UNIVERSITÀ DI PISA

PhD Course in Energy, Systems, Territory and Constructions Engineering - XVIII Cycle

DESTEC
DIPARTIMENTO DI INGEGNERIA DELL'ENERGIA, DEI SISTEMI, DEL TERRITORIO E DELLE COSTRUZIONI

Advanced Physics-Based and Data-Driven Modeling of Building Energy Systems

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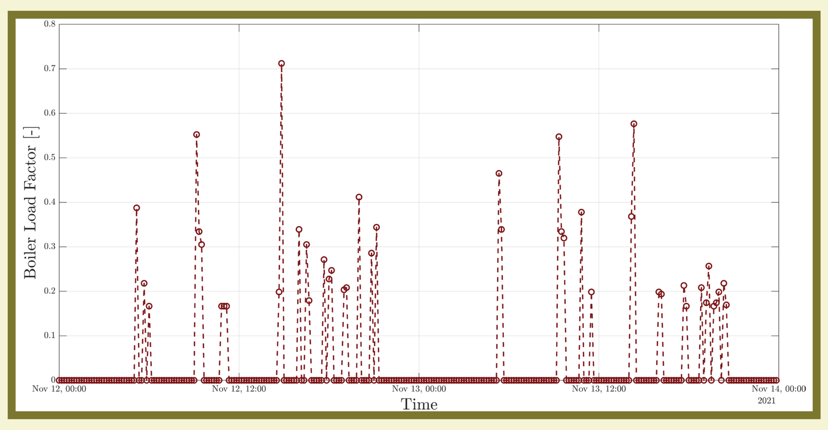
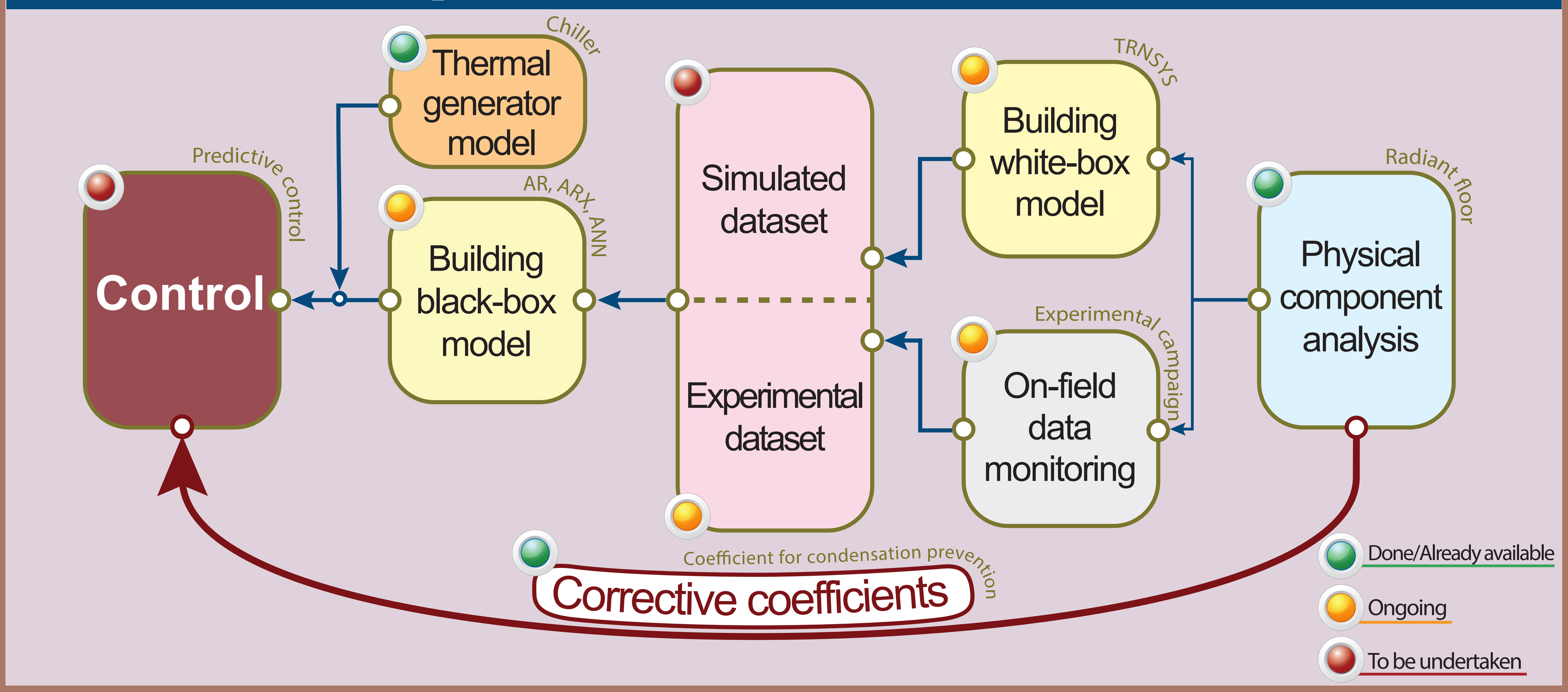
Research Goals

Control of **HVAC** systems is critical in applications, due to the multiple demands and conditions faced by the system. This is especially challenging for high thermal inertia devices, such as radiant floor systems (**RFS**). To develop efficient control strategies, the **modeling** step is essential to predict the building system behavior and guide the selection of control actions.
The 3-year path was designed to follow this logical map, starting from the analysis and modeling of critical systems, such as RFS, and finally studying and proposing efficient control strategies.

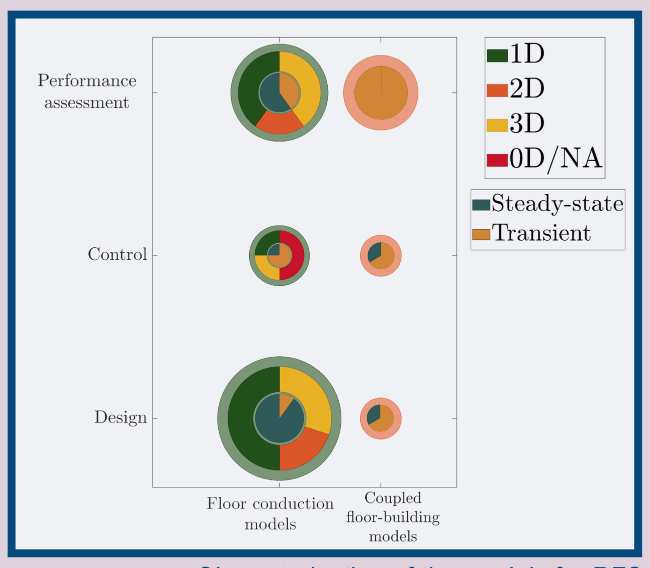


1. Roadmap

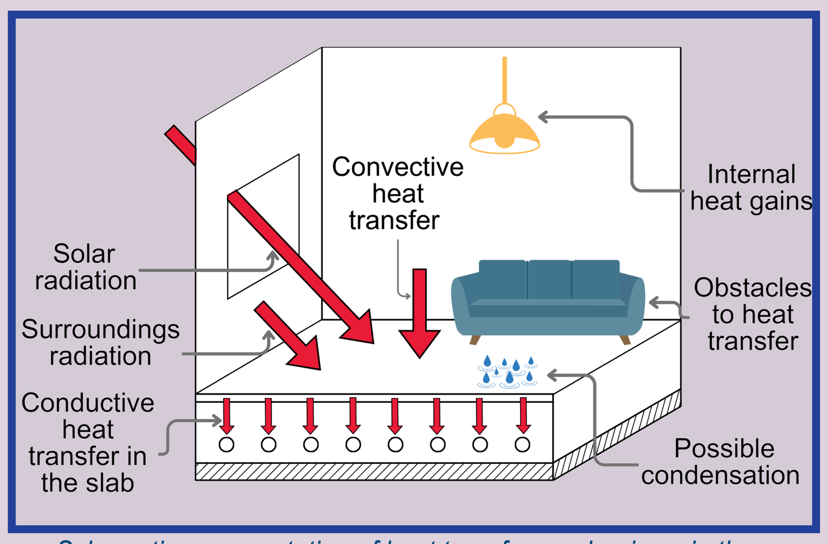


2. Survey on RFS Modeling Methods

The major distinction among models for radiant floors is shaped by the **target phenomenon being modeled**:
- Conductive heat transfer within the radiant slab
- Floor-building coupling



Characterization of the models for RFS



Schematic representation of heat transfer mechanisms in the room

Another important distinction is the modeling approach employed:
- Analytical
- Numerical
- Semi-analytical

3. Analytical and Numerical Models

Two modeling approaches have been used to describe the surface temperature non-uniformity in RFS:

- **Analytical Model** by Gluck (1982) → Steady-state

$$T(x,y) = T_{op} - \Gamma(T_w - T_{op}) \left[\frac{\pi}{l}\left(z_1 - y - \frac{2\lambda}{U_1} + |z_1 - y|\right) - \sum_{s=1}^{\infty} \left(\frac{e^{-\frac{2\pi s}{l}|z_1 - y|} + G(s) e^{-\frac{2\pi s}{l}(z_1 - y)}}{s} \right) \cos\left(\frac{2\pi s (x + l/2)}{l}\right) \right]$$

with: $\Gamma = \left[\ln\left(\frac{l}{\pi d}\right) + \frac{2\pi\lambda}{Ul} + \sum_{s=1}^{\infty} \frac{G(s)}{s} \right]^{-1}$, $G(s) = \frac{\frac{Bi+2\pi s}{Bi-2\pi s} e^{-\frac{4\pi s}{l} z_2} - 2e^{-\frac{4\pi s}{l}(z_1+z_2)} - e^{-\frac{4\pi s}{l} z_1}}{\frac{Bi+2\pi s}{Bi-2\pi s} + e^{-\frac{4\pi s}{l}(z_1+z_2)}}$

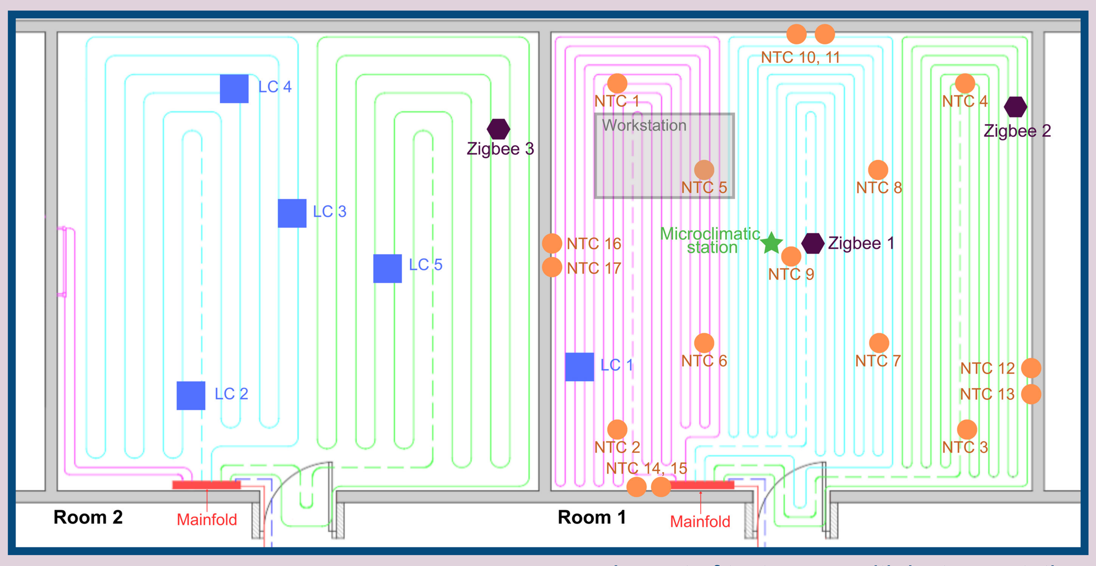
- **Numerical** FEM **Model** → Transient conditions

Results

In typical applications - 10 cm spacing and 5 cm depth - the non-uniformity in steady-state conditions is small, on the order of 0.04÷0.05°C, while in transient situations it can go to 0.5°C.

4. Experimental Test Rooms with RFS

Experimental Set-up

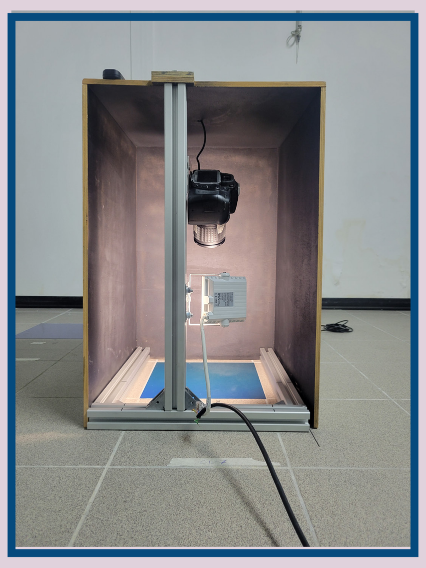


Layout of test rooms with instrumentation

Equipped test room (Room 1)

Room
- 9 calibrated TLC sheets → Surface T distribution
- 19 NTC sensors → Floor and wall/ceiling T
- 3 Zigbee sensors → Air T and RH
- Thermal microclimate station → Globe T, radiant T, air T and RH, air speed, PMV, PPD

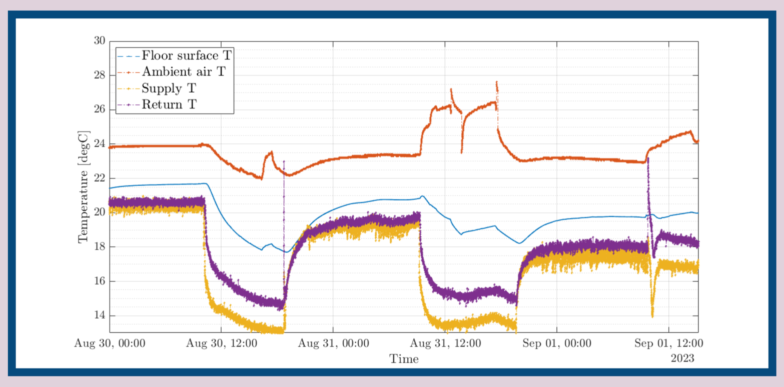
Heat pump
- PT100 sensors → Supply and return T
- Energy meter → Electric consumption



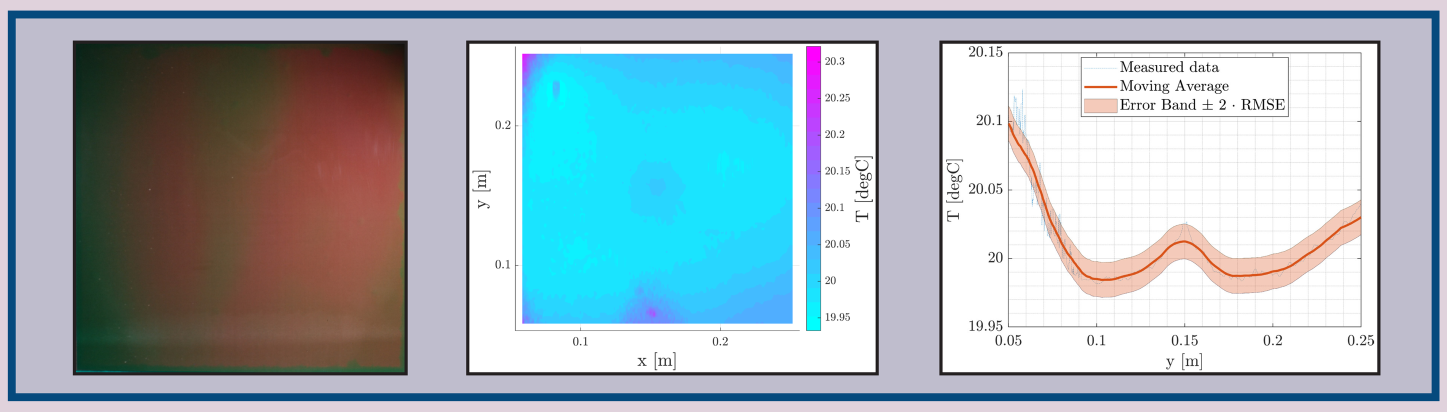
Camera and support for TLC image capture

Tests carried out
- Near steady-state conditions
- Transient conditions
- Internal heat gains
- Different heating/cooling conditions in Room 2

Preliminar Results
- 10 cm pipe spacing → **0.05°C** (steady) and **0.5°C** (transient) variations
- 25 cm pipe spacing → **0.5÷1°C** variations



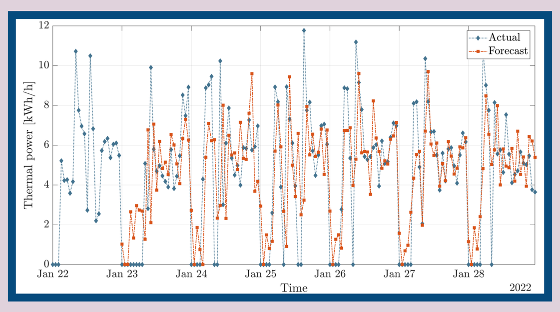
Data log of experimental measurements



TLC photo, temperature map, and temperature curve in a central section

5. AR Prediction of On-Field Dataset

First example of application:
- **350 real-world datasets** of building thermal load
- **Autoregressive** (AR) prediction



AR prediction based on thermal load data from installed boilers

6. Future Steps

1. White-box **modeling** of RFS to generate a data repository
2. Model **simplification** for application to control strategies
3. Control strategies **developement**

Main References

- Glück, B.; Windisch, K. *Strahlungsheizung. Theorie und Praxis.* Germany, Karlsruhe: Verlag CF Müller, 1982.
- Flores Larsen, S., et al. *Transient simulation of a storage floor with a heating/cooling parallel pipe system.* Build. Sim., 2010, 3: 105-115
- Yin, Y. L., et al. *Experimental investigation on the heat transfer performance and water condensation phenomenon of radiant cooling panels.* Build. and Env., 2014, 71: 15-23

Publications

- Bizzarri, M., Conti, P., Glicksman, L. R., Schito, E., & Testi, D. *Radiant Floor Cooling Systems: A Critical Review of Modeling Methods.* Energies, 2023, 16.17: 6160.
- (***In progress***) Bizzarri, M., Conti, P., Glicksman, L. R., Schito, E., & Testi, D. *Evaluation by Liquid Crystal Thermography of Transient Surface Temperature Distribution in Radiant Floor Cooling Applications and Assessment of Analytical and Numerical Models.* submission to ASME Journal of Heat and Mass Transfer