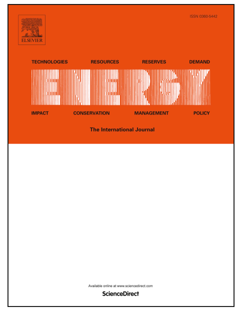
Accepted Manuscript



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PII: S0360-5442(17)30310-9

DOI: 10.1016/j.energy.2017.02.127

Reference: EGY 10420

To appear in: *Energy*

Received Date: 21 October 2016

Revised Date: 20 February 2017

Accepted Date: 21 February 2017

Please cite this article as: Hillary J, Walsh E, Shah A, Zhou R, Walsh P, Guidelines for developing efficient thermal conduction and storage models within building energy simulations, *Energy* (2017), doi: 10.1016/j.energy.2017.02.127.

Guidelines for developing efficient thermal conduction and storage models within building energy simulations

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Abstract

Improving building energy efficiency is of paramount importance due to the large proportion of energy consumed by thermal operations. Consequently, simulating a building's environment has gained popularity for assessing thermal comfort and design. The extended timeframes and large physical scales involved necessitate compact modelling approaches. The accuracy of such simulations is of chief concern, yet there is little guidance offered on achieving accurate solutions whilst mitigating prohibitive computational costs. Therefore, the present study addresses this deficit by providing clear guidance on discretisation levels required for achieving accurate but computationally inexpensive models. This is achieved by comparing numerical models of varying discretisation levels to benchmark analytical solutions with prediction accuracy assessed and reported in terms of governing dimensionless parameters, Biot and Fourier numbers, to ensure generality of findings. Furthermore, spatial and temporal discretisation errors are separated and assessed independently. Contour plots are presented to intuitively determine the optimal discretisation levels and time-steps required to achieve accurate thermal response predictions. Simulations derived from these contour plots were tested against various building conditions with excellent agreement observed throughout. Additionally, various scenarios are highlighted where the classical single lumped capacitance model can be applied for Biot numbers much greater than 0.1 without reducing accuracy.

Keywords: Buildings Energy Models; Discretisation; Transient Conduction; RC Networks; Biot & Fourier number

1. Literature Review

Buildings account for up to 40% of all energy consumed across the EU [1, 2] with heating and cooling systems typically accounting for approximately half of this figure. The EU has committed to reducing this percentage via the promotion of enhanced thermal designs, retrofitting of existing buildings, and the integration of renewable technologies [3, 4]. A myriad of options are available to reduce energy consumption in buildings, however, choosing one solution that provides optimal financial or environmental outcomes is a nontrivial matter. This is due to the unique conditions under which buildings operate along with their design parameters, i.e. climatic conditions, occupancy schedules, architectural designs, and the multitude of materials used during construction. All of these factors lead to individual buildings requiring distinct solutions in order to achieve optimal performance. This has motivated the use of simulations as they provide useful insight when engineered solutions for enhanced building designs and retrofitting actions are sought.

A high degree of confidence in the accuracy of such simulations is important to ensure their effectiveness in evaluating any potential energy saving measures. Additionally, accurate predictions of future building loads could be of importance for load leveling when combined with curtailment and constraint issues encountered with renewable energy sources on the electrical grid. To achieve these goals it is essential to implement appropriate numerical methods whilst maintaining reasonable computational costs. This is due to the large physical scales and extended time frames that need to be simulated. A review by Foucquier et al. [5] focuses on modelling approaches employed for building energy simulations. These can be catagorised as models based on physical laws; statistical models utilising acquired data alone; and a hybrid approach that uses measured data to define parameters within simplified physical models. For models informed by physical laws, the most detailed approach is that offered through computational fluid dynamics coupled with thermal transport in solid media. Such approaches are not typically feasible for building simulations due to large computational costs. Instead, simplified models that make significant

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