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Inverse estimation of the urban heat island using district-scale building energy calibration

Luis Guilherme Resende Santos [a], Dina Masri [a], Afshin Afshari [a*]

[a]*Masdar Institute of Science and Technology, Abu Dhabi 54224, United Arab Emirates*

Abstract

Over the past decade, building energy modelling research has increasingly focused on urban-scale models. The shortcomings of analyzing urban buildings in isolation are well known and far from negligible (mainly, the inability to account for urban heat island and shading from neighboring obstructions). The aim of this paper is to assess the impact of the urban context via urban-scale modelling and inverse parameter estimation (calibration) using metered energy consumption of each building. We describe an automated calibration method for 58 buildings in a representative downtown district of Abu Dhabi. This district has undergone a detailed energy audit and a large amount of data about the building envelopes, cooling loads and electricity consumption has been collected from 2008 to 2010. In our models, buildings are subdivided in up to three use types documented in the audit (Residential, Office and Retail). Since it is well known that, due to the urban heat island effect, the urban ambient air temperature can differ significantly from the reference rural air temperature used in most building simulations, the calibration procedure will also estimate this differential together with unknown building parameters. The main contribution of the paper is to demonstrate that the proposed district-scale calibration is, in average, more accurate than individual building calibration and informs not only on buildings but also on the outdoor environment. The calibration was performed using Genetic Algorithm, reaching an average building MAPE of 25.24%. For the district as a whole, a MAPE of 12.01% was achieved. The estimation of Urban Heat Island intensity revealed a daily maximum of 5.6°C and an average daily differential of 3°C for a typical day, showing the relevance to consider it for any building energy simulation.

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* Corresponding author*: aafshari@masdar.ac.ae*

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1. Introduction

1.1. Urban Energy Modeling

Urban population is in crescent growth throughout past decades, and most of the worldwide energy usage is directed to the cities, more precisely three quarters of the global energy use (Grubler et al., 2012). Scientists predict an increase in this number, as urban areas will be inhabited by up to 80% of world population in the next century (Santamouris et al., 2001). From the world's total energy consumption, around one-third comes from buildings (International Energy Agency, 2013), which shows the importance of studies of the urban environment.

In order to better understand energy use in the urban environment, latest studies have been trying to join applications from individual building energy models (BEM) and regional building stock models (Reinhart & Cerezo Davila, 2016). BEMs are well known and commonly used in single buildings during design and operating stages (Hensen & Lamberts, 2011). Although it is possible to run multiple building simulations, computation time as well as the level of detail of the model and model size affect the feasibility (Martin, Wong, Hii, & Ignatius, 2017). Furthermore, isolated BEMs are not able to account for urban heat island and shading from surrounding obstructions.

1.2. State of the Art

In the field of BEM calibration—matching simulation to measured data—extensive research has been conducted and compiled in literature in the past years. Coakley (2014) reviewed the topic and concluded that calibration is an indeterminate problem with variable solutions, depending heavily on the quality of inputs and outputs. Variable standards and simulation approaches amplify this problem and hinder the ability to reach consensus on the method to be followed. Nguyen (2014) reviewed optimization methods, observing that Genetic algorithms are by far the most used method given their ability to handle continuous and discontinuous variables, to solve multi-objective problems, to avoid local minimums and to allow multi-processor simulation. The most popular optimization engines are Matlab and GenOpt, while Energy Plus, together with TRNSYS are the most common BEM tools. Sanyal (2014) studied the use of machine learning for multi-objective optimizations to automate BEM calibration, especially when it involves large amount of data. Fabrizio (2015) analyzed issues faced during calibration, possible criteria of goodness-of-Fit and characterization of the calibration of 19 works found in the literature. Royapoor (2015) coupled an Energy Plus model with two environmental data sensors, highlighting the importance to include local weather files in the calibration process.

In the field of urban modelling, Pisello et al. (2012) considered inter-building effect to study how they influence the accuracy of building energy performance predictions, concluding that when considering the energy performance of a single building, the special relationship with surrounding buildings should be taken into account. Martin M. et al. (2015) coupled an urban canopy model with EnergyPlus using Building Controls Visual Test Bed (BCVTB) to estimate temperature and humidity for urban canyon in Masdar city, Abu Dhabi. Later Martin et al. (2016) introduced an extension with specific methods to account for waste heat releases, traffic-related heat gains and direct normal irradiance in order to design a model suitable for Central European cities. Allegrini et al (2015) compiled latest approaches and tools that can be used in district-scale energy systems. Similarly, Reinhart et al. (2016) reviewed emerging simulation methods, considering inputs organization, thermal model generation and results validations, giving an overlook for future development. Andrić et al. (2016) included effects of climate change to study drops in heat demand with district data validated by EnergyPlus and weather data created by the CCWorldWeatherGen, finding significant changes for the future, with heat demand dropping by 22-52% in 2050.

In this study, we consider a district in downtown Abu Dhabi, capital of the United Arab Emirates. The city has a hot and humid climate, with temperatures easily reaching more than 45 degrees Celsius during summer (Afshari &