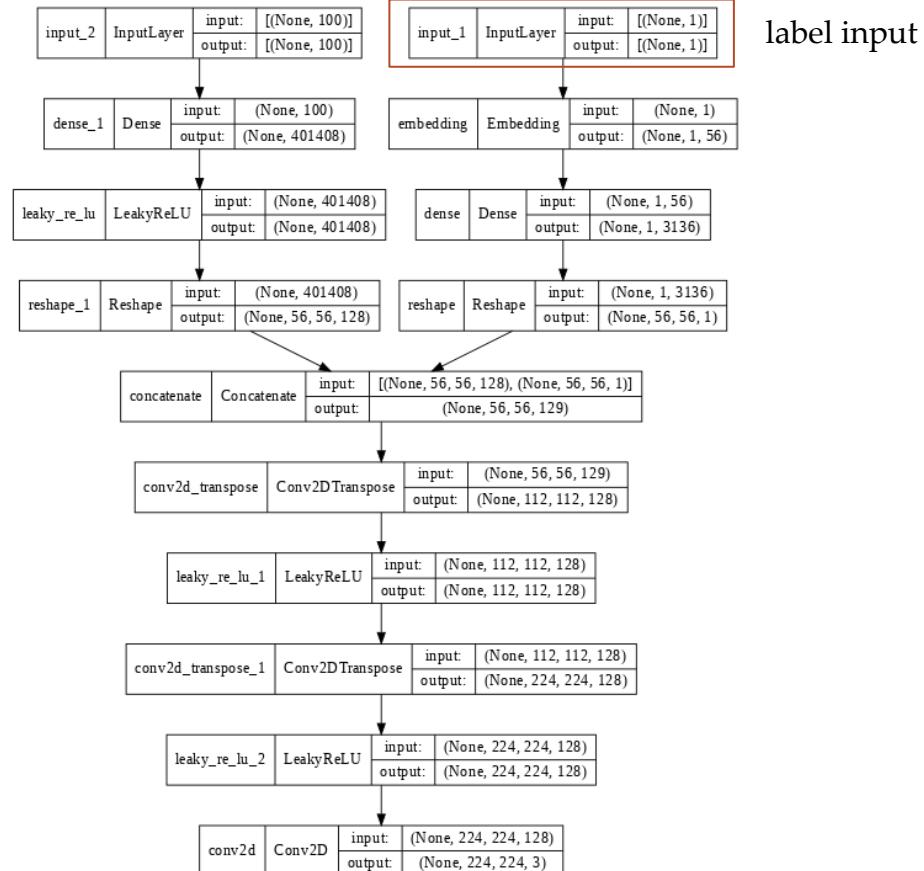
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# Reference Detailed network structure



**Discriminator**



**Generator**