An RC Network Model

## Motivation

To lower costs and improve thermal performance, transient building load prediction is important for the development of smart building features. In the present study, we need to predict the heating and cooling rates of a radiant slab system for the Living Laboratory at Purdue University. According to Braun[1] and Jaewan[2],a “gray-box” thermal resistor-capacitor (RC) network model, whose parameters initialized by their physical representation, has been constructed and optimized by particle swarm optimization (PSO) in this section.

## Model Foundation

A gray-box RC network model is formed from heat balance equations on each temperature or state variable. A general heat balance equation has been listed below. represent the node temperature, the specific heat capacity, the resistance between two nodes, the heat flux input to the node. And neighboring temperature node is denoted as .

A general state-space model for estimating radiant slab systems load is of the form

For a radiant slab system model, the output variable is the cooling and heating load. The state vector contains all the temperature nodes, which are surround by the estimated resistors and capacitors. The input vector includes all of the driving conditions, such as the hot water or chilled water temperature and derivation along the sampling time within tubes, outdoor air temperature, solar radiation, lighting and occupancy schedule.

The discrete version of the above state-space model can be written in terms of a recursive formula as

A typical objective function for RC network model is to minimize the root-mean-square error for the training duration, denoted as

In general, the above gray-box RC model optimization problem is not linear nor convex in terms of the estimate parameter and output variable trajectory. Particle swarm optimization (PSO) from python package (pyswarms[3]) was used to solve the above optimization problem.

## Networks

Diagram, schematic

Description automatically generated

Figure 1. Thermal Network for Hydronic Radiant Slab Systems

The above figure depicts electrical analog for radiant slab systems RC network, in which denote temperature, capacitances, resistances, heat flux due to radiation and corresponding coefficients. And the subscripts, , represent outdoor air, façade cavity, slab concrete, hot water or chilled water within tubes, insulation below tubes, envelope, room air, internal wall, solar radiation, internal heat, lighting, air handling unit, thermal heat flux load requirements.

The above thermal network can be represented with a state-space model with the following definition for state, input, and output variables:

And the non-zero elements for the state-space coefficient matrices and vectors are:

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## RSCS Estimation

Thermal resistances, (), and thermal capacity, (), are estimated from the following equations

Table Estimated Values for Rs (K/W) and Cs (J/K)

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| 3.6E-3 |  |  |  |
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## Results Discussion

Graphical user interface, application

Description automatically generated

Figure . Training and Testing Sets Performance for the Radiant Slab System RC Network from the Initial Parameters Assumption

Graphical user interface, application

Description automatically generated

Figure . Training and Testing Sets Performance for the Radiant Slab System RC Network from the Optimized Parameters

Figure 2 and Figure 3 show the Normalized RMSE (NRMSE) of radiant slab systems thermal load for training set and testing set. And Figure 2 is the performance from the initial estimates of Rs and Cs, while Figure 3 indicates the optimized performance. From the above figures, the RC network model appears to be optimized reasonably with training set NRMSE as 0.36 and testing set NRMSE as 0.25. However, this RC model has a non-optimal performance when the actual load doesn’t follow the normal pattern.

In which is the standard deviation of the predicted output variable.

In terms of the model development efforts, there were in total 7 energy balance constructed, 24 parameters are estimated.

# References

[1] J. E. Braun and N. Chaturvedi, “An Inverse Gray-Box Model for Transient Building Load Prediction,” *HVACR Res.*, vol. 8, no. 1, pp. 73–99, Jan. 2002, doi: 10.1080/10789669.2002.10391290.

[2] J. Joe and P. Karava, “Agent-based system identification for control-oriented building models,” *J. Build. Perform. Simul.*, vol. 10, no. 2, pp. 183–204, Mar. 2017, doi: 10.1080/19401493.2016.1212272.

[3] L. James V. Miranda, “PySwarms: a research toolkit for Particle Swarm Optimization in Python,” *J. Open Source Softw.*, vol. 3, no. 21, p. 433, Jan. 2018, doi: 10.21105/joss.00433.