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Long term forecasting of building systems: CFD, stochastic collocation and Perron Frobenius based model reduction

Anthony Fontanini[1], Umesh Vaidya[2] and Baskar Ganapathysubramanian[3]

[1] Department of Mechanical Engineering, 2025 Black Engineering, Iowa State University, Ames, IA, 50011, USA, fontania@iastate.edu
[2] Department of Electrical and Computer Engineering, 3215 Coover Hall, Iowa State University, Ames, IA, 50011, USA, ugvaidya@iastate.edu
[3] Department of Mechanical Engineering, 2100 Black Engineering, Iowa State University, Ames, IA, 50011, USA, baskarg@iastate.edu

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Around the world, buildings utilize approximately 40% of the world's energy usage [1]. Advancing simulation tools responsible for the prediction and evaluation of energy consumption in buildings is critical to identify problems with current buildings and design more efficient new buildings. A key necessity is accurate predictions of the dynamics of buildings over extended periods (as long as a year!) to investigate their energy performance, and the comfort of the occupant. Although current reduced order energy models allow for yearly simulations of building all over the globe, these modeling techniques lack accuracy in determining the fluid flow and heat transfer characteristics in the conditioned space, and cannot resolve thermal comfort in the occupied zone. Computational Fluid Dynamics (CFD) can resolve the complex ventilation structures along with the occupant thermal comfort metrics, but are computationally expensive for 3D simulations due to potentially large length scale differences that limit the time step required for accuracy or stability. This is specifically challenging considering the long term forecasting required. We present a method that combines a reduced order energy modeling strategy with high-resolution CFD simulations to produce long-term forecasts of a building's airflow physics, temperature profiles, energy efficiency metrics, and occupant thermal comfort performance.

We consider a realistic 3D geometry of an actual high efficiency house. The boundary conditions (wind speeds, temperature conditions, etc) are all experimentally collected over a one year period in one hour increments. We first construct a stochastic representation of these inputs by considering them to be snapshots of a set of correlated random variables. We then employ an adaptive sparse grid collocation strategy to sample this stochastic input space, and construct an interpolated representation of the output variables [2-3]. The output variables at ***each*** sample point are computed by post-processing a high resolution CFD simulation. Post processing consists of constructing the Markov (or Perron Frobenius operator) for the thermal and mass flows in the geometry [4-5]. The long term behavior of the system is formulated as time-stepping the Perron-Frobenius operator corresponding to the instantaneous input configuration.

The strategy that we present allows for highly resolved CFD simulations to characterize energy performance and thermal comfort of a prototype building in many different climates. The method gives the ability to directly compare and improve the reduced order energy models with the CFD simulations. This process yields a yearly thermal comfort profile of the building not possible before by reduced order energy models. This process also presents an option that is computationally more efficient as compared to a direct coupling of the conjugate heat transfer and fluid problem present between the building envelope and the conditioned space [6-8].

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