Analysis of Food Processing Operations Using a Coupled CFD/Food Model

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Motivation

Methods are needed for improving production scale food processing operations

Current tools:

- **Research-scale testing**
- **Pilot-scale testing**
- **In-plant testing**
- **Computer simulation**

Motivation

An effective simulation must include:

- **Prediction of the actual flow field**
- **Prediction of gas properties (T, RH)**
- **Effects of product on flow field**
- **Effects of local environment on product**
- **Effects of upstream product on environment**
- **Effects of product history**
- **Effects of product internal gradients**

Motivation

Why computational fluid dynamics (CFD) alone won't do:

Length scale problem

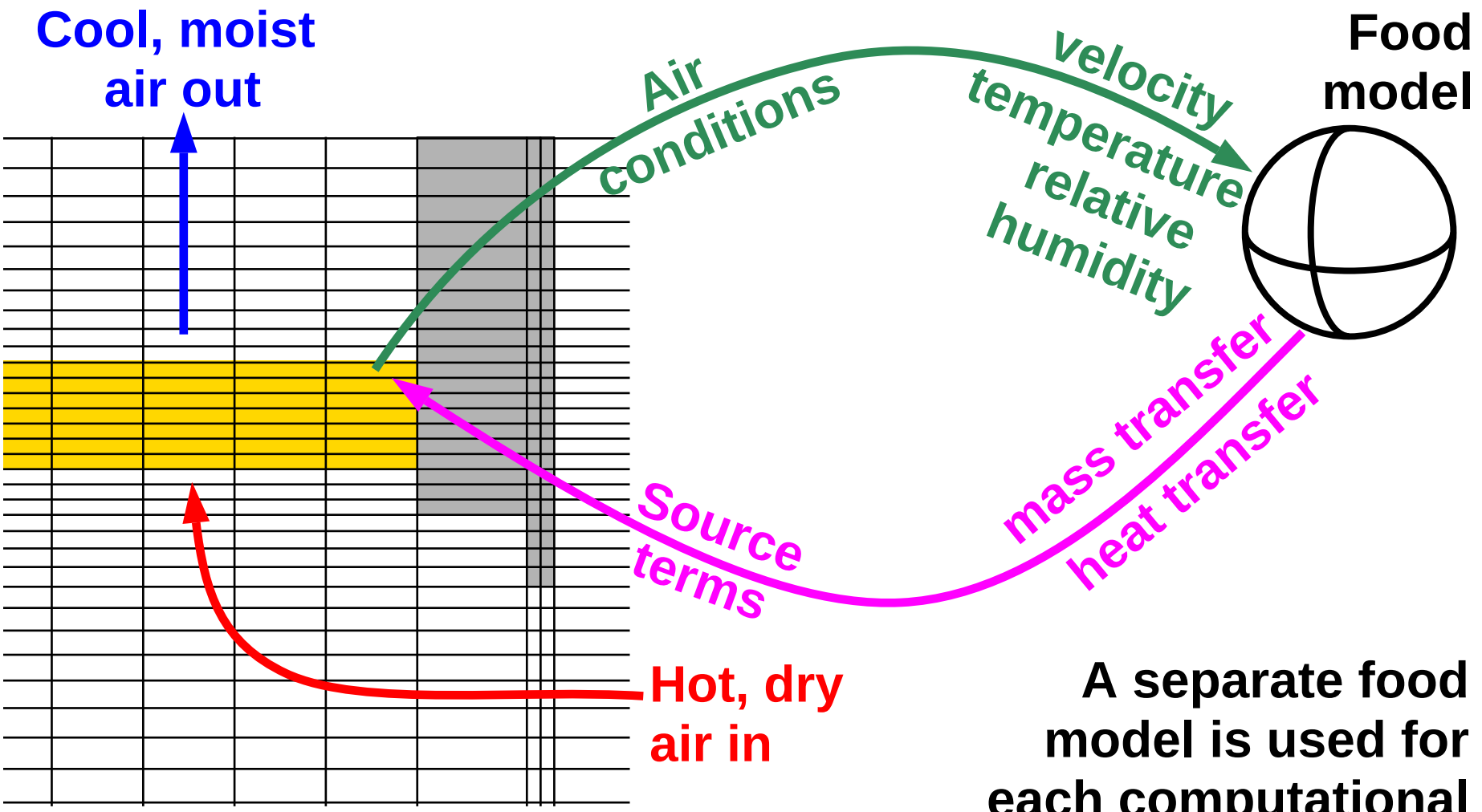
- **Food pieces much smaller than equipment**
- **Difficult to have sufficient grid density**

Movement problem

- **Belt motion**
- **Drop to lower level**
- **Continuously mixed**

Approach

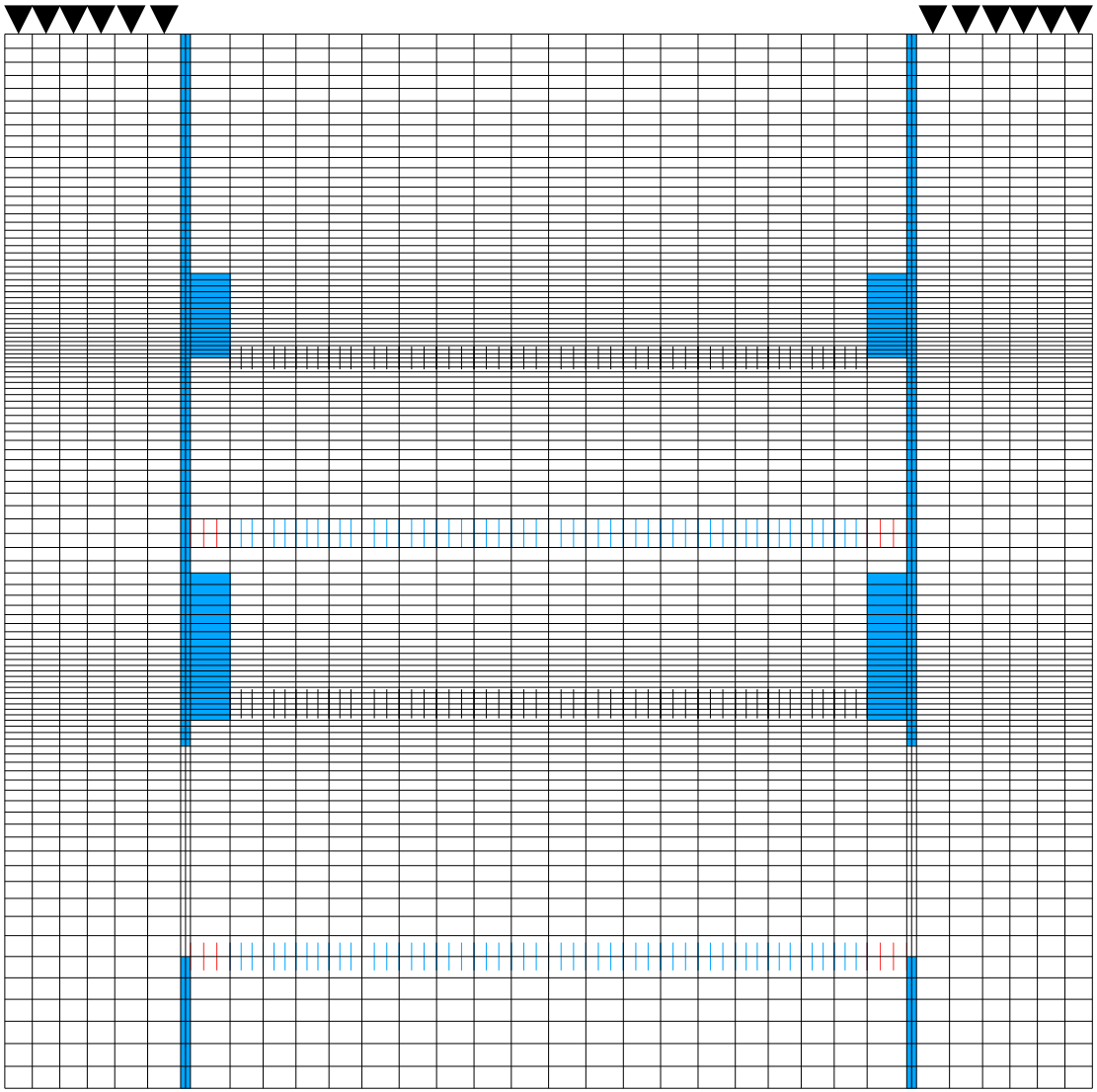
Couple CFD model of equipment to food models



A separate food model is used for each computational cell (or location) within the CFD model

Approach - CFD model details

Model domain divided into computational cells



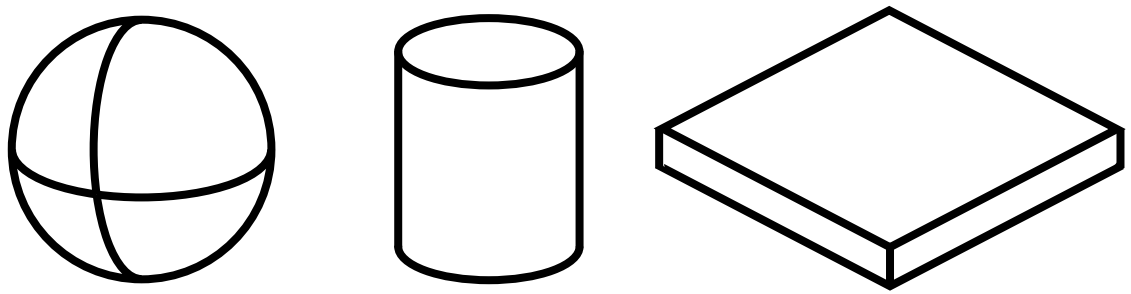
Differential equations solved across each cell for:

- **momentum**
- **energy**
- **moisture**
- **pressure**
- **turbulence**

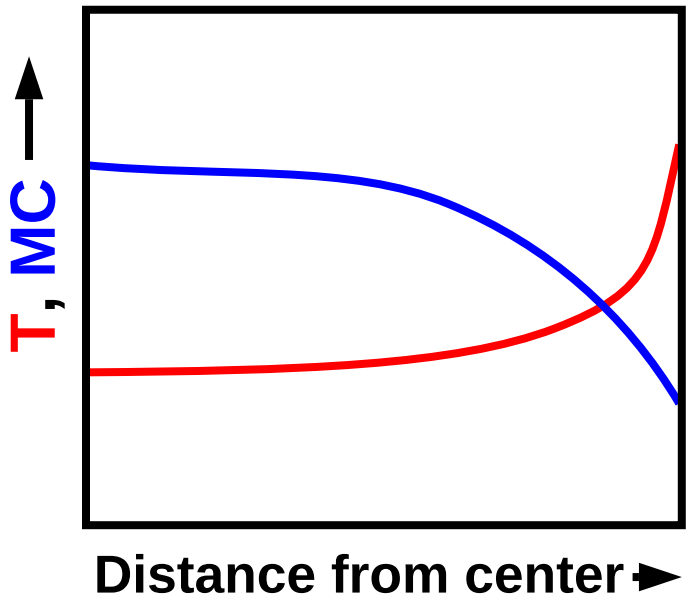
Approach - Food model details

1-D model for food internal gradients

3 geometries



Spherical Cylindrical Plate

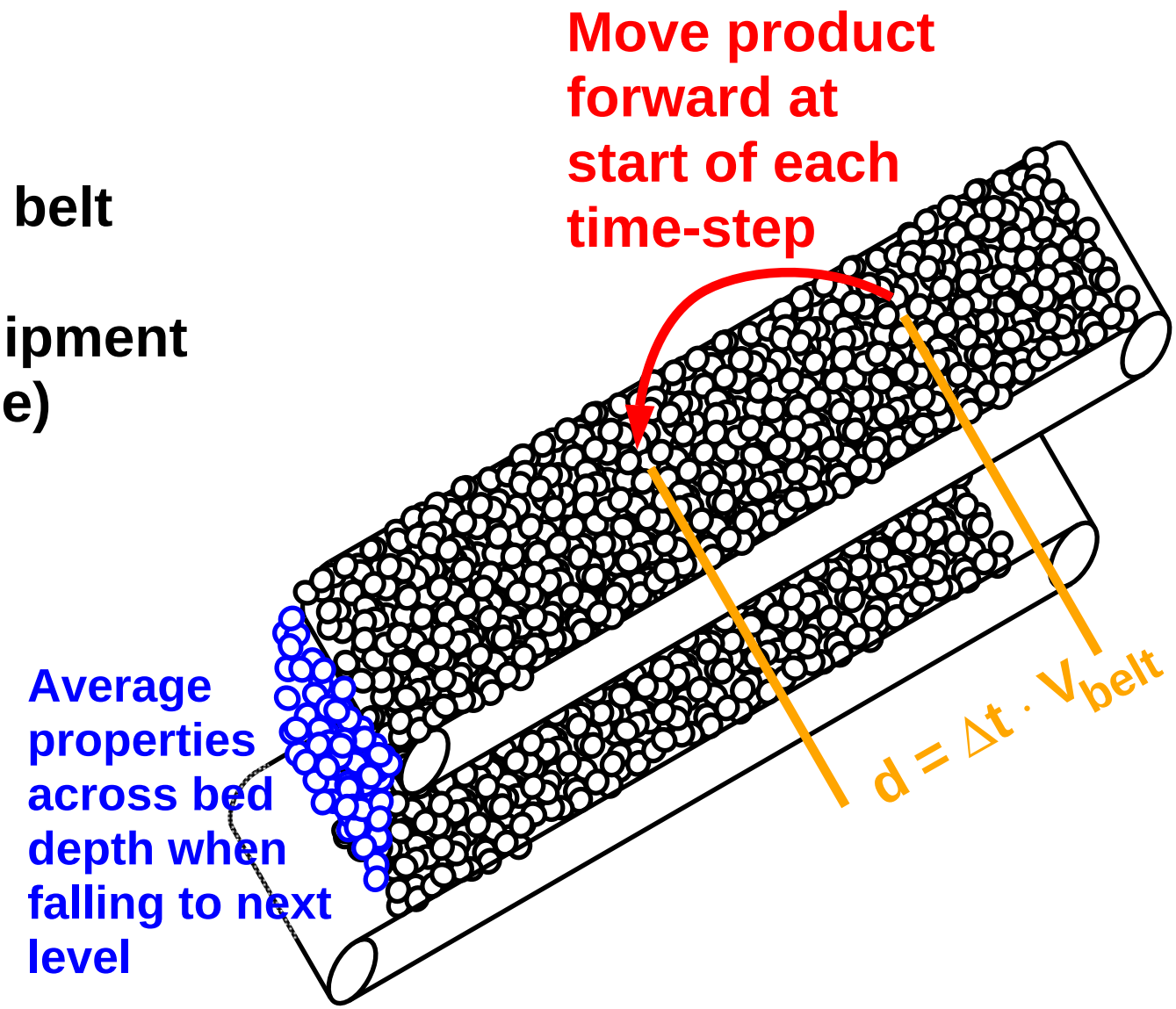


Fick's Law D = f(T, MC, etc.)
BCs: convection, water activity

Fourier's Law k = f(T, MC, etc.)
BCs: convection, radiation, conduction

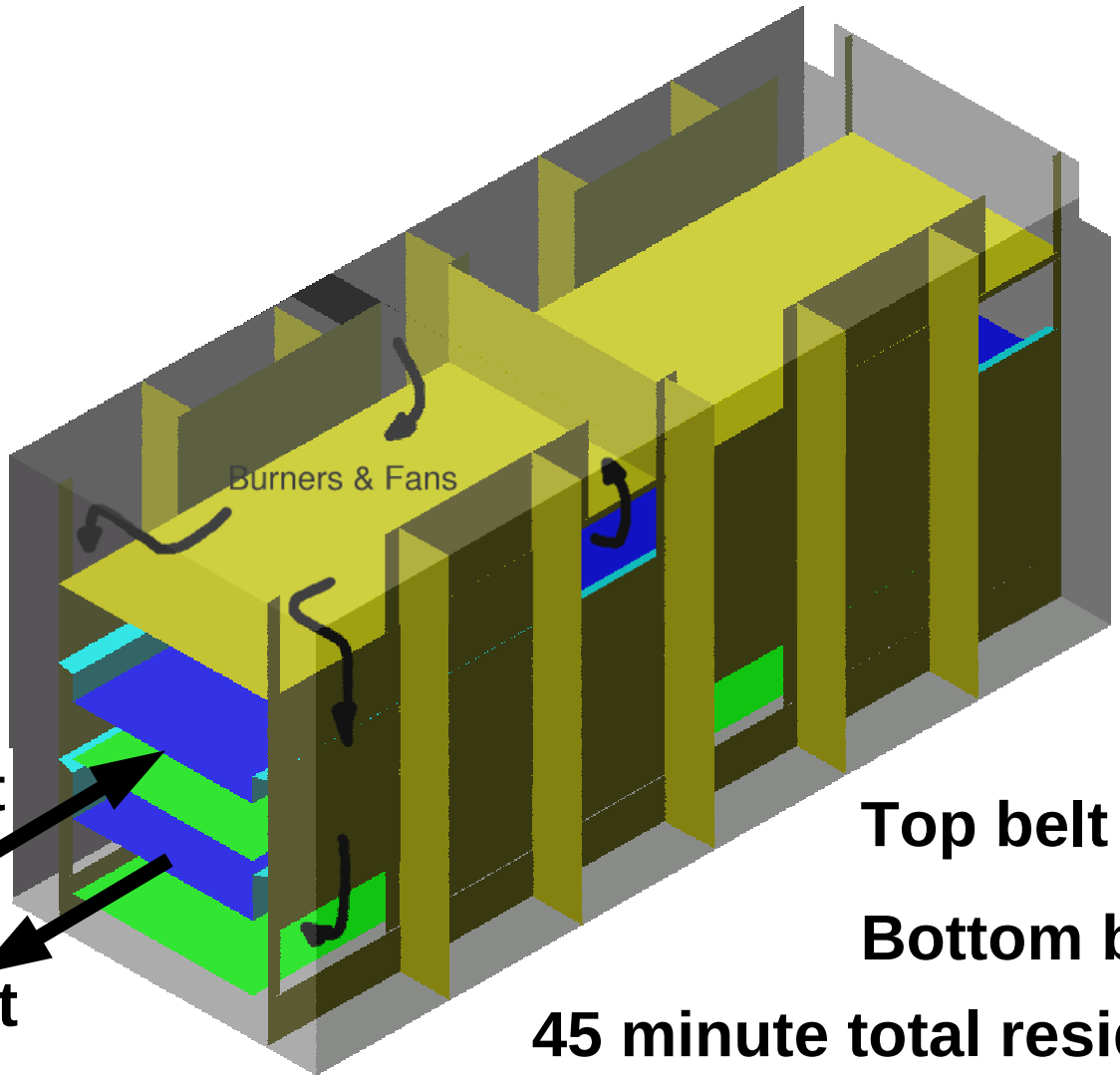
Approach - Product Movement

- **Moving belt**
- **Drop to lower belt**
- **Tumbling equipment (full average)**



Example Case

Two belt, two zone dryer



Zone 1:

120 °C (250 °F)
4% RH
5600 CFM

Zone 2:

100 °C (212 °F)
7.5% RH
5600 CFM

Product In

Product Out

Top belt : 38mm bed

Bottom belt: 89mm bed

45 minute total residence time

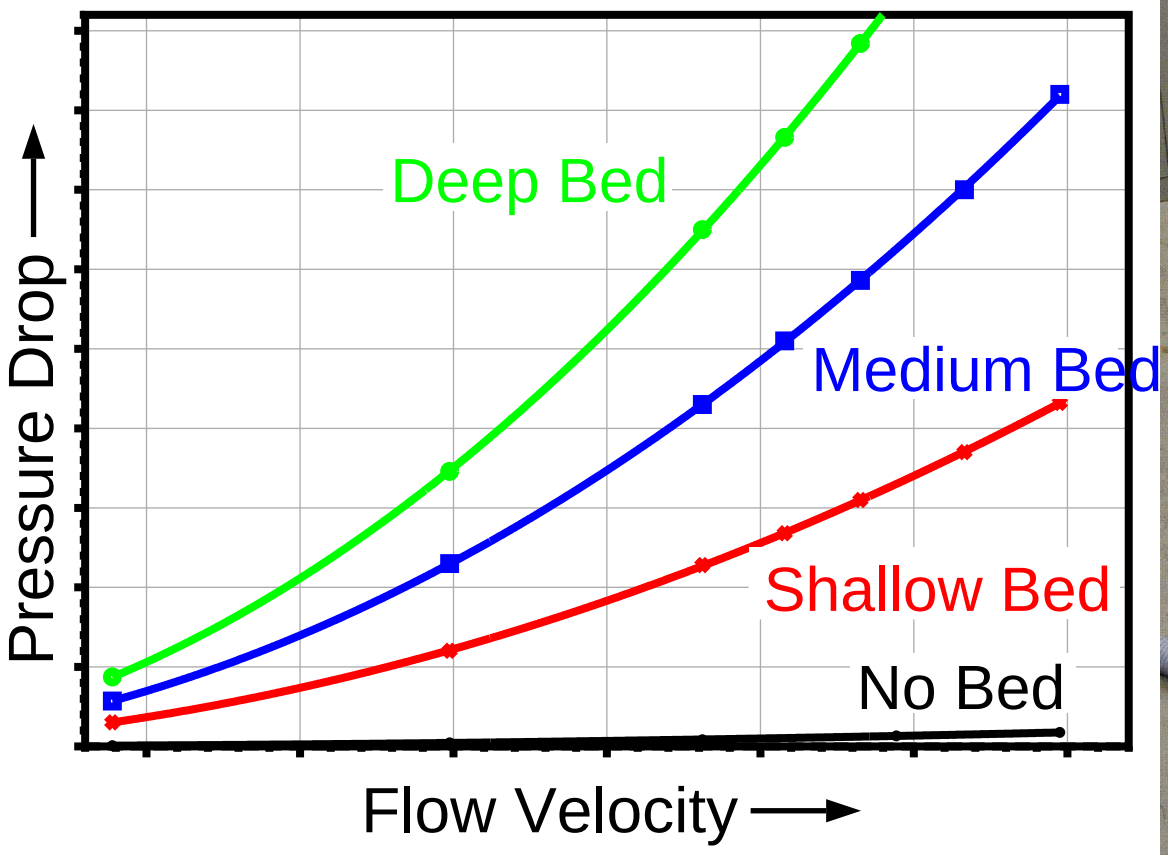
Example Case

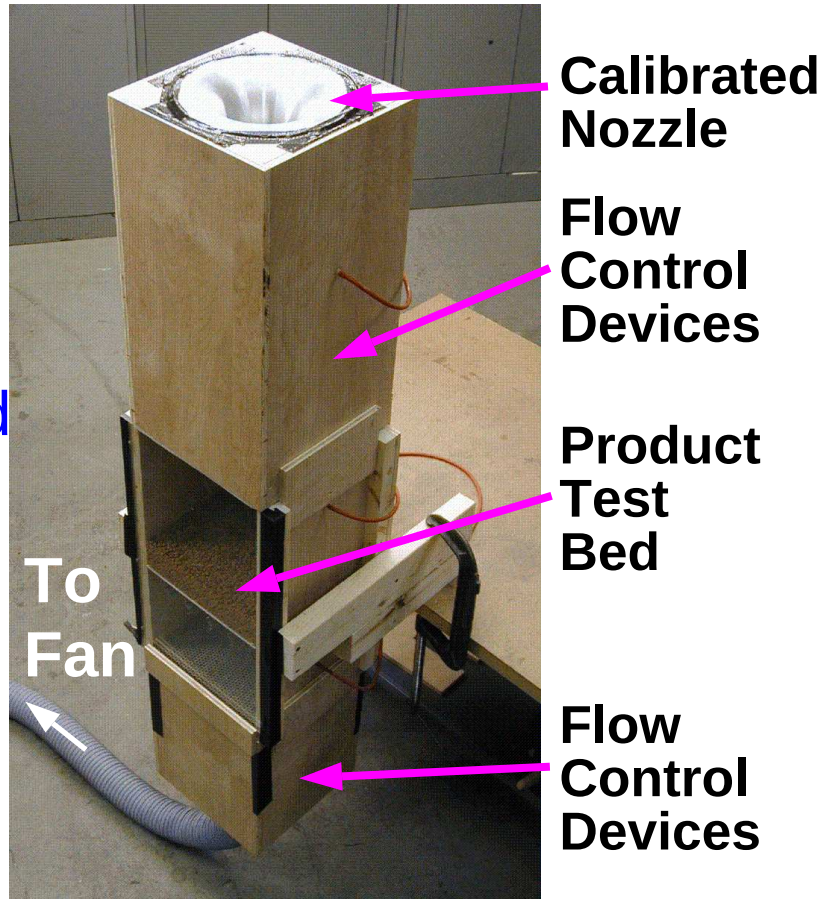
Product details

Product flow rate:	**1325 lbs/hour**
Incoming temperature:	**30 °C (86 °F)**
Incoming moisture content:	**25% (wb)**
Product shape:	**Spherical**
Product size:	**0.25” diameter**
Number density:	**2,728,416 pieces/m^3**
Thermal conductivity:	**combined solid and moisture**
Liquid diffusion:	**$D = D_o \bullet e^{(-K/T)}$**
Water activity:	**Modified Oswin's eq.**

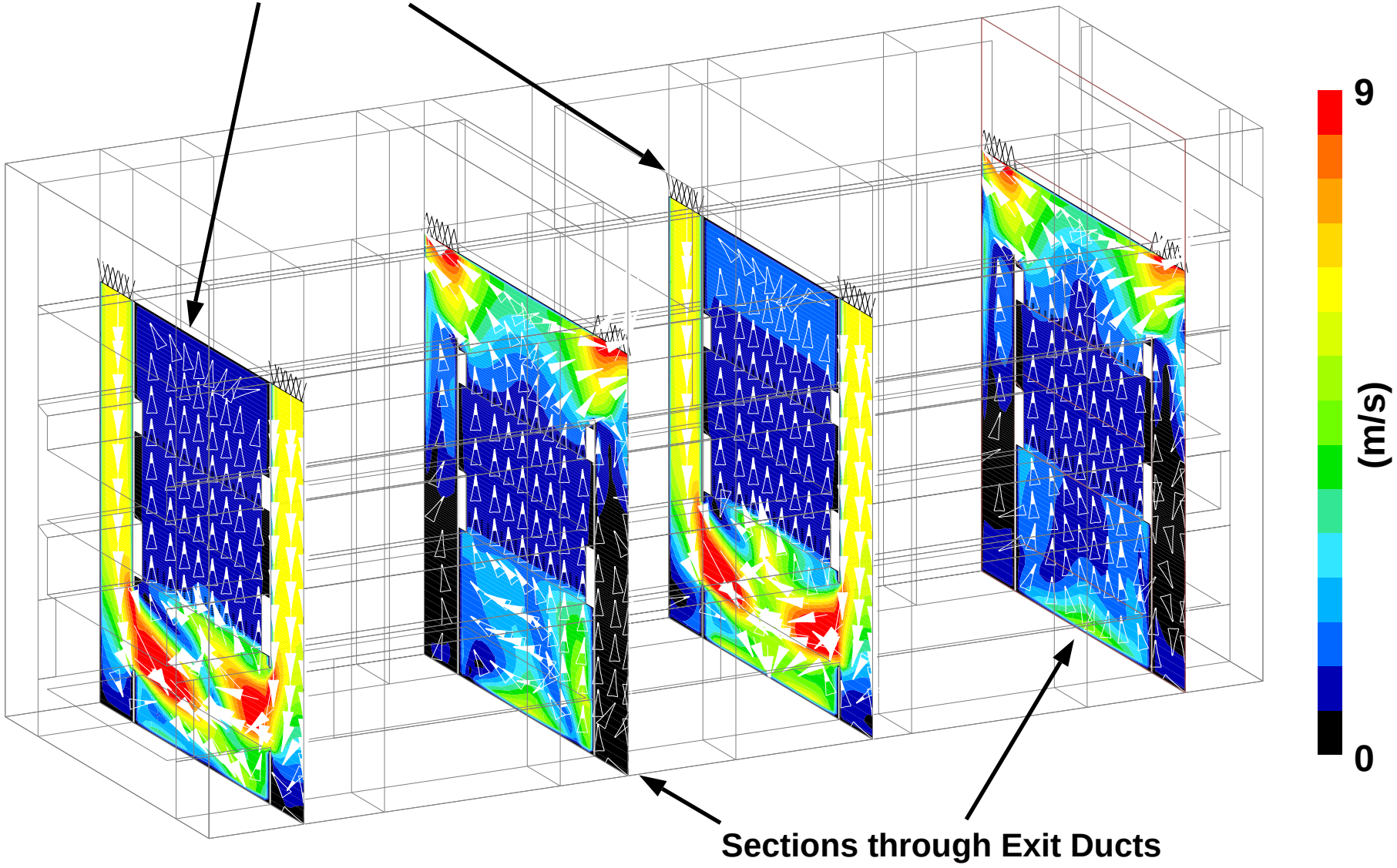
Example Case

Flow resistance of food bed

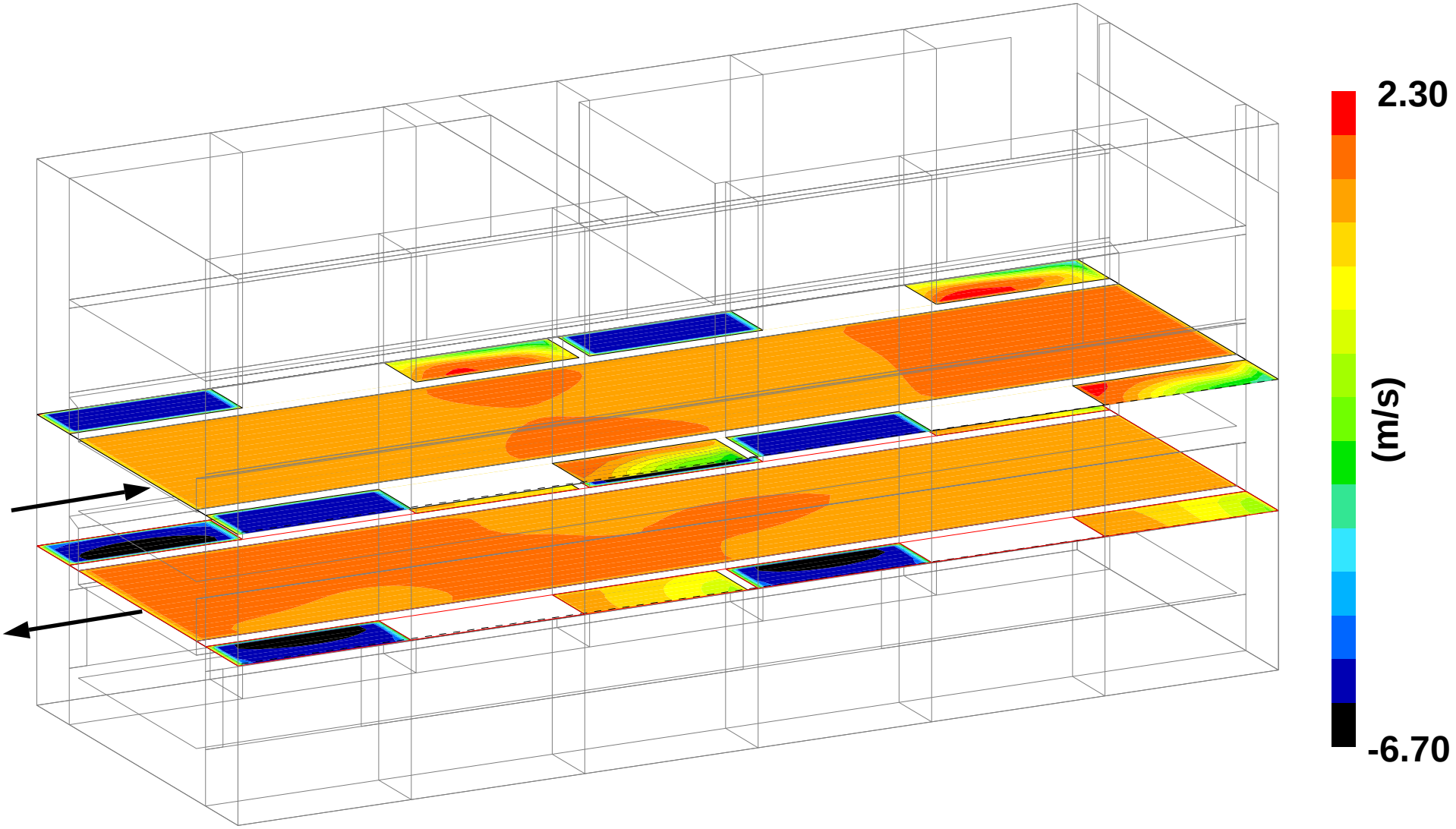




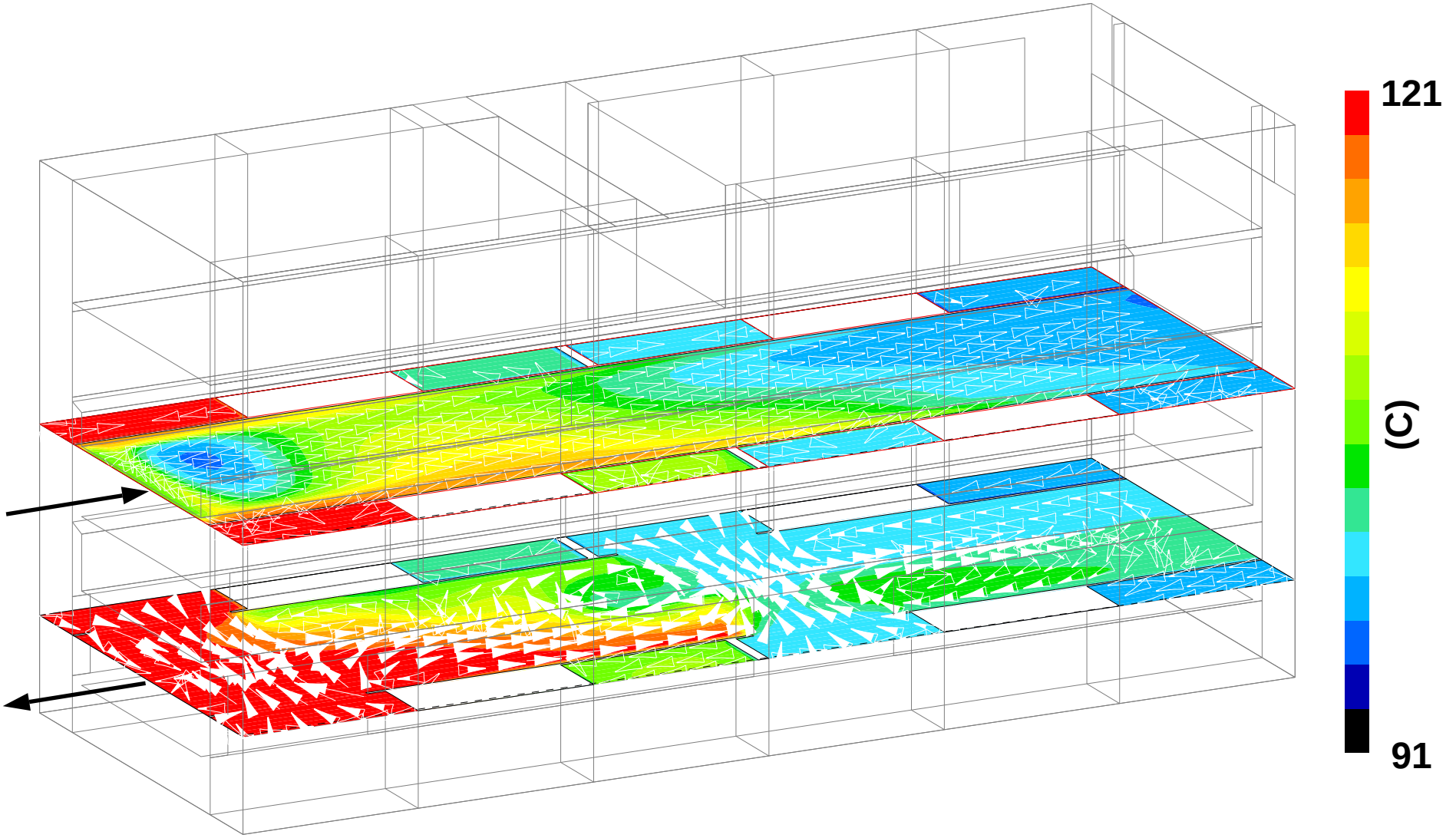
Total Velocity



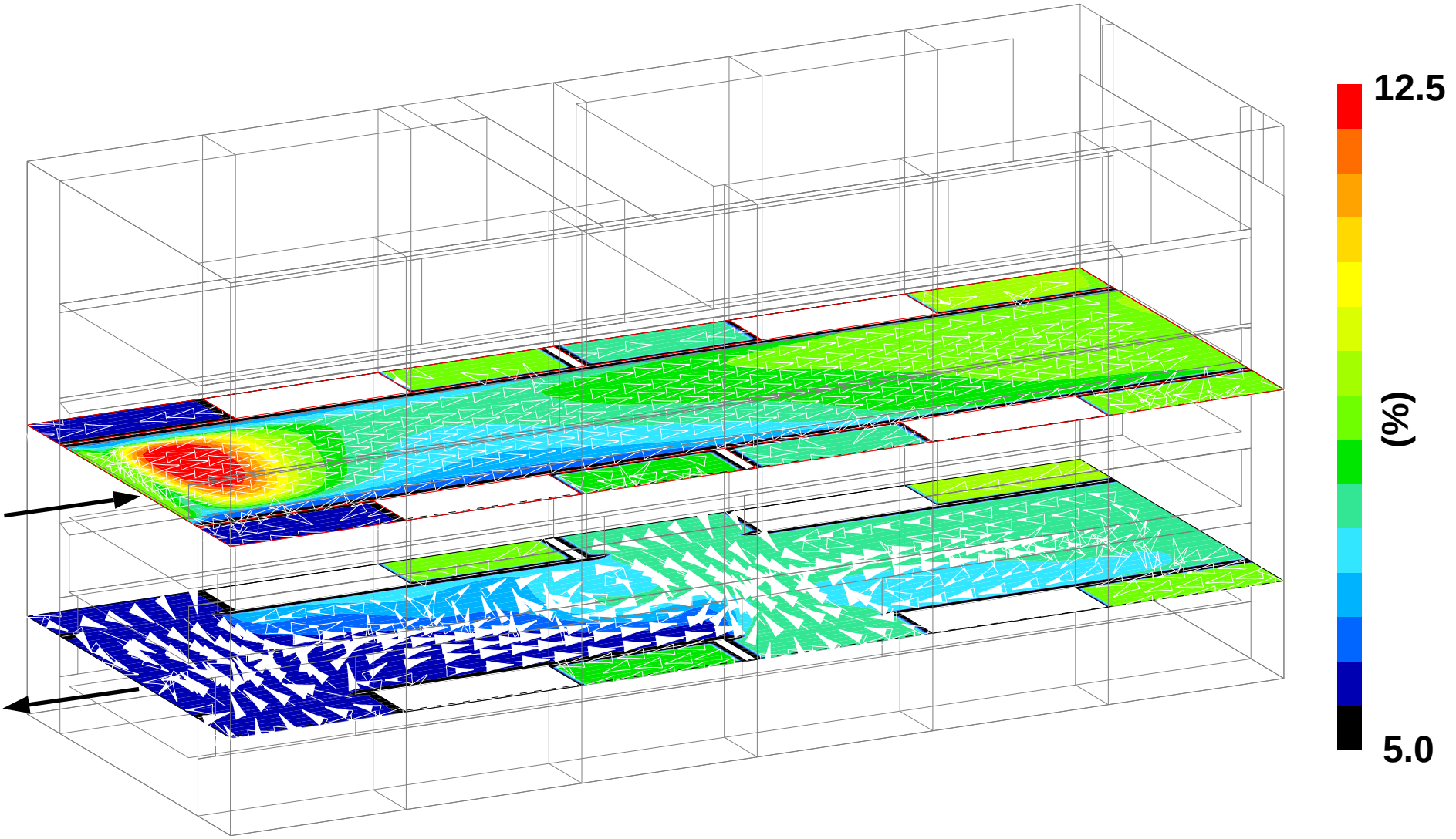
Vertical Velocity



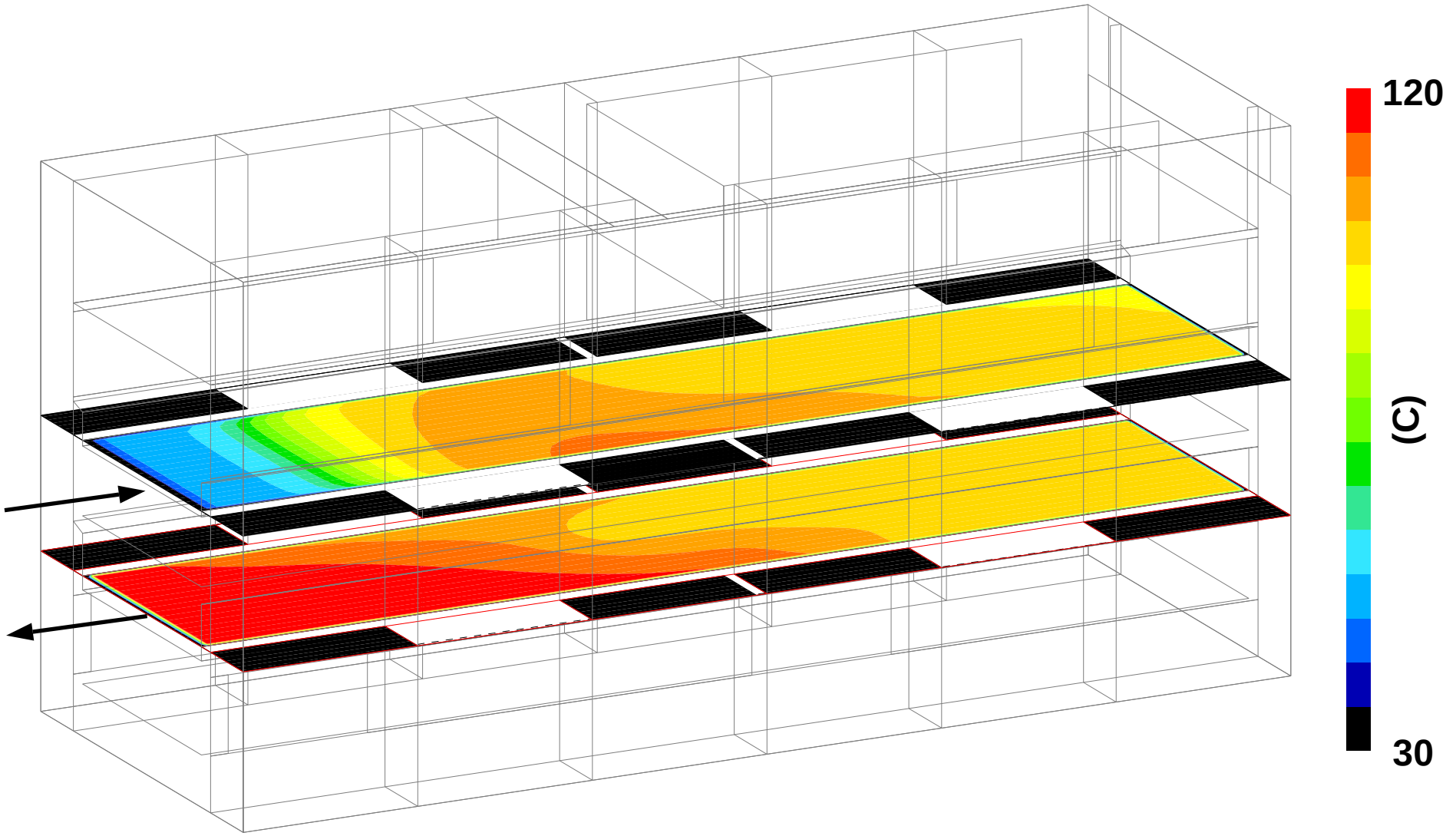
Temperature Distribution



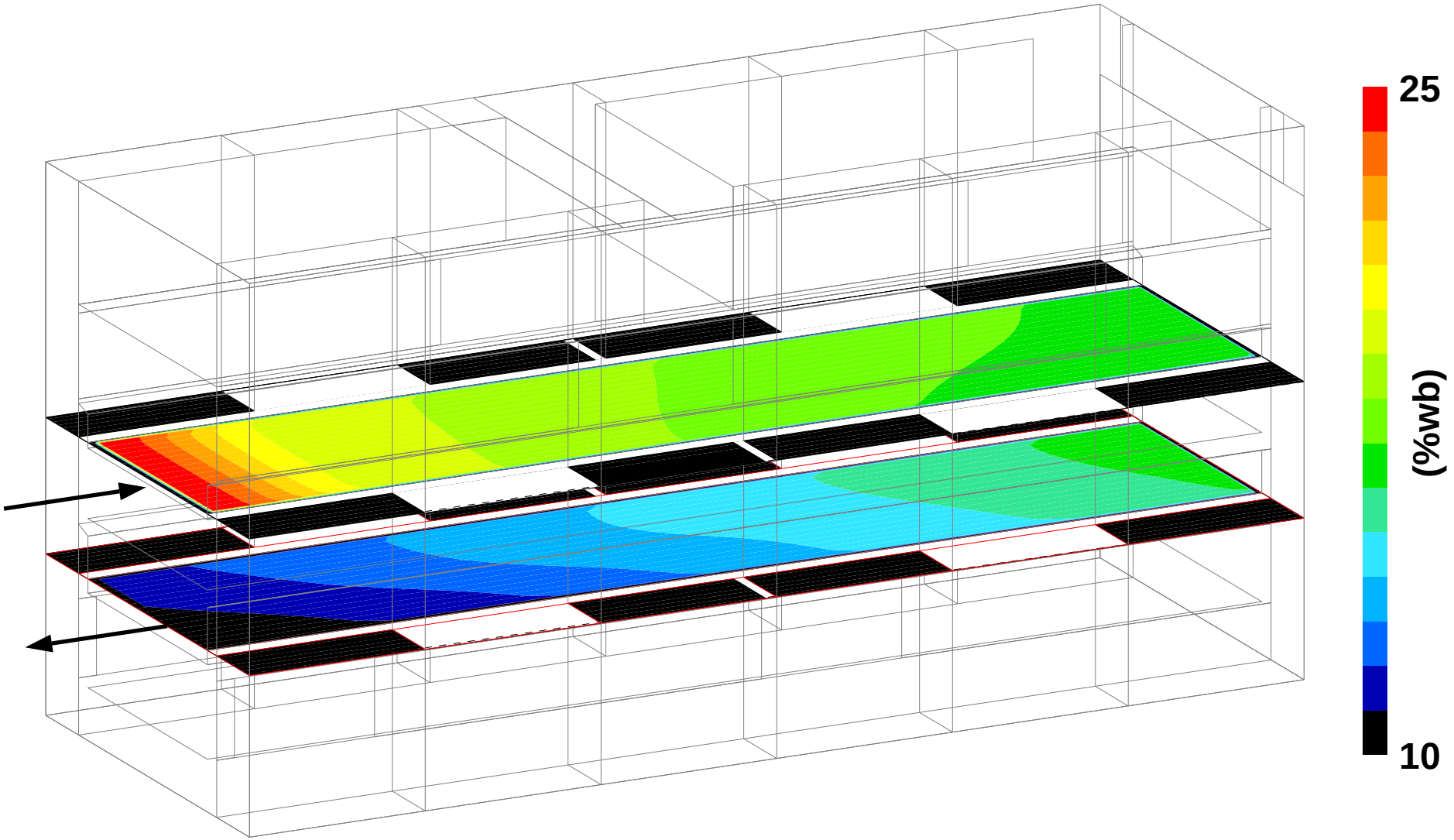
Relative Humidity Distribution

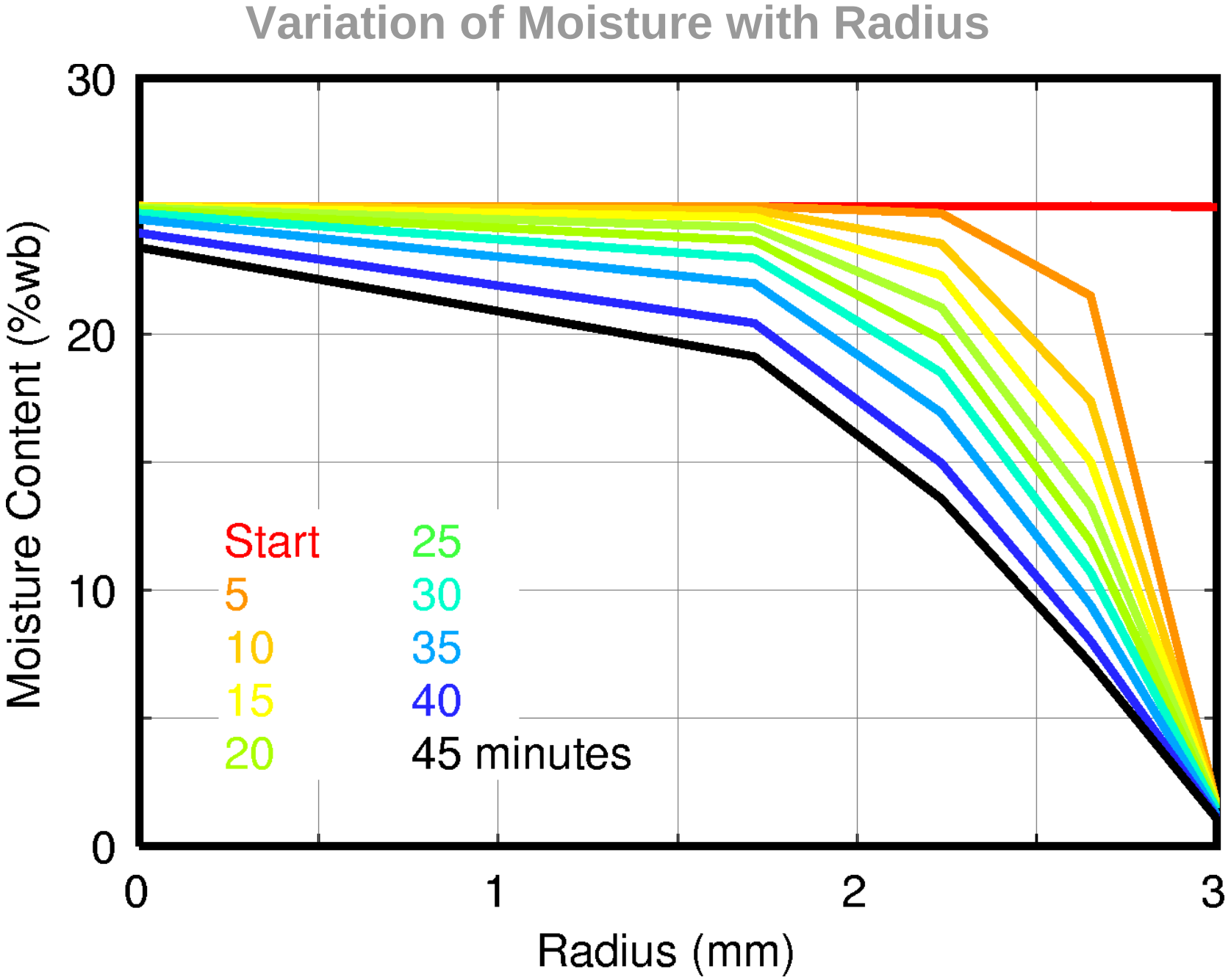


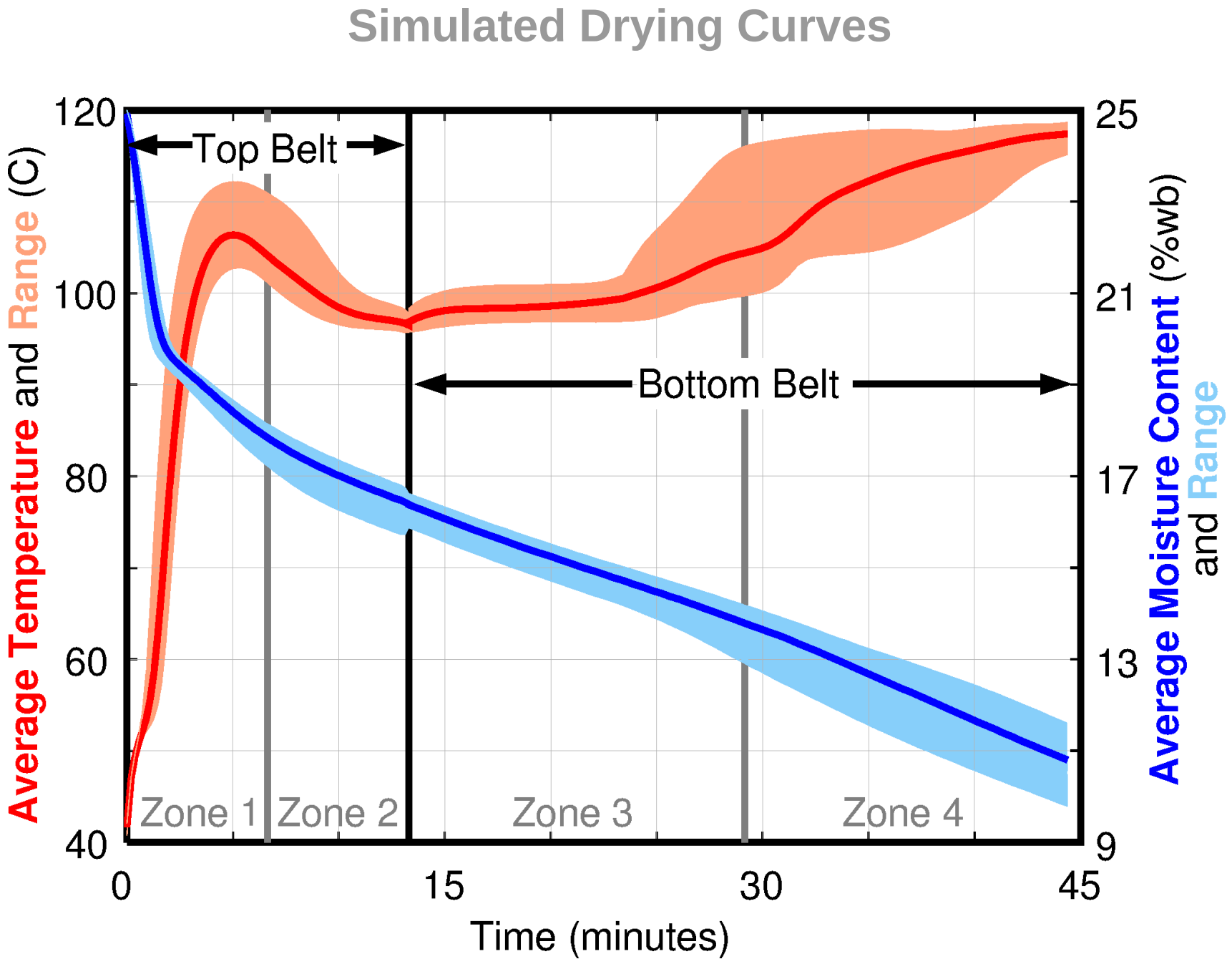
Surface Temperature Distribution



Average Moisture Content




Variation of Moisture with Radius
Moisture Content (%wb)
30
20
10
0
0
1
2
3
Radius (mm)
Start
5
10
15
20
25
30
35
40
45 minutes


Simulated Drying Curves
Top Belt
Bottom Belt
Zone 1
Zone 2
Zone 3
Zone 4
120
100
80
60
40
25
21
17
13
9
0
15
30
45
Time (minutes)
Average Temperature and Range (C)
Average Moisture Content (%wb) and Range

Validation

The coupled model approach has been validated against

- **Research scale equipment**
- **Production scale equipment**

Good correlation has been found

Most model adjustments were related to representation of food properties

Applications

The combined simulation approach can be applied to:

- **Dryers (including coating dryers)**
- **Toasting ovens**
- **Roasters**
- **Pasteurizers**
- **Coolers**
- **Non-food related processes**

Summary

- **A simulation method has been developed to analyze and improve food processing operations**
- **The approach includes most of the actual phenomena that affect the food**
- **The simulation results have been found to provide accurate results**
- **The simulation results can provide valuable insight into process operation**