Characterization of Linear Reduced Order Building Models Using Bode Plots

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Simulations of energy supply systems on the urban scale call for dedicated thermal building models with low simulation times and still considering relevant dynamic effects. A common approach for such models are reduced order thermal networks that model heat transfer and storage via thermal resistances and capacitances. To contribute to the open question, how much wall elements should be used in such approaches, this paper characterizes and compares four different model topologies with one, two, three and four wall elements. The characterization using the Linear Analysis toolbox in Modelica and Bode plots in Python reveals a significantly different behavior of the One-Element-Model compared to the higher order models. In consequence, the Two-Elements-Model with comparably low simulation times and a similar behavior as the higher order models qualifies for urban scale simulations.

Reduced order models account for relatively small simulation times by using a small number of state variables, in the case of thermal networks associated solely to thermal capacitances. In this way, they qualify for urban scale simulations, where uncertainties due to unknown boundary conditions and estimated parameters outweigh modeling accuracy. Still, this leads to the question, what the optimal number of capacitances is for the case of urban scale simulations.

To contribute to this question, this paper investigates four different model topologies by lumping either all walls to one element (as for DIN EN ISO 13790), distinguish between external and internal walls (as for VDI 6007-1, Figure 1), further divide between walls exposed to solar radiation and floor plates and finally separate the roof elements as well. The merging or separation of the building elements leads to four different models with the open question, which model considers all dominant dynamics while neglecting all others to have as small simulation times as possible. For this purpose, all four models need to be characterized, e.g. by using Bode plots (Figure 2).

The results show that the behavior of the One-Element-Model significantly differs from the higher order models, for the magnitude as well as the phase shift, when observing the indoor air temperature while exciting outdoor air temperature or internal gains. This originates in neglecting internal masses, what leads to a significantly different transfer function.The Two-, Three- and Four-Elements-Model show slight differences in the Bode plots, what requires further analyses in the time domain. The simulation of one year reveals maximal differences in the free-floating indoor air temperature between Two- and Four-Elements-Model of 0.4 K.

Based on these results, the Two-Elements-Model qualifies for urban scale simulations with low simulation times while keeping a similar behavior compared to higher order models. As the differences partly depend on the insulation and thermal mass level, further research should result in an adaptive method to automatically choose a reduced order modelling approach based on these properties.

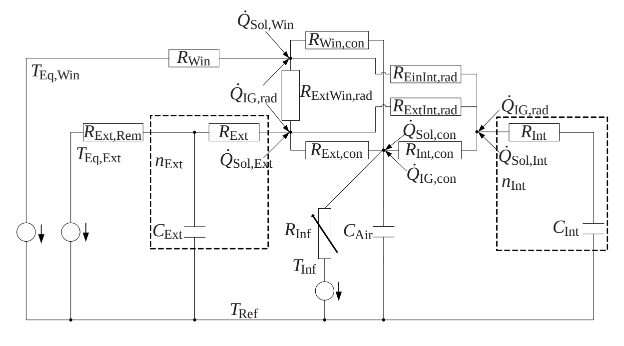

Figure 1. Thermal network of the Two-Elements-Model from `AixLib`.

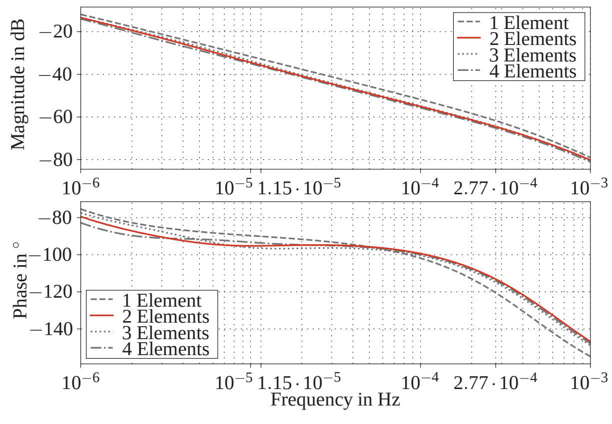

Figure 2. Bode plot for external excitation with heavy-weight setup (EnEV 2009) and indoor temperature as observed output.