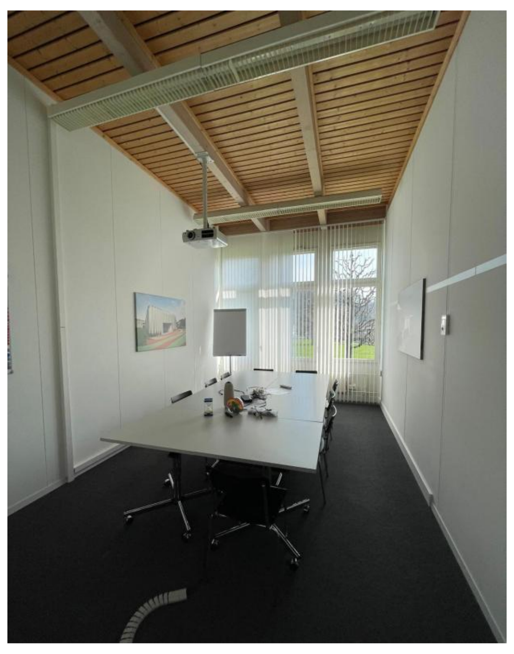
HSLU Hochschule Luzern

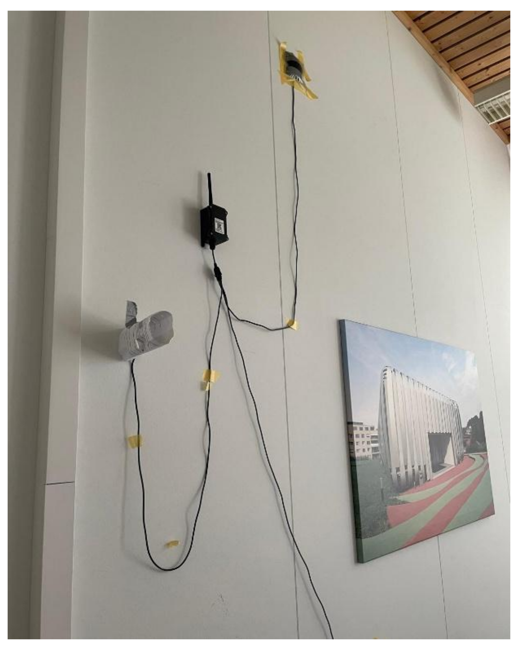
Technik & Architektur
Building Technologies

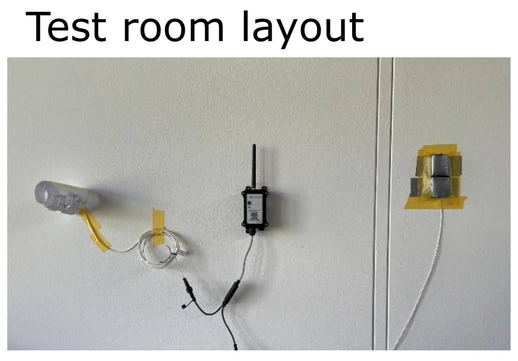
Master – Thesis Studiengang

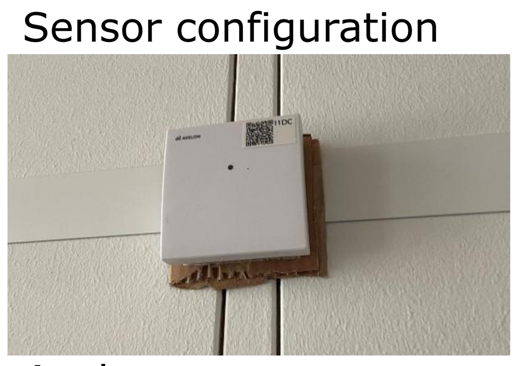
Resolving The spatial Limitations of Lumped Capacitance Models

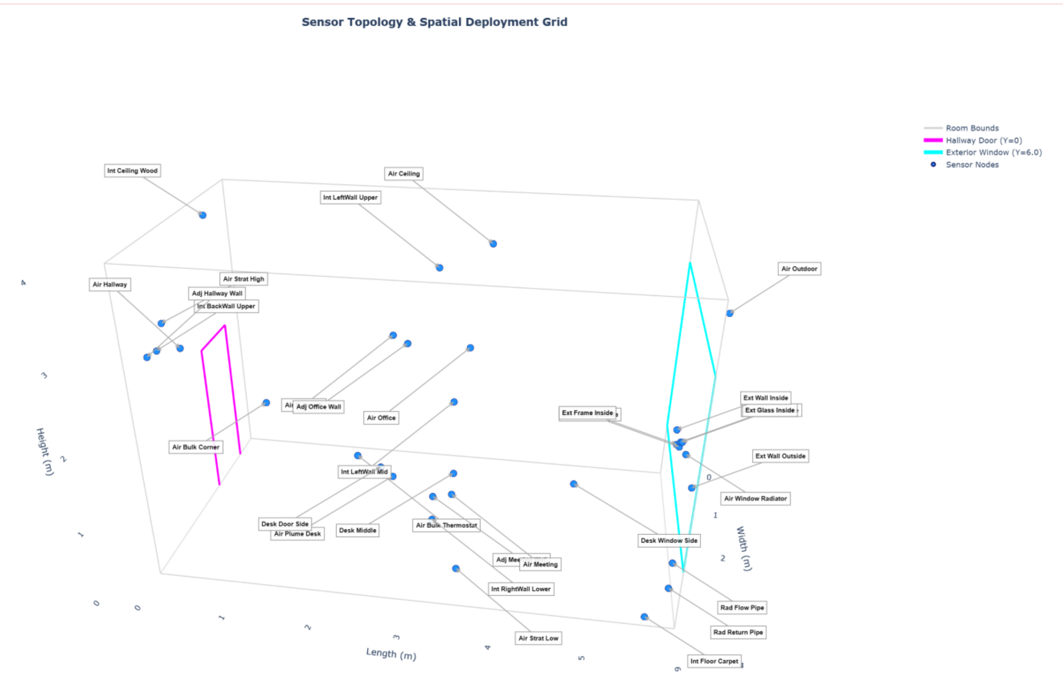
A Zonal Approach to Building Thermodynamics

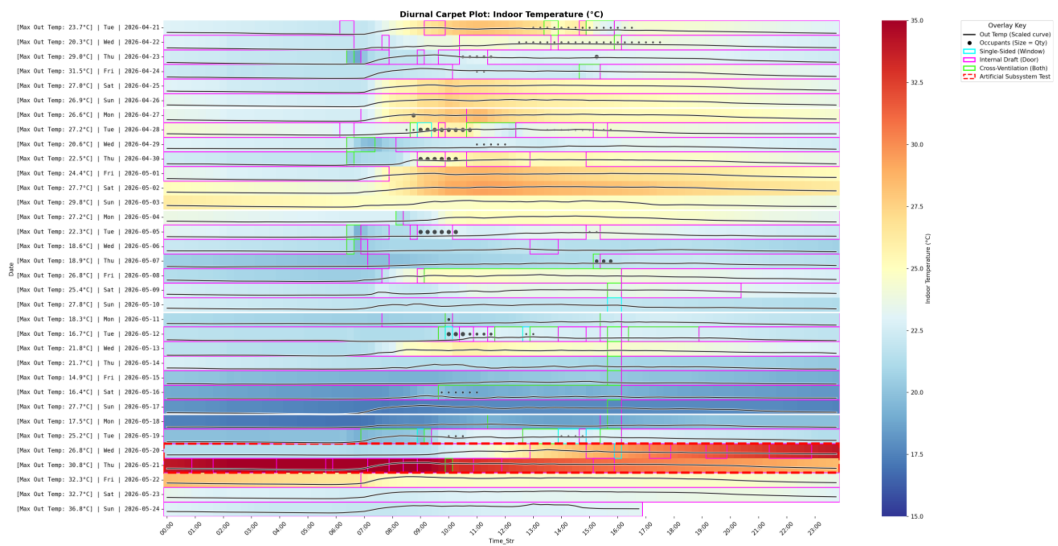

Test room layout

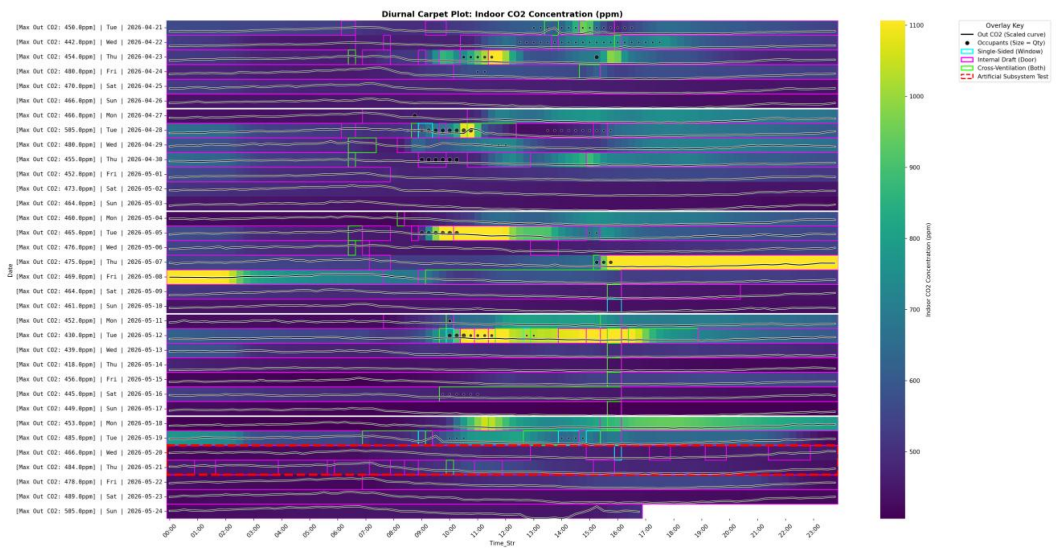

Sensor configuration

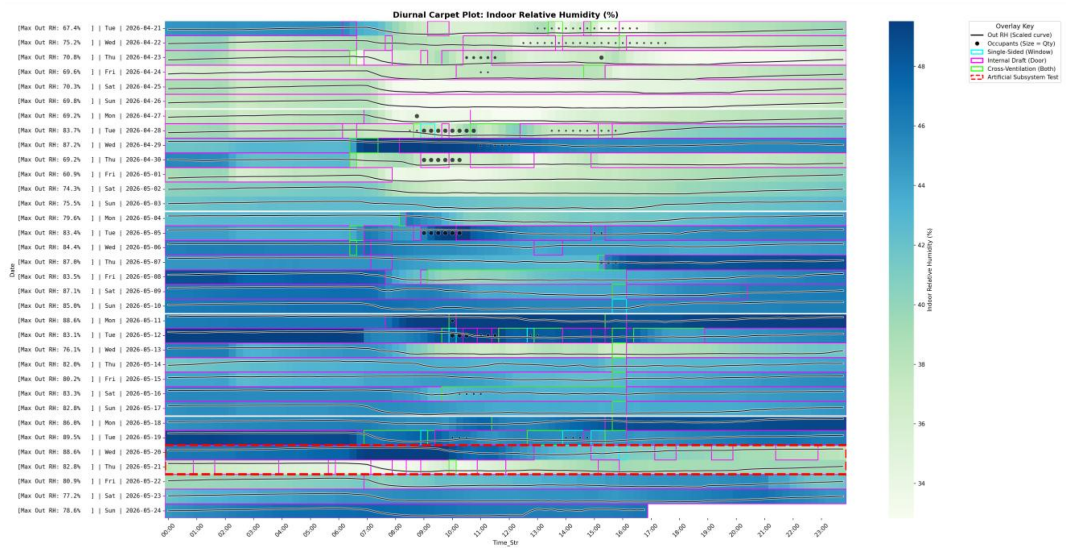

Sensor configuration

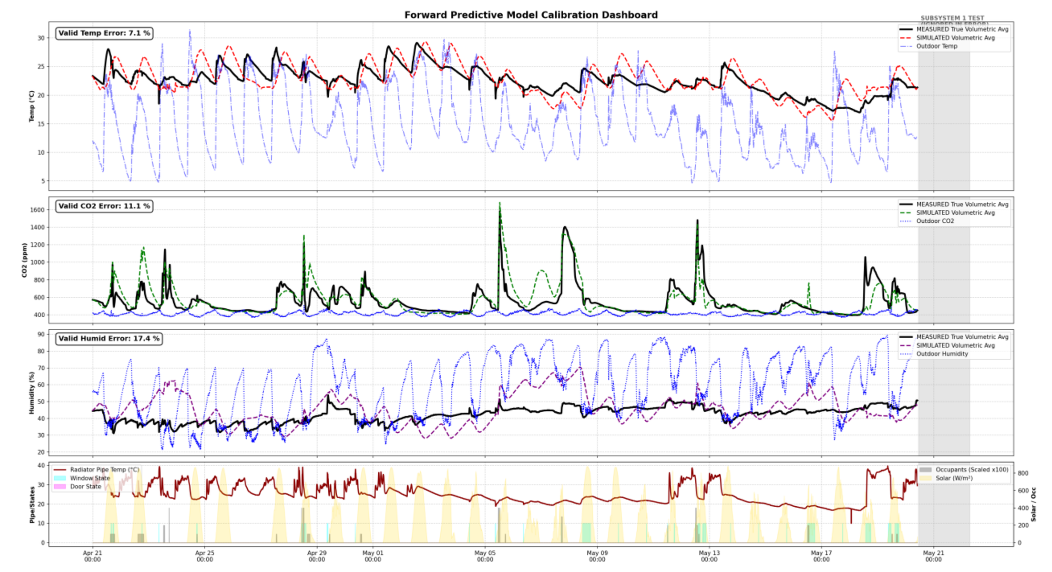

Avelon type sensor

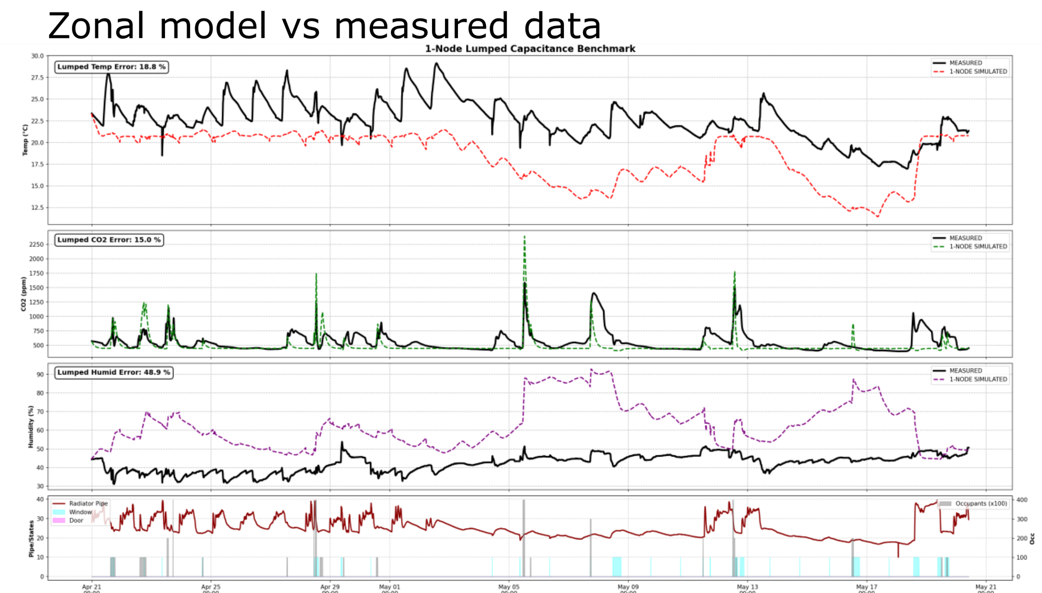

All sensor nodes mapped to the room

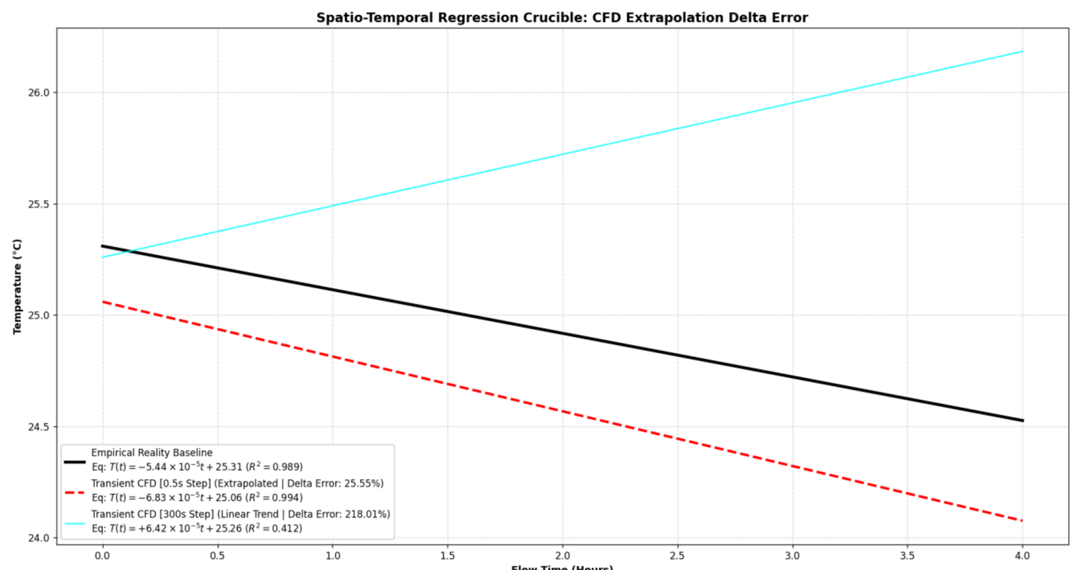

Temperature carpet plot for data set

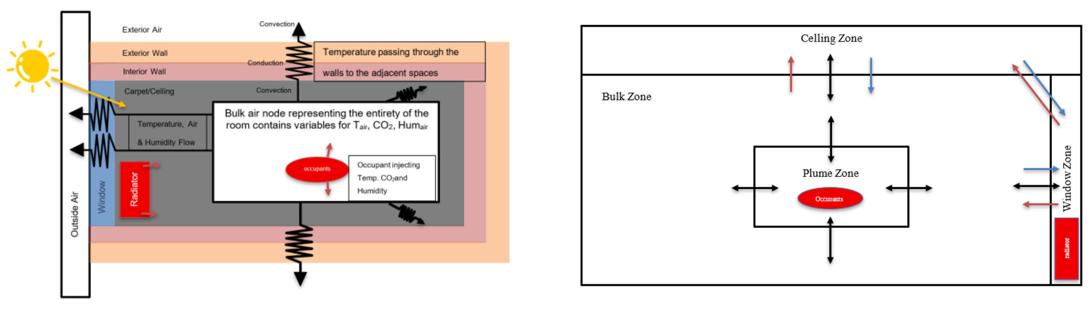

CO_2 carpet plot for data set

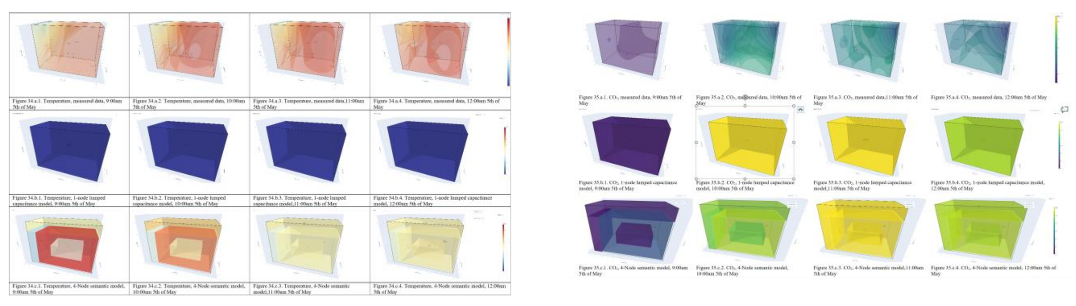

Humidity carpet plot for data set

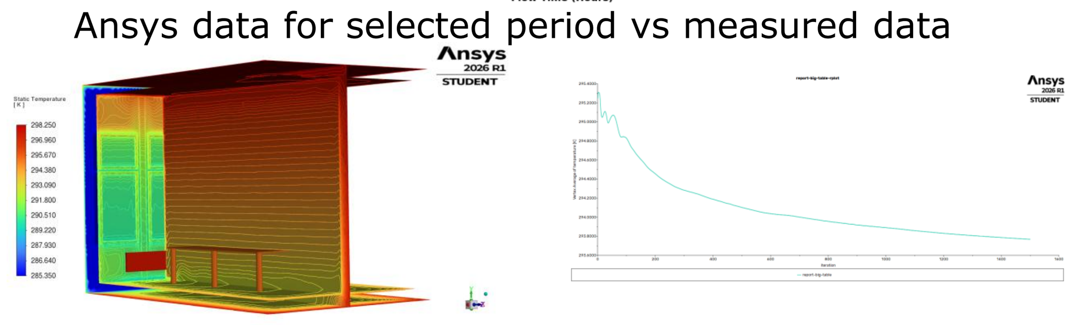

Zonal model vs measured data


Lumped capacitance model vs measured data


Ansys data for selected period vs measured data


Diagrammatic representation of Lumped and Zonal


3D representations for temperature and CO_2


Temperature distribution & results in Ansys Sim.

Problem Statement

Current indoor air quality (IAQ) and thermodynamic modelling is caught between two extremes.

High-fidelity Computational Fluid Dynamics (CFD, PDE centric models) is highly accurate but computationally prohibitive for long-term or real-time simulation.

Conversely, fast lumped-capacitance (1-Node ordinary differential equation (ODE) models) models rely on a "perfectly mixed" assumption, blinding them to physical realities like thermal plumes, stratification, and dead zones.

There is a need for an intermediate Reduced Order Model (ROM) that maintains spatial accuracy but executes faster than real-time. Developing this tool may provide a use for engineers seeking to understand building physics before construction or to integrate predictive thermodynamics directly into live building management systems (BMS).

Methodology & Approach

Deployed a 60-node IoT sensor network in an active HSLU meeting room to capture high-resolution spatial and temporal gradients for temperature, humidity & CO_2.

A commercial CFD model (Ansys) simulation was built to benchmark high-fidelity spatial and temporal execution limits.

A 1-Node ODE model was created. This lumped capacitance approach assumes the room is perfectly and instantaneously mixed, acting as the control.

Developed the Zonal model to capture physical gradients without the extreme computational burden of CFD. This model is based on the topology of the room, functionally splitting the room into interacting zones: plume (the immediate zone around occupants), celling (captures highly stratified air), window (heat gains from radiator and window), bulk (primary ambient air). Instead of instant mixing, heat and mass are physically transported between these zones via mathematically delayed buoyancy loops (e.g., occupant updrafts, cold window downdrafts). This preserves kinematic inertia and conservation of mass.

Results and Conclusion

The baseline 1-Node model achieved an 18.8% temperature error, a 15.0% CO_2 error and a 48.9% humidity error. Completing the simulation in 4.434 seconds (550,000x speedup)

The zonal architecture, reached an error of 7.1% temp. and 11.1% CO_2 and 17.4% humidity error. Completing the simulation in just 734 seconds (a 3,463x speedup).

The most successful Ansys benchmark required 9 hours of real-time computing to resolve just 5 minutes of fluid flow. An error of 1.42%. It proved fundamentally unscalable for longitudinal building simulation or agile design.

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MSE MASTER OF SCIENCE IN ENGINEERING

FH Zentralschweiz