

Innovative Solutions for Laboratory HVAC: Leveraging CFD for Better Outcomes

Session F4 – System Optimization
October 21st, 2025





Design Moment

The Critical Role of Laboratory Ventilation in Protecting Health

Why it matters:

In laboratories, ventilation is the first line of defense against airborne hazards. Whether you're working with chemicals, biological agents, or radioactive materials, proper ventilation ensures contaminants are captured and removed before they can be inhaled.





Agenda

1. Introduction
2. Learning Objectives
3. Understanding Laboratory Energy Use
4. Importance of Ventilation in Laboratories
5. CFD in Laboratory Design
6. Integrating CFD into Design Workflow
7. Summary
8. Q&A





Introductions



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Learning Objectives

- Understand the **energy consumption patterns** of laboratories.
- Recognize the **importance of proper ventilation** in laboratories.
- Explore the application of **computational fluid dynamics (CFD)** in laboratory design.
- Evaluate the benefits of incorporating **CFD into design workflows**.



Why Labs Consume More Energy?

Specialized Equipment and Operations - Labs house energy-intensive equipment like fume hoods, biosafety cabinets, autoclaves, and ultra-low temperature freezers.

100% Outside Air Ventilation - Unlike commercial buildings, labs often use 100% outside air to prevent recirculation of contaminants, which dramatically increases heating and cooling loads.

High Air Change Rates - Labs typically require **10–15 ACH**, far exceeding typical office spaces (2–4 ACH), to maintain safety and air quality.

Stringent Safety Requirements - Ventilation systems must operate continuously and reliably, often with redundancy, which adds to energy demand.





Why Ventilation Matters in Labs?



Safety Through Ventilation – Effective ventilation removes hazardous fumes to protect lab workers and maintain a safe environment.



Energy Efficiency Importance – Proper ventilation design improves energy efficiency, reducing operational costs in labs.



Occupant Comfort – Ventilation maintains healthy indoor air quality, enhancing comfort for lab occupants.



Compliance – Supports compliance with health, safety, and building code standards.

Laboratory ventilation safety related standards –
ANSI/ASSP Z9.5-2022, ANSI/ASHRAE 110-2016, NFPA 45-2024,
OSHA 29 CFR 1910.1450





Traditional HVAC Design Limitations

Simplified Design Assumption

- Often rely on rules of thumb rather than detailed analysis, which can lead to over- or under-ventilation.

Poor Performance Prediction

- Struggle to accurately model airflow in complex lab geometries, especially around equipment and obstructions.

Limited Validation

- Physical testing alone may not capture dynamic airflow patterns or identify dead zones and recirculation areas.

Energy Inefficiency

- Overdesign for safety can result in excessive energy use due to high air change rates and constant volume systems.

Lack of Flexibility

- Traditional systems may not adapt well to changing lab configurations or usage patterns.

Higher ACH != Better IEQ



Leveraging CFD in Laboratory Design





Computation Fluid Dynamics (CFD)

What is CFD?

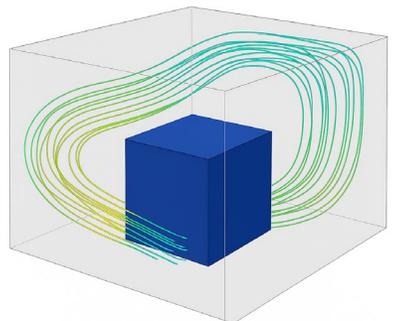
Numerical analysis technique simulating fluid flow, heat transfer, and mass transport using mathematical models.

Why it's a breakthrough for HVAC ?

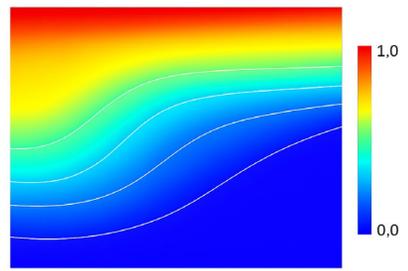
In contrast with physical testing, CFD provides the ability to run multiple virtual prototypes, which is faster and more cost-effective.

What CFD simulates?

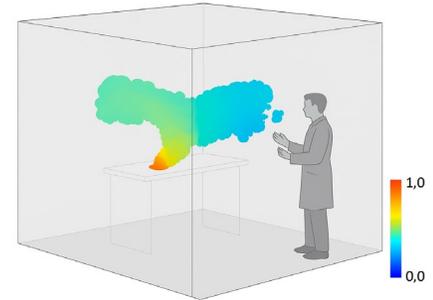
- 3D airflow distribution and velocity
- Temperature and pressure gradients
- Contaminant and chemical dispersal



3D airflow distribution and velocity



Temperature and pressure gradients



Contaminant and chemical dispersal



Using CFD in Laboratory Design

HVAC Scenario Simulation

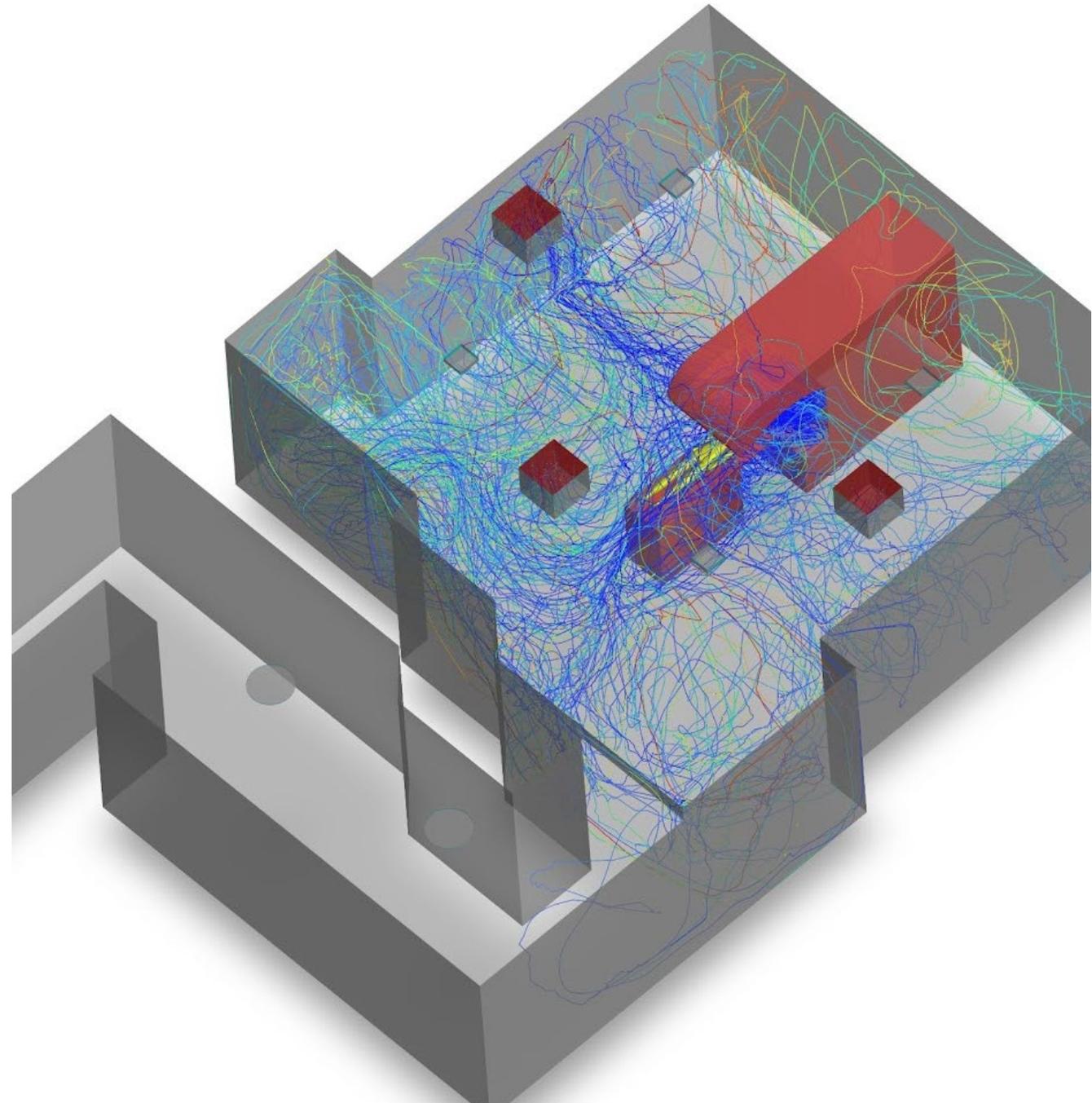
CFD simulates diverse HVAC setups in labs to analyze airflow and temperature distribution effectively.

Optimization of Fume Hoods

CFD helps optimize fume hood placement for maximum containment and safety in laboratory environments.

Exhaust Strategy Effectiveness

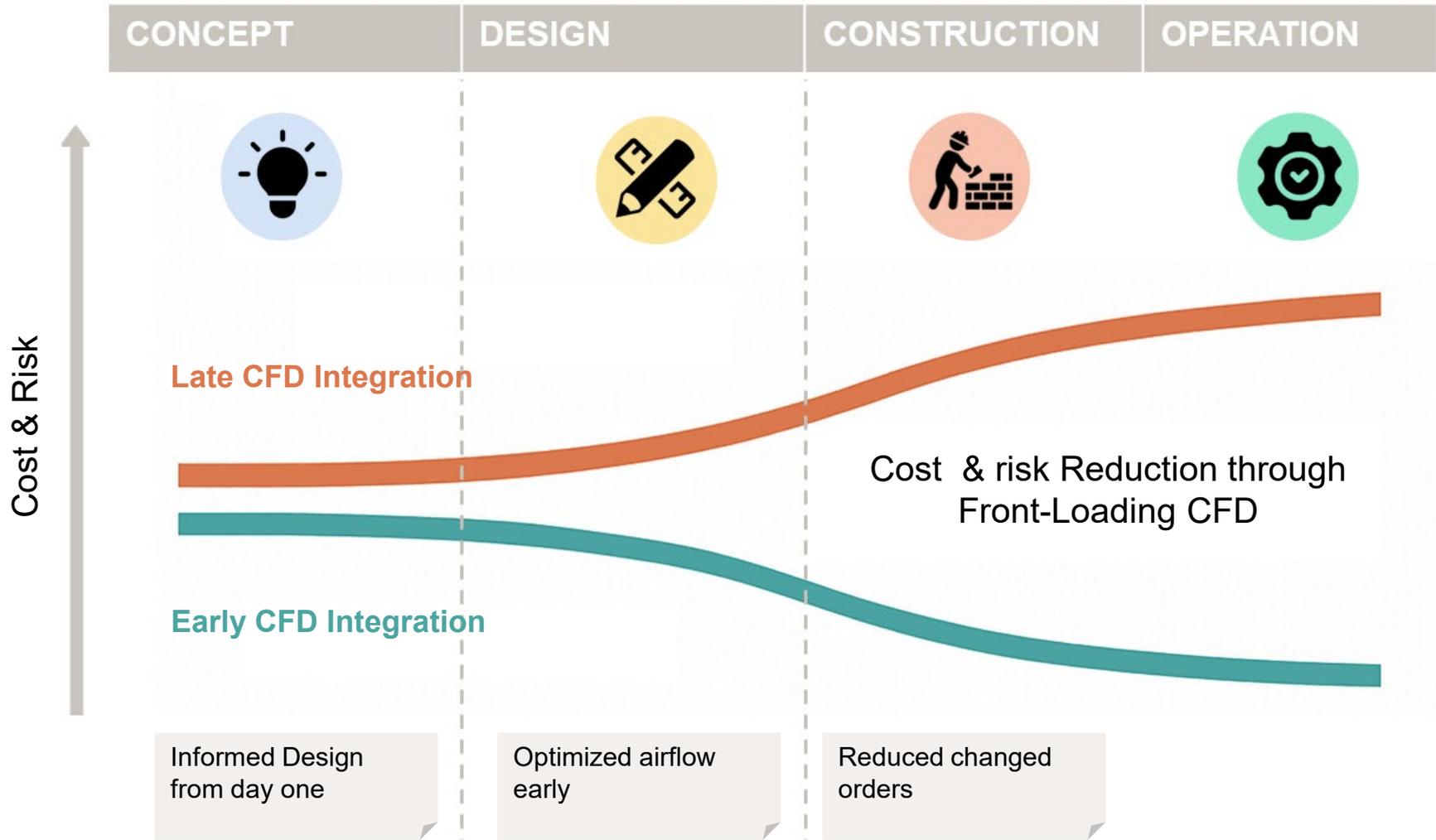
Simulations ensure exhaust systems efficiently remove contaminants, enhancing lab safety and energy efficiency.





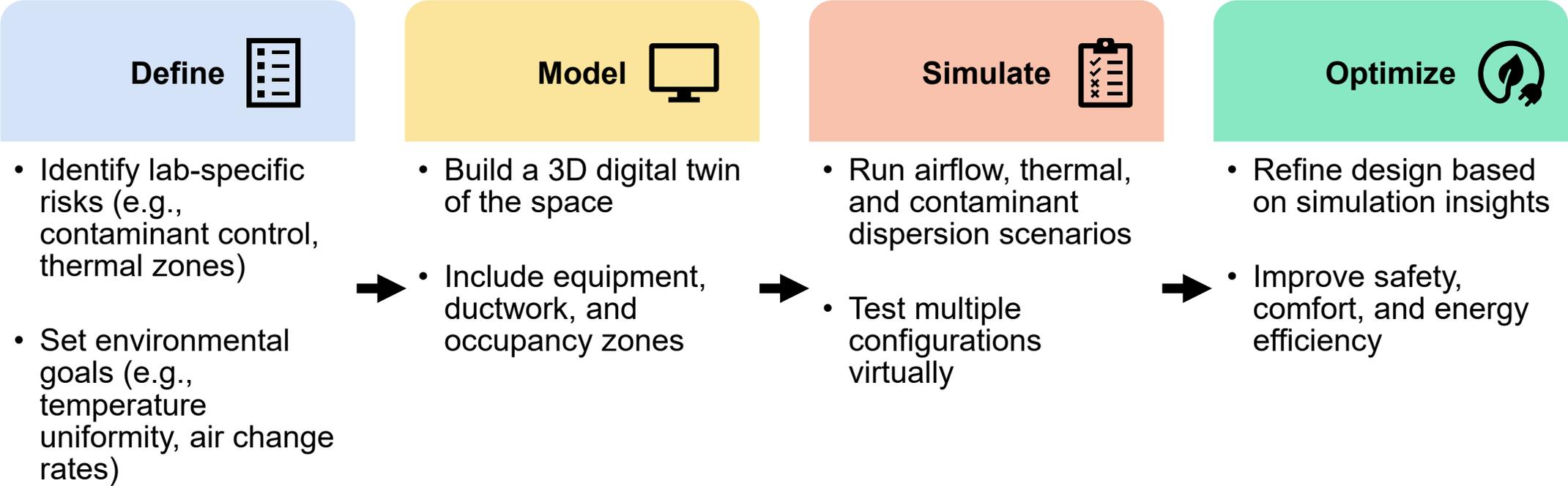
Front-Loading CFD: Saving Time, Cost, and Complexity

- Early CFD simulations reveal design flaws before construction, when modifications are cheapest.
- “Front-loading” the design process means investing effort upfront to prevent downstream rework.

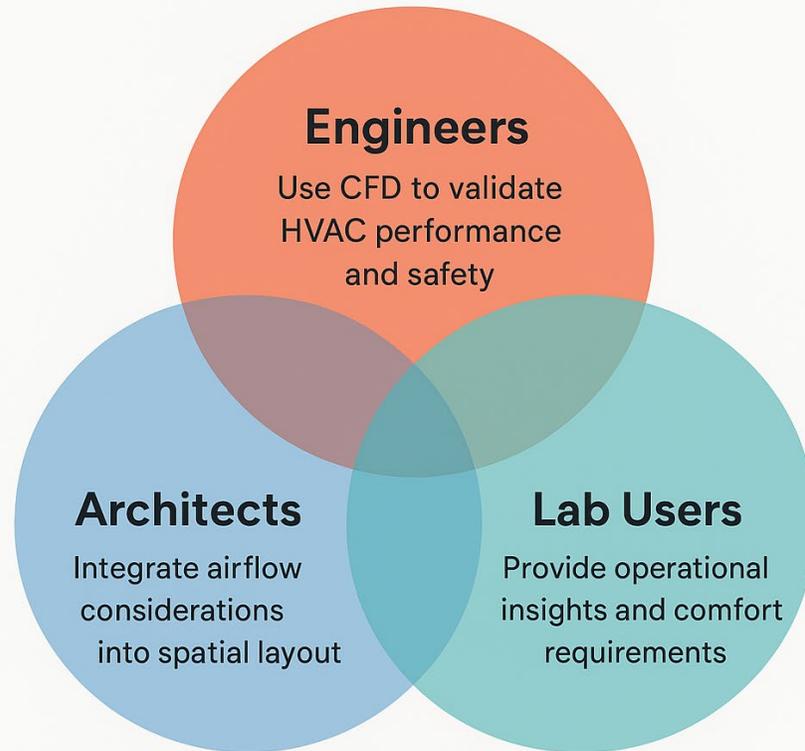




From Concept to Optimization: The CFD Process



Interdisciplinary Design for Smarter Labs



Outcome:

- Better stakeholder alignment
- Fewer design conflicts
- More resilient and adaptable lab environments

“CFD bridges the gap between design intent and real-world lab performance.”

CFD Simulation Workflow

Stage 1: Pre-Processing

- This stage involves setting up the simulation domain, defining geometries, and generating a computational mesh. Critical parameters like fluid properties and initial conditions are established to prepare the model for calculation.

Stage 2: Solution

- Here, the CFD solver iteratively calculates the fluid flow and heat transfer equations. The process refines pressure and velocity fields until convergence criteria are met, ensuring stable and accurate results for complex flow patterns.

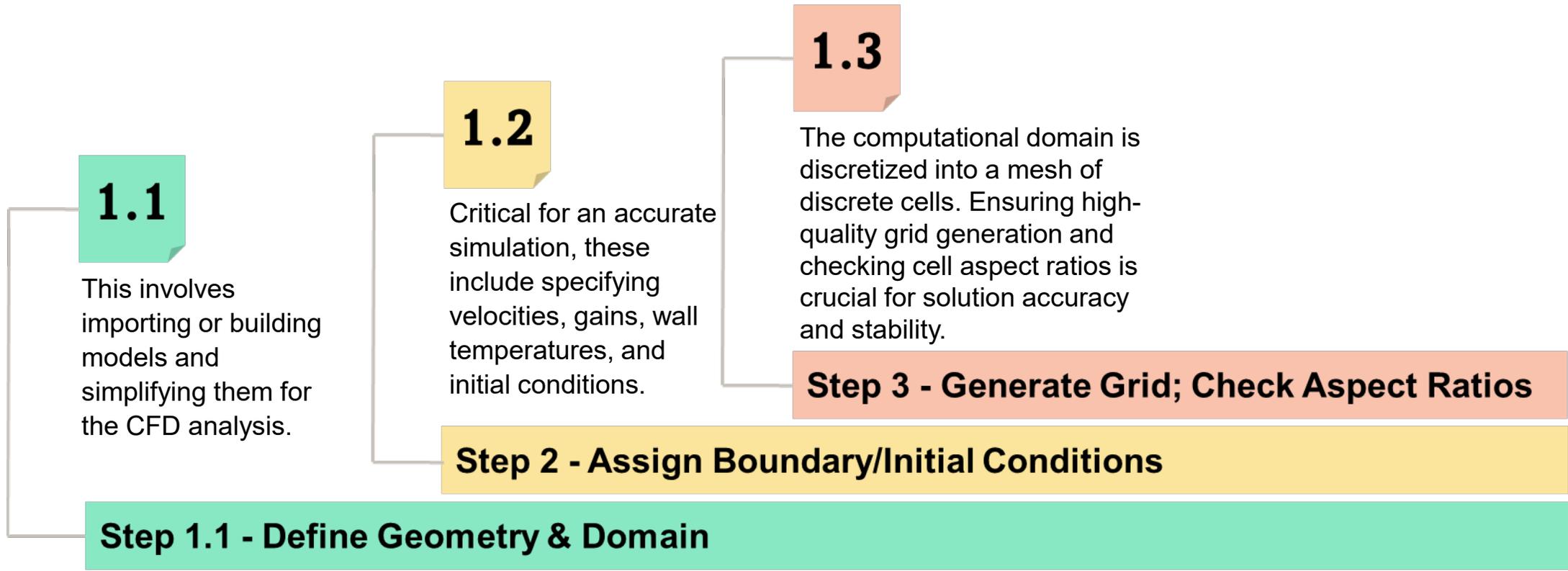
Stage 3: Post-Processing

- The final stage focuses on visualizing and analyzing the simulation results. This includes generating contour plots, velocity vectors, and streamlines to interpret flow behaviors, temperature distributions, and other key performance indicators.



CFD Simulation Workflow

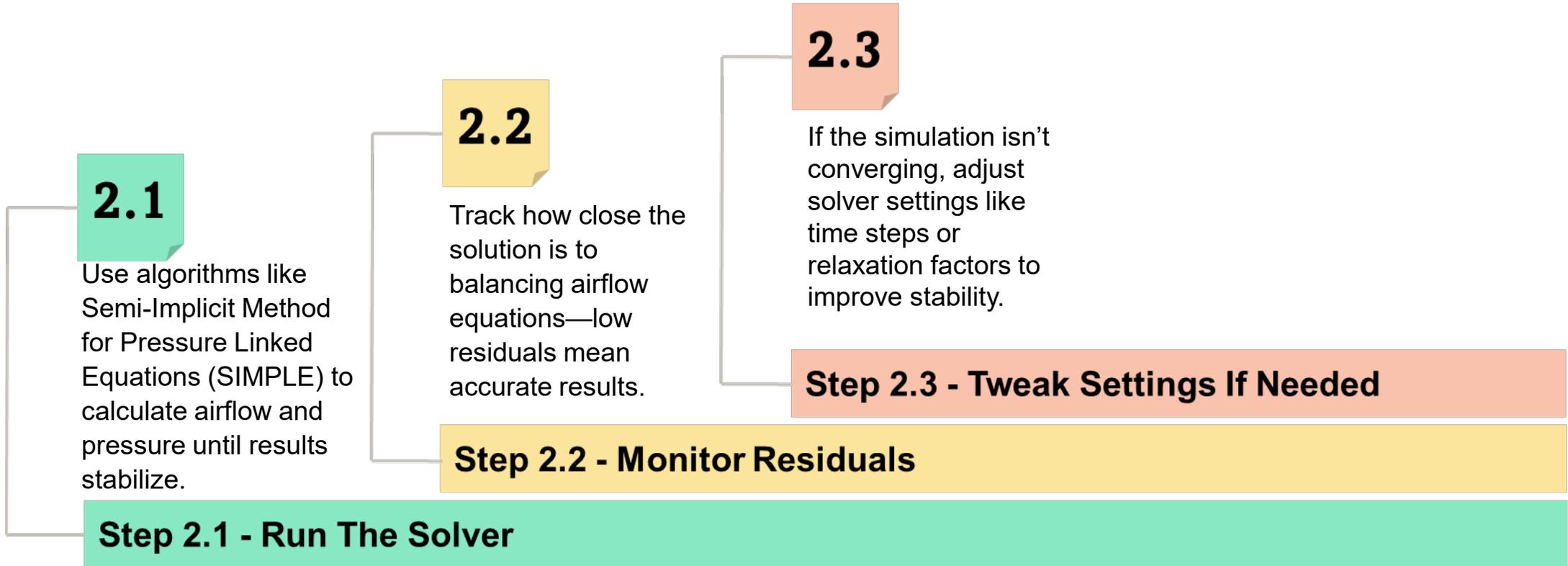
Stage 1: Pre-processing





CFD Simulation Workflow

Stage 2: Solution





CFD Simulation Workflow

Stage 3: Post Processing

3.1

Advanced visualization tools are used to display scalar fields like temperature and pressure, as well as vector fields for air velocity, providing qualitative insights into the fluid flow patterns and heat transfer within the space.

Step 3.1 - Visualize Airflow and Temperature

3.2

Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) and Indoor Air Quality (IAQ) parameters, such as air change effectiveness and contaminant removal rates.

Step 3.2 - Assess Comfort and IAQ Metrics

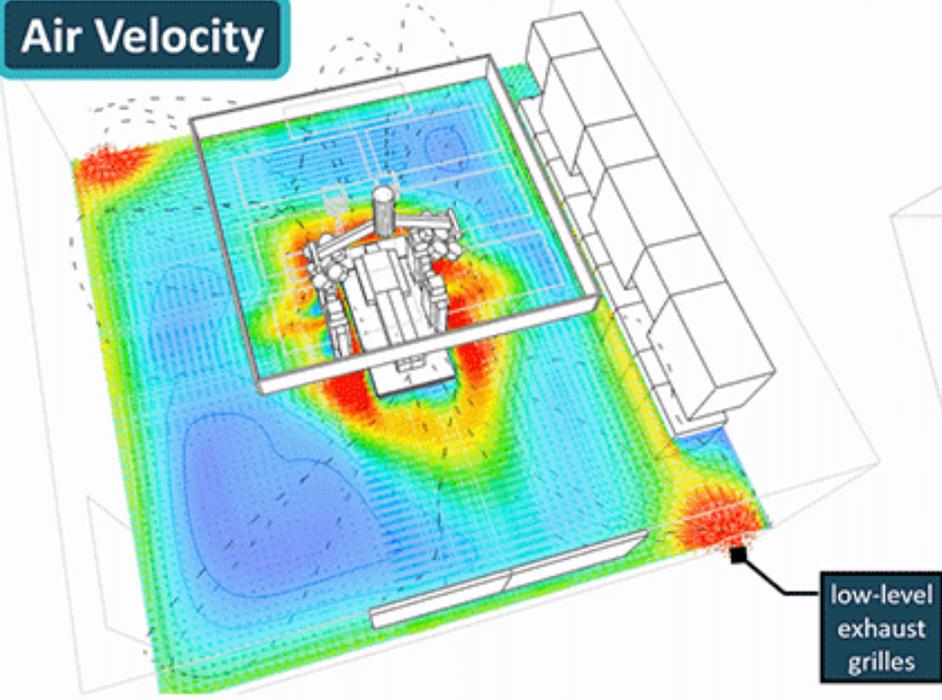
3.3

The CFD results should be rigorously validated against simplified hand calculations or empirical data where possible

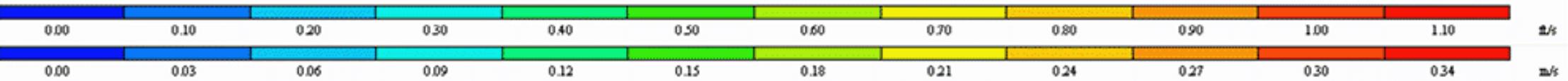
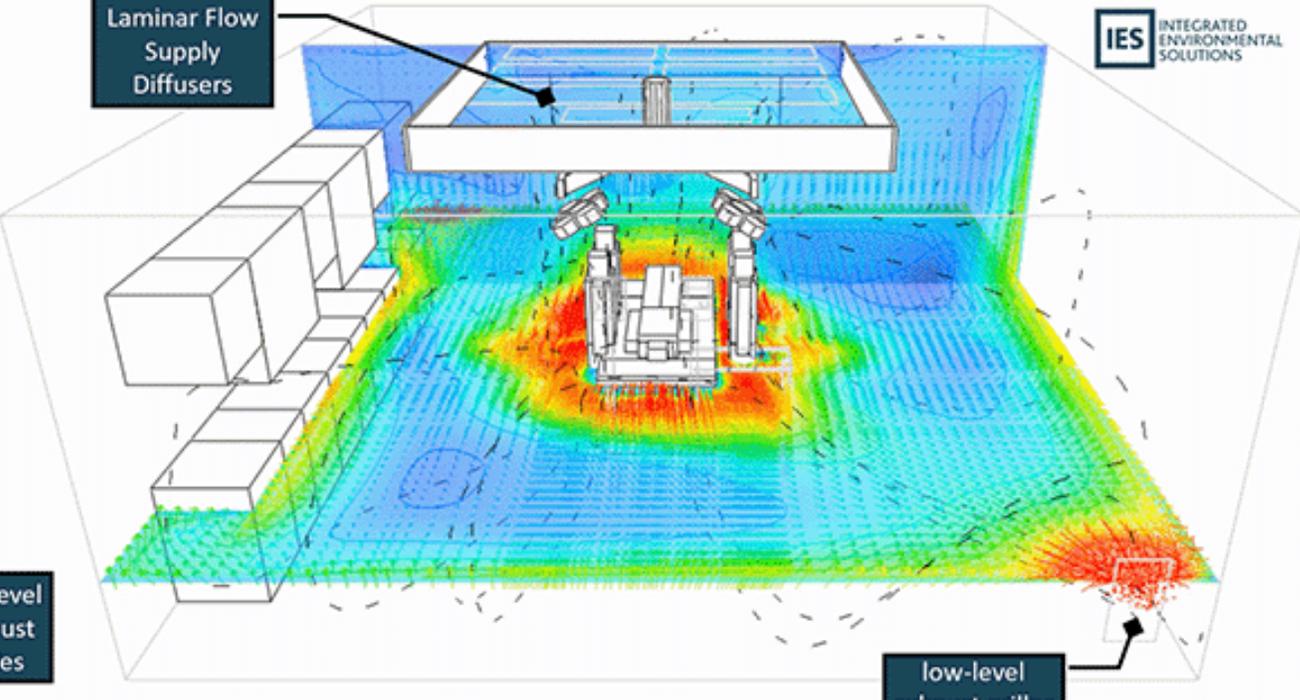
Step 3.3 - Validate Results



Air Velocity



Laminar Flow Supply Diffusers





The Path Forward: Smarter, Safer Labs

Summary of Benefits



Improved safety through optimized airflow and contaminant control



Increased energy efficiency by refining ventilation strategies



Enhanced environmental control for occupant comfort and compliance

CFD's Role in the Future



Integration with Building Information Modeling (BIM) for real-time performance feedback



Enabling **adaptive ventilation systems** that respond dynamically to lab conditions



Foundational tool for **Smart Labs** of the future



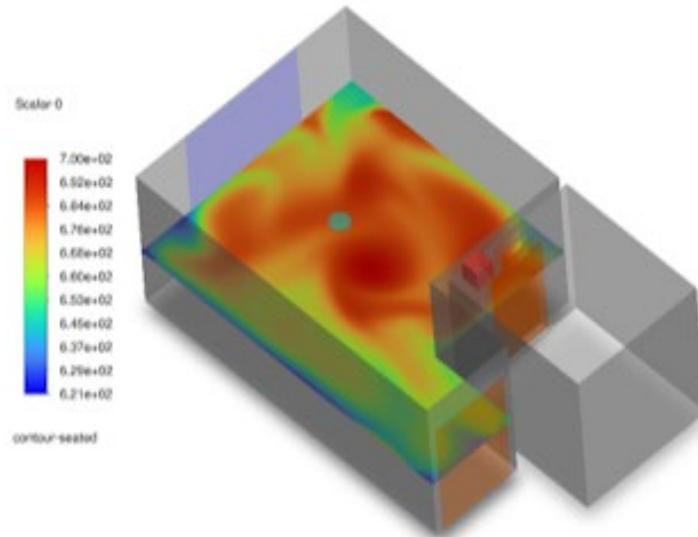
Summary of Key Takeaways

CFD for HVAC Optimization

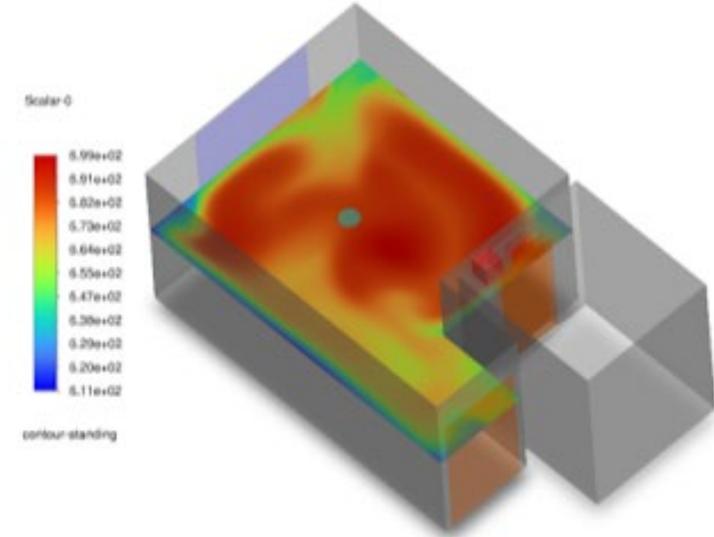
Computational Fluid Dynamics (CFD) enables the optimization of HVAC systems to improve safety and potentially minimize energy consumption.

Early CFD Integration Benefits

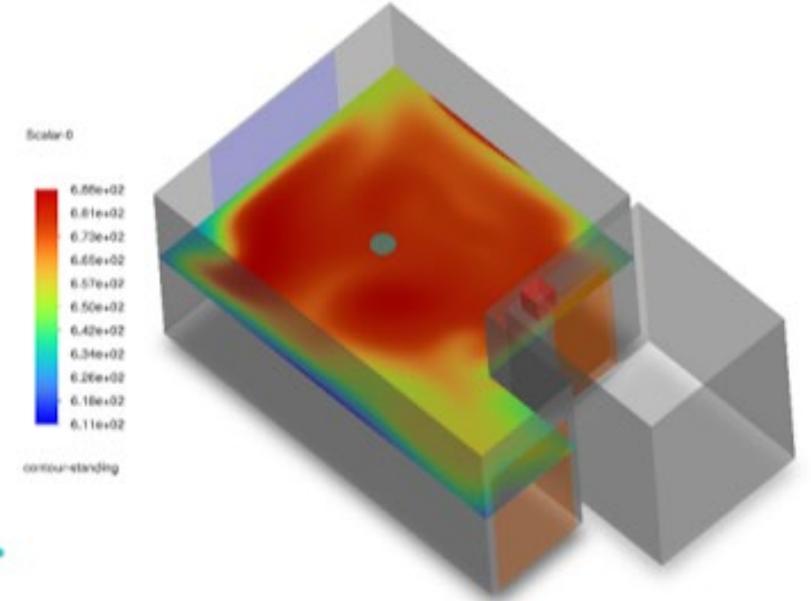
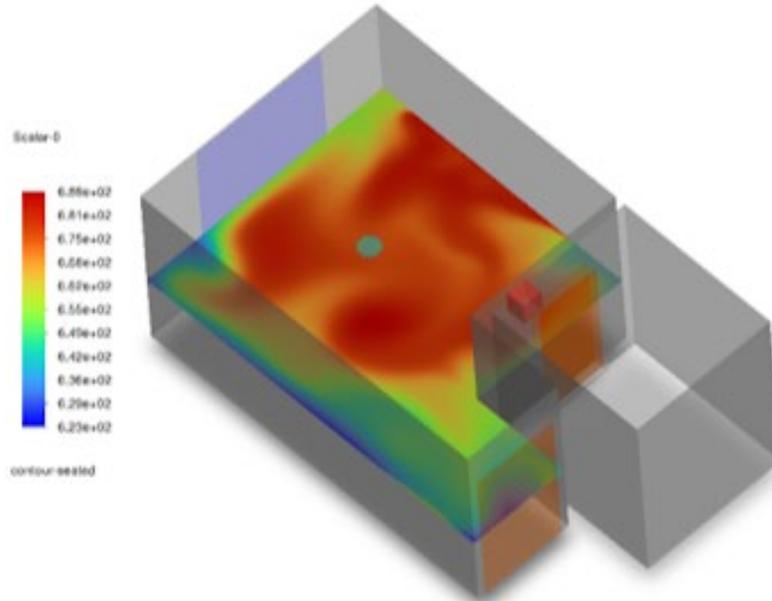
Incorporating CFD early in design phases promotes data-driven decisions and leads to more sustainable laboratory outcomes.



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Call to Action:

“Embrace simulation and data-driven design to build laboratories that are safer, more sustainable, and more efficient.”

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Thank you

