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TRANE TECHNOLOGIES™

Integrated Microclimate Model in Modelica

for Data Center Chiller Farms



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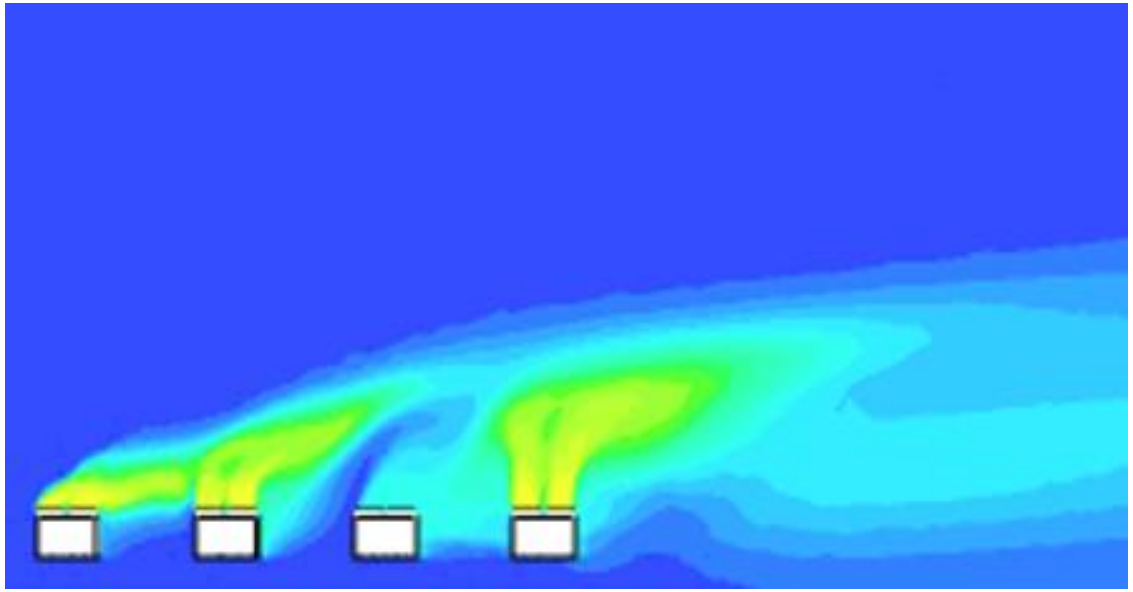
Trane Technologies, USA

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The air at the condenser is not always ambient



Dense, modular air-cooled plants



Wind transports exhaust downstream

Higher condenser inlet temperature → more compressor lift → lower COP

CFD, Modelica, and Plant Simulation

Introducing a Microclimate Model inside Modelica Chiller Farm simulation to update Inlet temperatures

CFD

Detailed Design

Geometry and flow fields

Screens and Nearby Buildings

Design validation

Expensive to repeat



Microclimate block

Reduced-order model

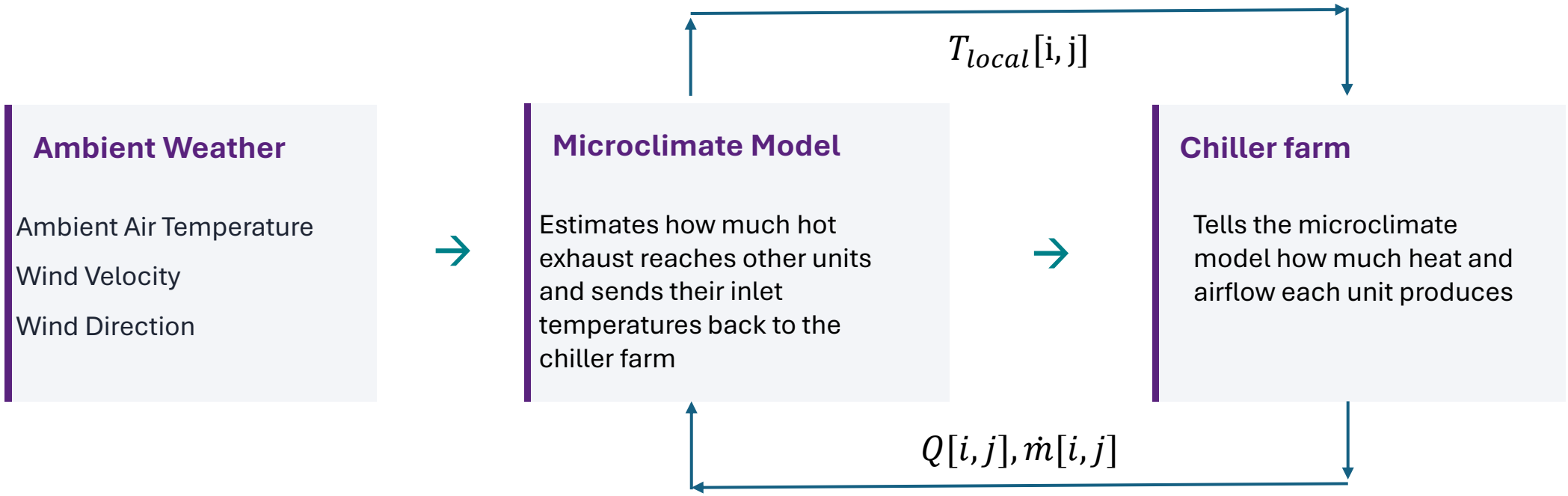
Run inside Modelica Chiller Farm

Retaining dominant control dependencies

Coefficients calibrated by CFD

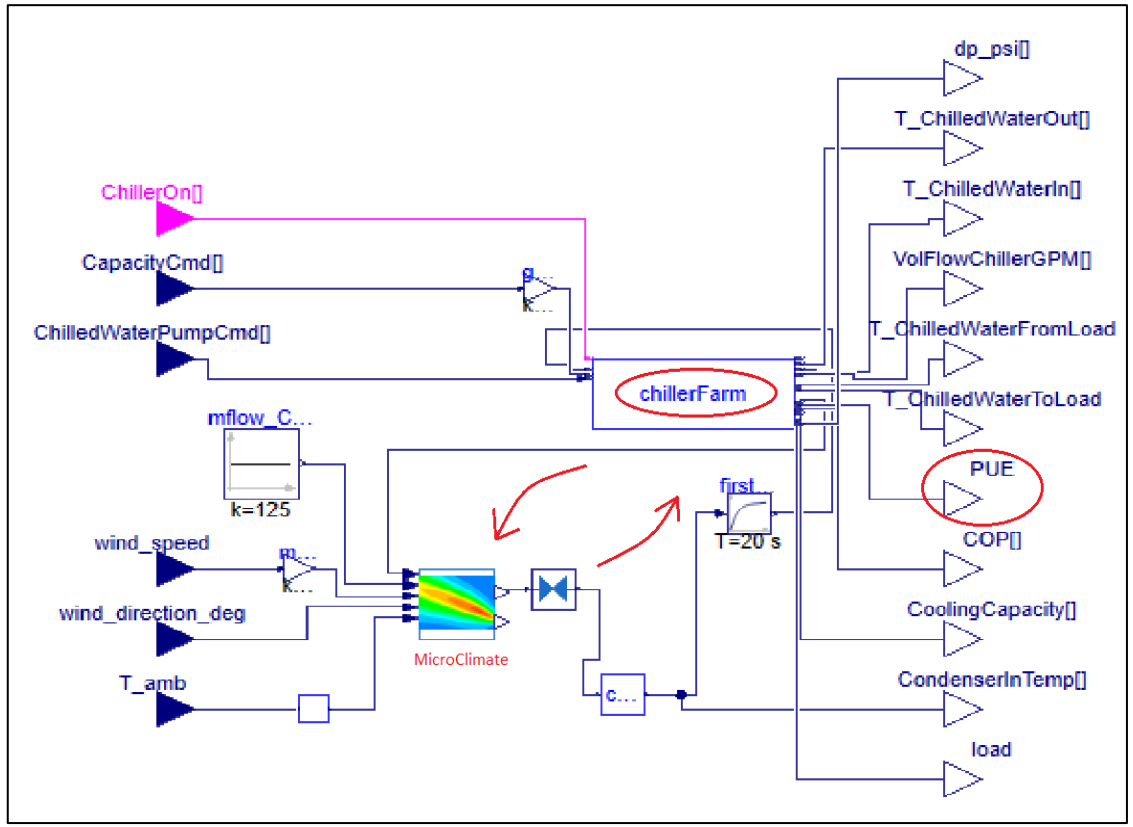
Complement CFD not replace it

Chillers warm the surrounding air, affects how the farm operate



The microclimate model estimates how much hot exhaust reaches other units and sends their inlet temperatures back to the chiller farm.

The microclimate block sits inside the farm model



Separation of concerns

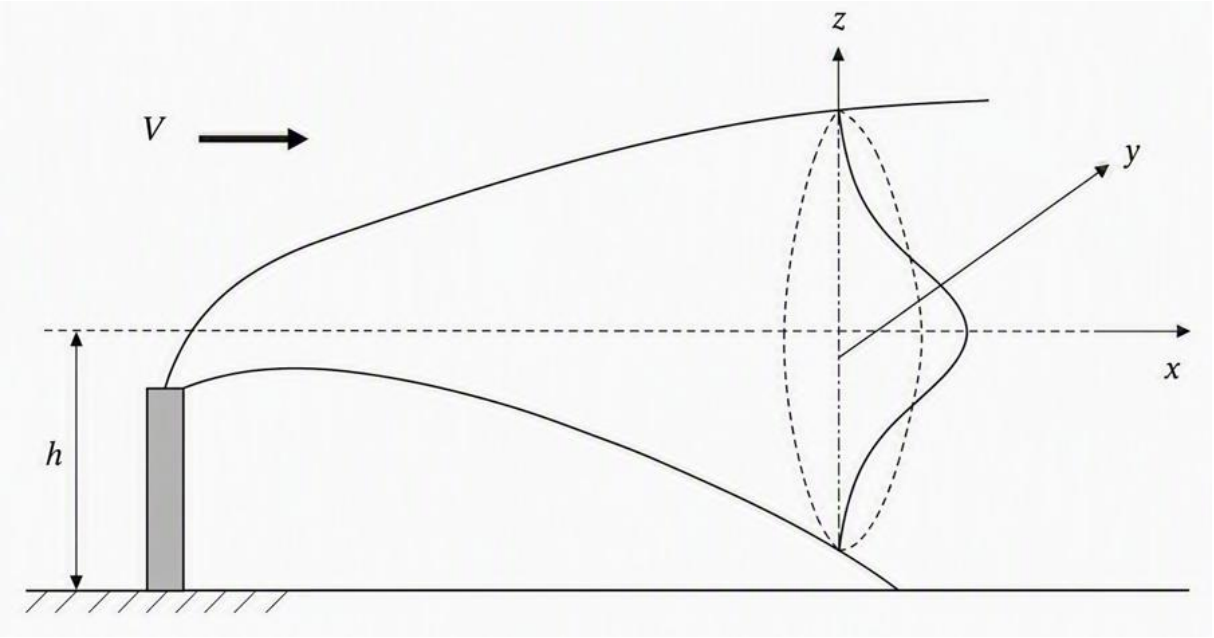
Farm thermo-fluid model

+

Microclimate block

Optional first-order feedback lag

Four effects produce a local inlet temperature



Gaussian-plume-inspired

1 Heat rejection sets source strength

2 Buoyancy and fans lift the exhaust

3 Wind and spacing set transport

4 Superposition of sources at target

Wind sets direction; buoyancy suppresses recirculation

Gaussian-Plume Inspired Model

Source strength and Buoyancy

$$\Delta Tsrc = \frac{Qcon}{\dot{m}air\ cp} \qquad V_b = \sqrt{g\beta\Delta T_{src} L_{ch}}$$

Wind-Active

Wind-Aligned Decay is applied when there is wind

$$d_{down} = -\Delta_{row} Cos(\theta) + \Delta_{col} Sin(\theta)$$

$$d_{cross} = |\Delta_{row} Sin(\theta) + \Delta_{col} Cos(\theta)|$$

$$\alpha_{base} = \alpha_0 exp\left(-\frac{k_{down} d_{down}}{L_{char}}\right) exp\left(-\frac{k_{cross} d_{cross}}{L_{char}}\right)$$

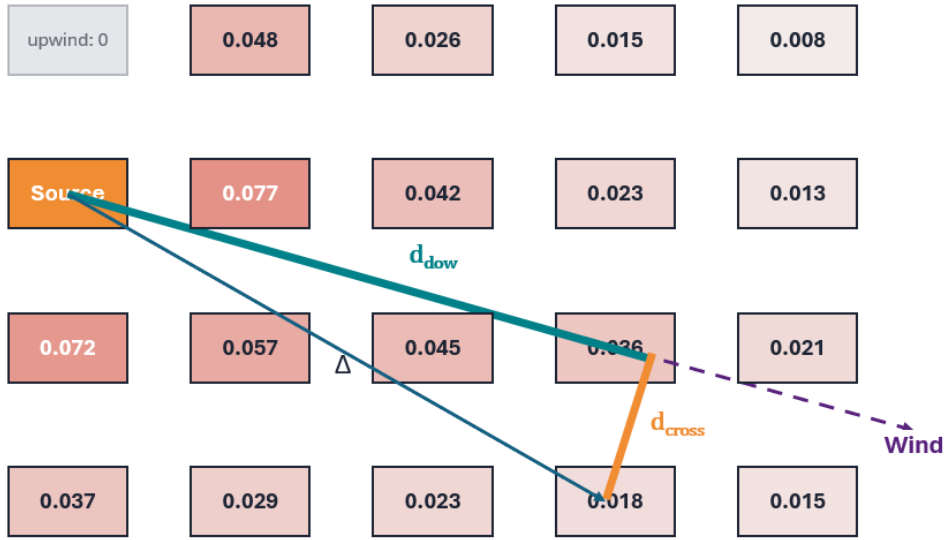
Wind-Calm

Calm wind uses isotropic distance decay instead of wind-aligned decay.

$$d_{Eff} = \max(\sqrt{(\Delta_{row}{}^2 + \Delta_{col}{}^2)})$$

$$\alpha_{base} = \alpha_0 exp\left(-\frac{k_{calm} d_{Eff}}{L_{char}}\right)$$

Wind Direction Coordinates



Source – Target Effects controlled by Coefficients

Suppression factor **Large vertical velocity to wind, ratio suppresses recirculation**

$$\alpha_{s,t} = \alpha_{base}[1 - tanh(k_{bou}\Pi)] \qquad \Pi = \frac{V_{bou} + V_{conFan}}{V_{wind}}$$

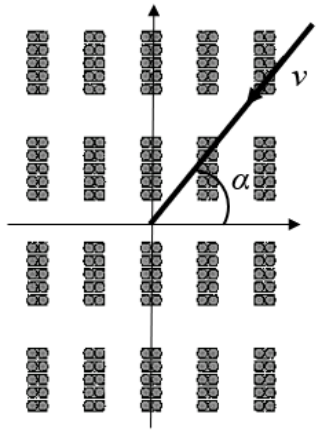
Superposition **Only downwind targets receive wind-aligned contributions**

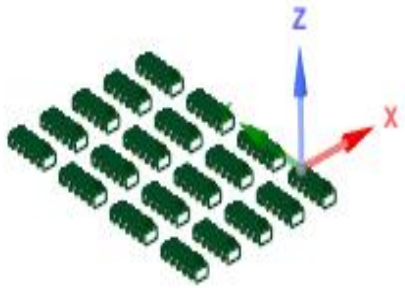
$$T_{in,t} = T_{amb} + \sum_{s \neq t} \alpha_{s,t}(T_{out,s} - T_{amb})$$

- α_0 : Baseline Recirculation
- k_{down} : Control Downwind Decay
- k_{cross} : Control Crosswind Decay
- k_{calm} : Control Calm Decay
- k_{bou} : Buoyancy Transition
- V_{Th} : Wind Threshold Velocity

Least-Squares applies to fit these 6 coefficients

Applying the reduced-order model to a 20-unit yard





Study configuration

4 × 5 chiller array

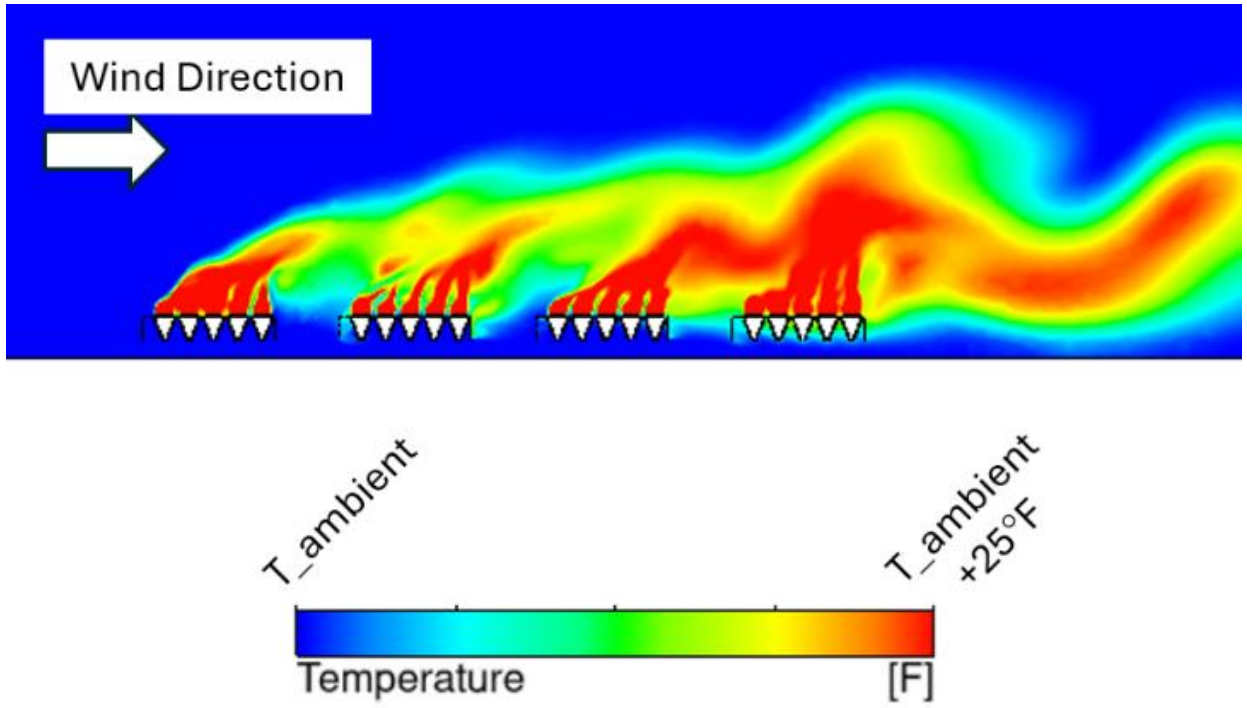
300-ton representative unit

65 CFD cases

Wind speed and direction, varied CFD boundary conditions

Approximately 12 hours per case on 200 CPU cores.

Vertical slices show the exhaust path through the yard

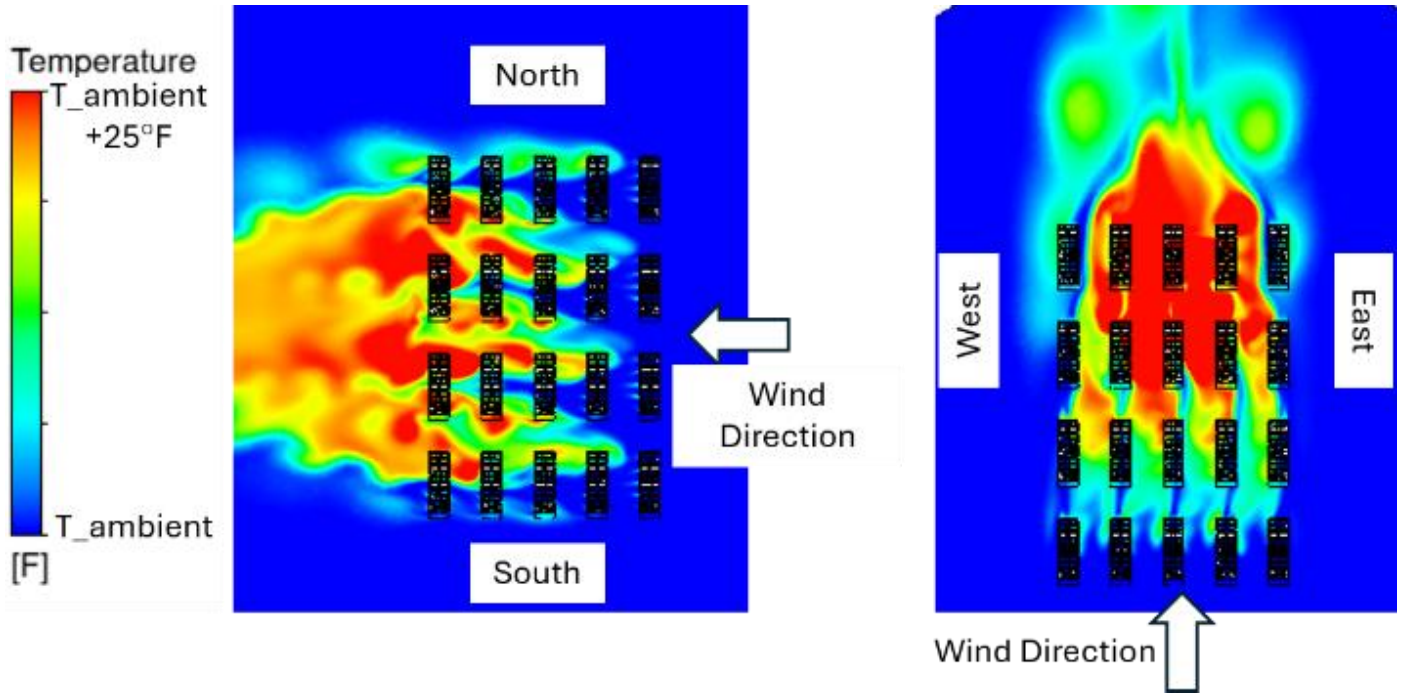


Physical interpretation

Upstream exhaust bends with wind.

Downstream condenser inlets encounter warmer air.

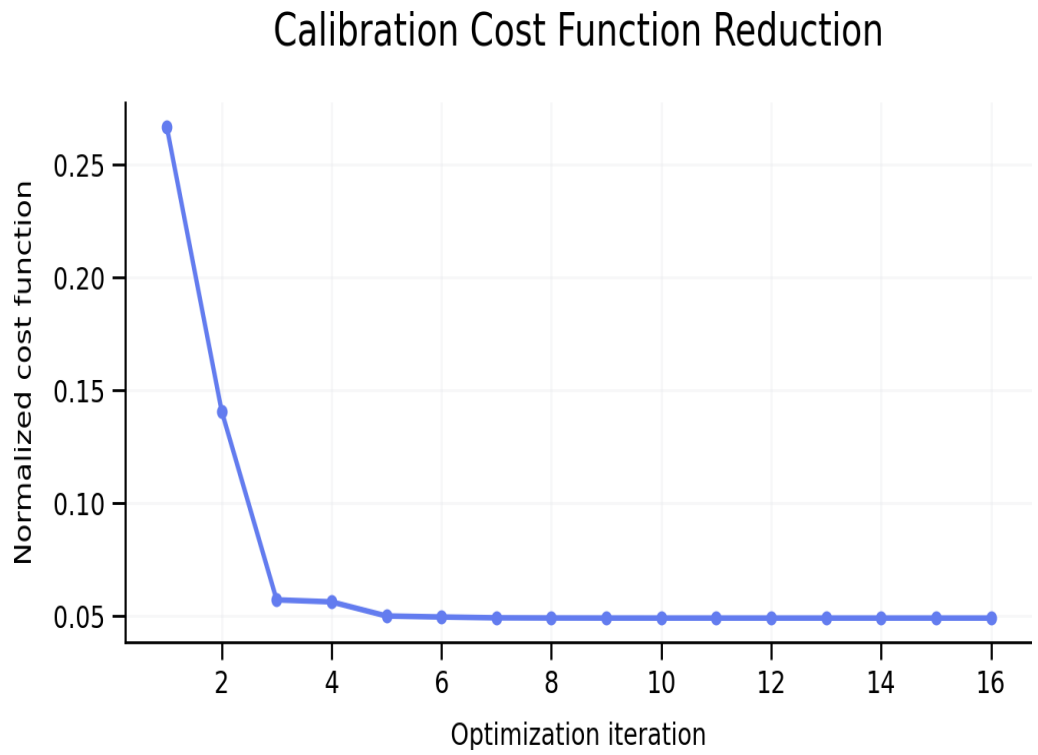
Changing wind direction changes which chillers are exposed



A single outdoor-air temperature removes this directional, spatial penalty.

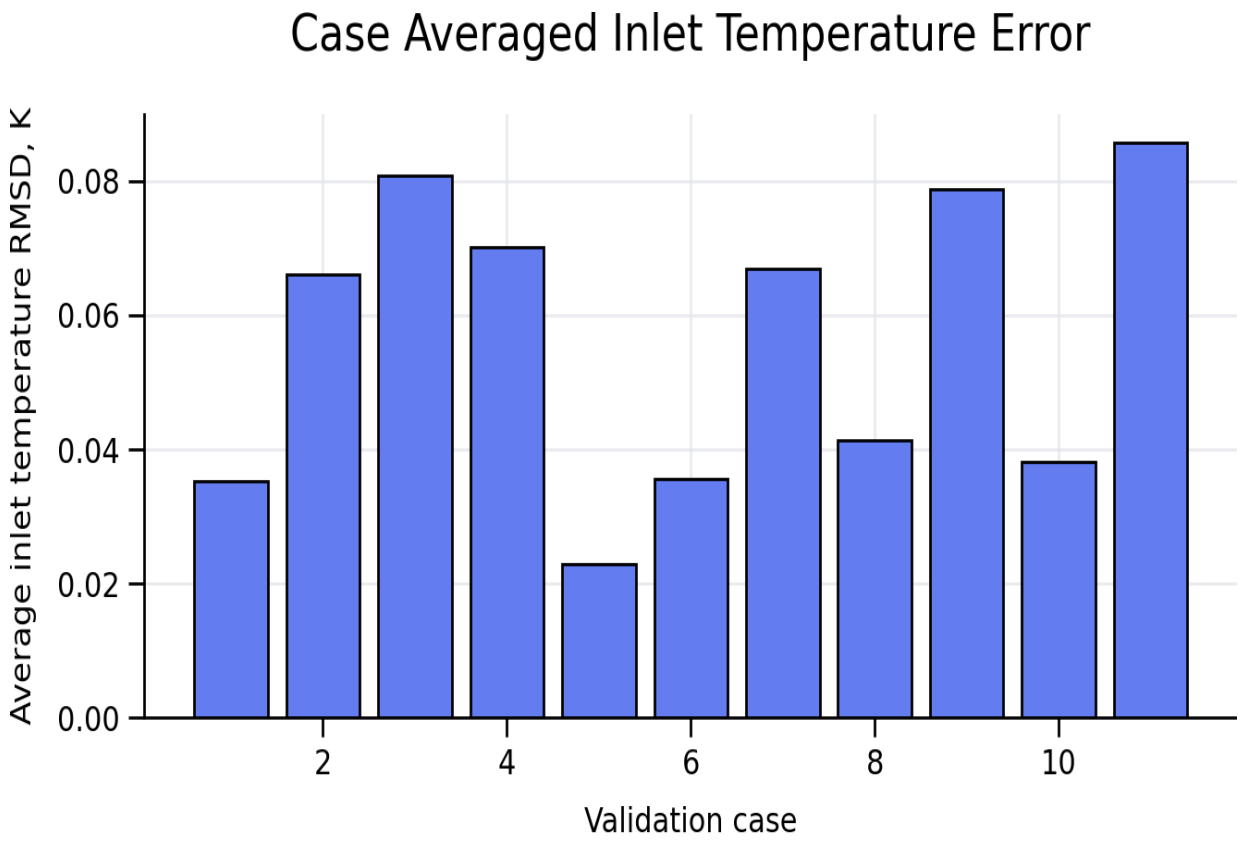
Six fitted coefficients make the plume model practical

Parameter	Optimized	Lower bound	Upper bound
k_bou ($Buoyancy\ Transition$)	0.22	0	10
α_0 (Baseline Recirculation)	0.14	0	2
k_down (Control Downwind Decay)	0.43	0	4
k_cross (Control Crosswind Decay)	0.7	0	4
k_calm (Control Calm Decay)	1.8	0	4
V_Th (Wind Threshold)	0.87	0	2

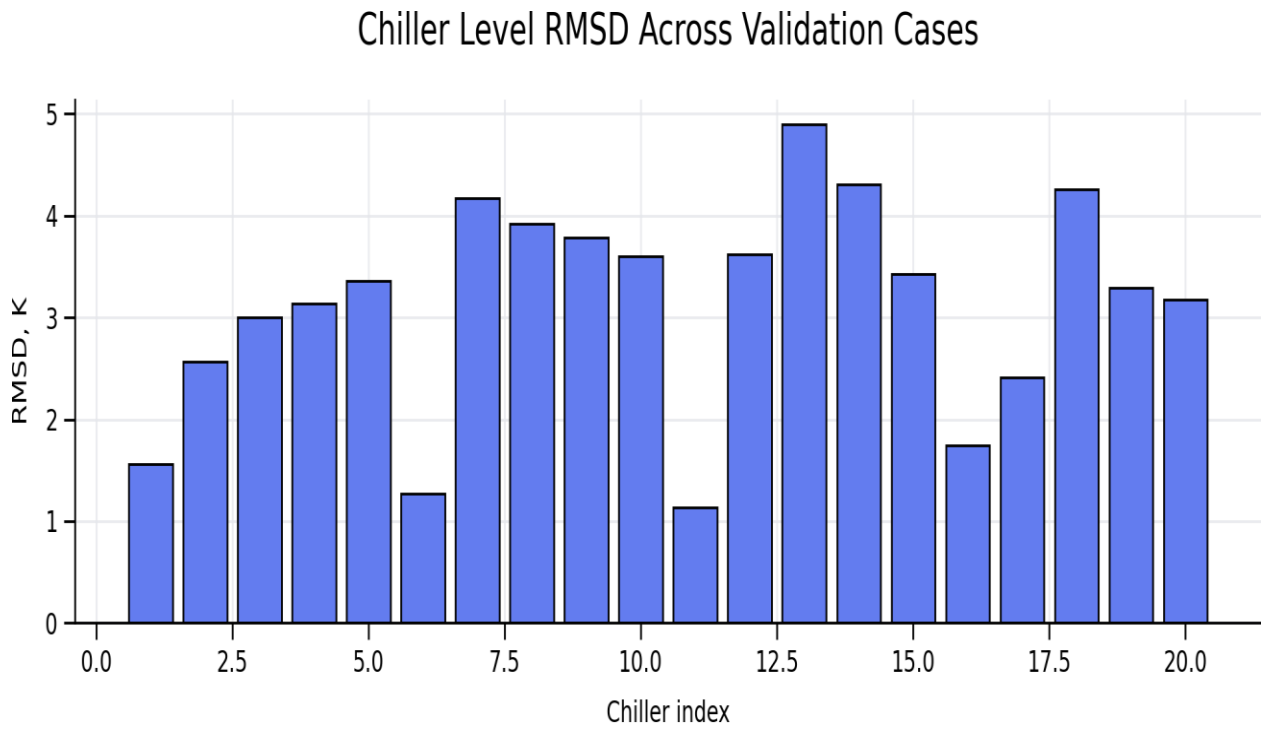


Paper Figure 7. Normalized calibration cost; full coefficient values and bounds in backup.

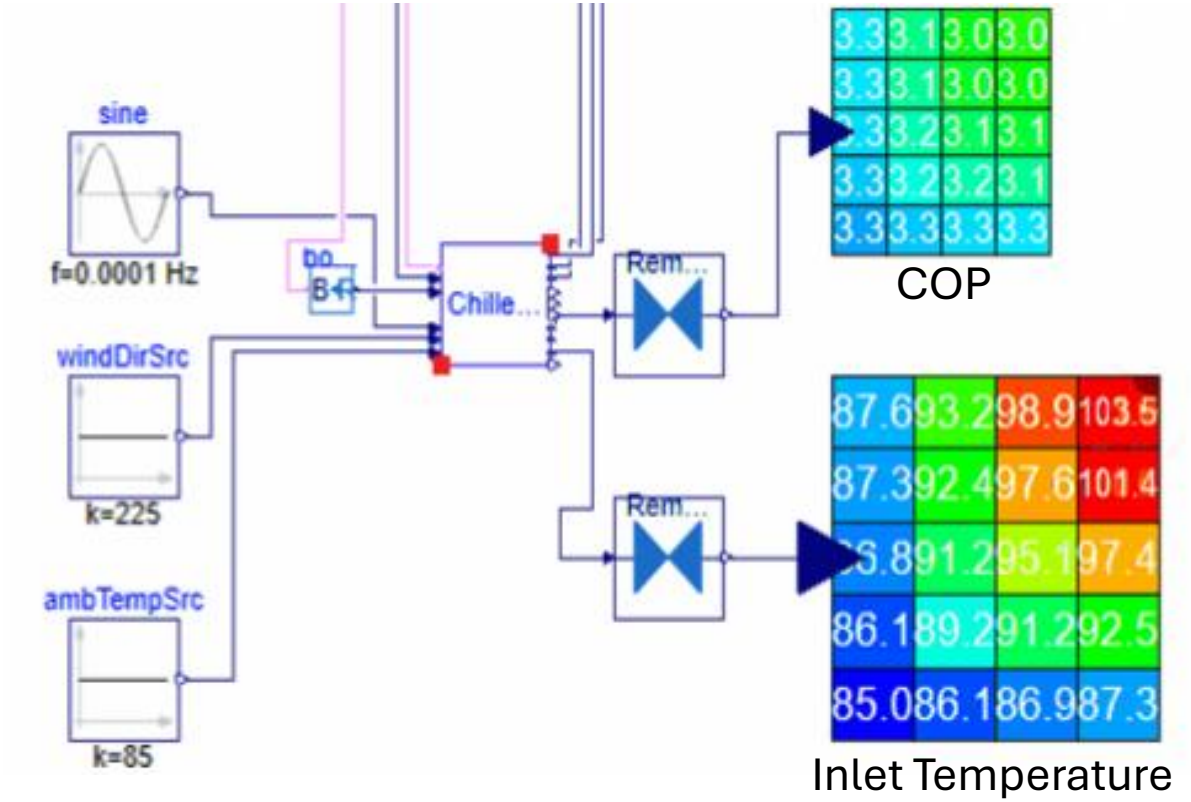
Validation is evaluated on eleven held-out wind conditions



Prediction error is not uniform across the chiller array



One weather condition produces many equipment states

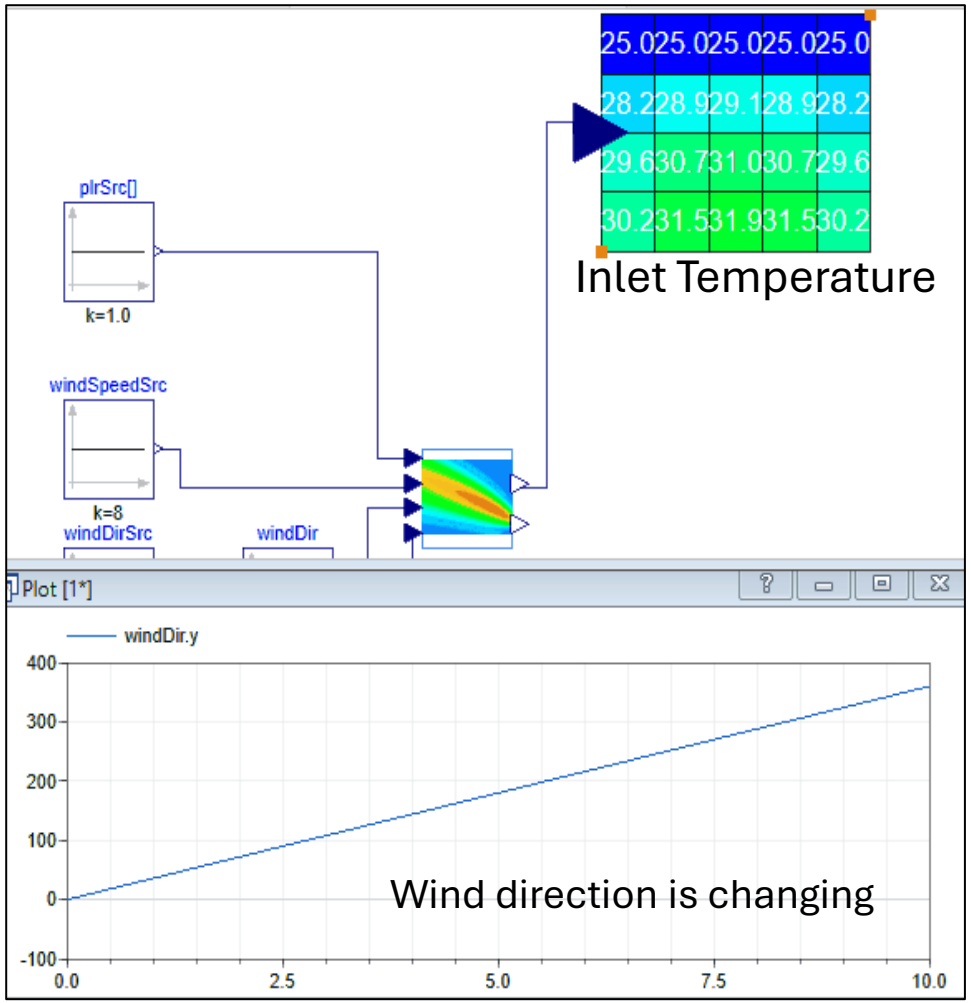


Spatial feedback

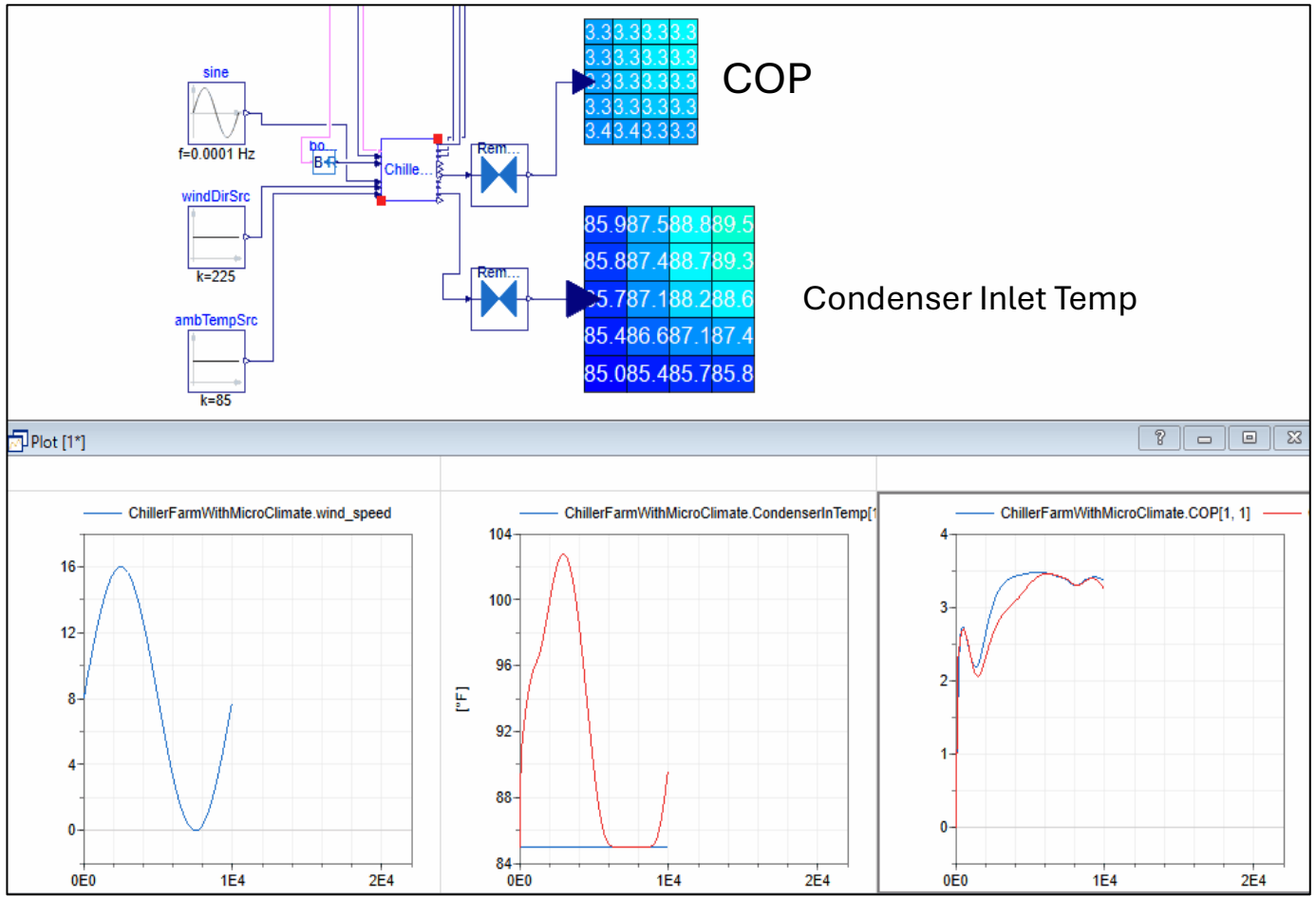
Each position gets its own inlet temperature.

The chiller model converts local exposure into COP and capacity.

Approximate, fast, pseudo-transient



The illustrative inlet penalty approaches 10°C



≈16 m/s | 85 → 102.8°F | 3.4 → 3.0 COP

Microclimate makes sequencing hypotheses testable

Sequencing and Load sharing

Compare which units operate and how load is distributed.

Weather and wind sensitivity

Explore long horizons without a CFD run at every time step.

Layout and spacing screening

Identify sensitivities before detailed CFD design studies.

Diagnostics and instrumentation

Identify positions likely to reveal recirculation exposure.

Model scope must remain explicit

Current representation

Quasi-steady plume interaction

Compact empirical coefficients

Regular row / column layout

No explicit screens, buildings, fan jets or transient vortices

Next development steps

Broader CFD conditions and loads

Lower spatial validation error

Explicit coordinates / irregular yards

Field measurements and recirculation-aware control

Use for screening, diagnostics and control development; retain CFD for final design.

Local inlet temperature belongs in plant simulation

01 Connect plant heat rejection to local condenser exposure.

02 Expose spatial penalties hidden by a single ambient signal.

03 Use CFD-calibrated trends now; strengthen validation next.

Illustrative result: +17.8°F inlet rise and approximately 11.8% COP difference.

Thank you — questions?

From one ambient temperature

to a spatially aware chiller farm.

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