



Engineering advance

Urban building energy modeling – A review of a nascent field

Christoph F. Reinhart^{*}, Carlos Cerezo Davila

Massachusetts Institute of Technology, Cambridge MA 20139, USA

ARTICLE INFO

Article history:

Available online 2 December 2015

ABSTRACT

Over the past decades, detailed individual building energy models (BEM) on the one side and regional and country-level building stock models on the other side have become established modes of analysis for building designers and energy policy makers, respectively. More recently, these two toolsets have begun to merge into hybrid methods that are meant to analyze the energy performance of neighborhoods, i.e. several dozens to thousands of buildings. This paper reviews emerging simulation methods and implementation workflows for such bottom-up urban building energy models (UBEM). Simulation input organization, thermal model generation and execution, as well as result validation, are discussed successively and an outlook for future developments is presented.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Contents

1. Introduction	196
2. Urban building energy modeling	197
2.1. Data input	197
2.2. Thermal modeling	199
2.3. Validation	199
3. Discussion and conclusions	199
Acknowledgment	200
References	200

1. Introduction

The United Nations estimates that the number of city-dwellers worldwide will grow until 2030 at a net rate of about two million per week [1]. If this unprecedented urban growth continues to be largely *ad hoc* via informal settlements, sprawl and haphazard densification, global and local consequences for the environment, the economy and the mere quality of life of billions could be severe. Policy measures at the international and national level as well as technical advances can support positive change but the immediate implementation of sustainable infrastructure measures mostly happens at the municipal and neighborhood level. In response to those global challenges, city governments world-wide have

developed ambitious long-term GHG emission reduction targets such as 40% and 60% by 2025 (San Francisco and London) or 80% by 2050 (New York City and Boston) [2,3]. Interestingly, such targets increasingly command substantial political willpower, especially in regions that have already suffered from increased hurricane activity, draught and/or prolonged summer heat waves. While the significance of GHG emissions from transportation and industrial activities varies among cities, building-related emissions are always a key contributor.

In order to manage and notably reduce those emissions for both new and existing neighborhoods, cities need to better understand not only which sectors and buildings *currently* cause those emissions but also what *future* effects comprehensive energy retrofitting programs and energy supply infrastructure changes might have. The analysis of current overall energy flows can be realized via “top-down” building stock energy models which start with the building energy demand for a region and increasingly subdivide the

^{*} Corresponding author.

E-mail address: creinhart@mit.edu (C.F. Reinhart).

existing stock into smaller subsections [4]. Top-down models can provide estimates of what would happen if more buildings of a certain type were to be built or converted into another type. But, such models necessarily extrapolate from the status quo and are hence less suitable when more integrated energy supply-demand scenarios are being investigated or when an analysis focuses on a specific neighborhood. At this meta-scale – ranging from several dozens to thousands of buildings – “bottom-up”, urban building energy models (henceforth referred to as UBEM) are expected to become a key planning tool for utilities, municipalities, urban planners and even architects working on campus level projects.

The basic approach of UBEM is to apply physical models of heat and mass flows in and around buildings to predict operational energy use as well as indoor and outdoor environmental conditions for groups of buildings. At the individual building level, such heat flow or building energy models (BEM) are already widely used in many parts of the world for design development, code-compliance demonstration and improved operation [5]. The typical usage case for BEM is that an energy modeler is provided with geometry, construction data and usage schedules for an initial sketch, mature design or existing building. The level of available information is commensurate with the design stage of the project which requires the modeler to make educated guesses regarding certain simulation inputs. The modeler then enters the available information into a building energy modeling software, a mostly manual, time consuming and costly process. A number of BEM simulation programs have been validated against measurements [6,7] and various standards are in place to ensure their continued reliability [8,9].

While the above outlined BEM process can in principle be successively applied to any number of buildings, this process would require prohibitively high financial and time resources. Translating a net world-wide growth of 2 million city dwellers per week to the Boston context would require the design, modeling and construction of some 400,000 buildings per week. To put this number in perspective, as of February 2015 there were around 70,000 LEED certified buildings worldwide (LEED. URL: <http://www.usgbc.org/LEED>). To become globally relevant and affordable, BEM hence needs to expand its scope to the urban realm. This manuscript reviews recent attempts to make UBEM a viable decision support tool for architects, urban planners and energy policymakers. This process requires the reconceptualization and automation of building energy model workflows as well as the validation of UBEM predictions against measured energy use. While the document focusses on operational building energy use of neighborhoods based on building-by-building simulations, the same approach has also been applied to other urban performance criteria such as embodied energy use [10], daylight availability [11] and walkability [12]. Perez and Robinson called this larger field of exploration, which UBEM is a part of, “urban micro-simulation” [13,14]. Within the model classification schemes used by Ugursal/Swan [15] and Kavgić et al. [16], UBEMs are “bottom up engineering” or “bottom up building physics” models, respectively. The UBEMs discussed in this paper focus specifically on synthesizing building load profiles. Complementary models to design matching building energy supply systems were recently reviewed by Allegrini et al. [17].

2. Urban building energy modeling

The task of creating a reliable building energy model of a new or existing neighborhood can be broken into the following subtasks: simulation input organization (data input), thermal model generation and execution (thermal modeling) as well as result validation (validation).

2.1. Data input

An UBEM requires the combination of several data sets including climate data, building geometry, construction standard and usage schedules. Climate data sets for building performance simulation have been available for a number of years following the initial establishment of a viable data format, the typical meteorological year (TMY) [18,19], and the subsequent provision of data available in this format for multiple regions worldwide (US-DOE EPW Weather Data. URL: <http://apps1.eere.energy.gov/buildings/energyplus>). Apart from improving the world-wide coverage of these datasets, researchers have recently been exploring methods of how to model local microclimatic phenomena within cities such as the urban heat island effect [20]. For the City of London, Mavrogianni et al. coupled locally measured temperature profiles with an UBEM in order to resolve the effect of the urban heat island effect on building energy use and resident health [21]. Predicting local wind patterns [22] and linking IPCC climate change predictions to current day TMYs [23] are equally active areas of research with direct implications for UBEM.

The geometry input data required by an UBEM consists of building envelope shapes and window opening ratios as well as terrain data. Depending on whether a new or existing neighborhood is the subject of investigation, this information can either be extracted from existing datasets or generated from scratch. Over the past decades, city-wide Geographic Information Systems (GIS) databases have not only become commonplace in many regions of the world but are also increasingly accessible to the general public, especially in the US. GIS shape files combined with LiDAR data or building heights [24] as well as open semantic formats such as CityGML [25] can be used to automatically generate extruded or “2.5D” massing models of whole cities such as the one shown in Fig. 1(a) for South Boston. Due to their ability to combine geometry and building databases, CityGML models have recently become the file format of choice for several European research projects [49,50,65]. Massing models with similar characteristics as Fig. 1(a) are routinely generated for architecture and urban planning projects as well, as shown in Fig. 1(b) which depicts an early design proposal for Boston’s new Innovation District (Boston BRA Urban Design Dept. 2010). As far as the simulation process is concerned, geometric simulation inputs are therefore identical for existing and new neighborhoods.

In addition to the outer shell, non-geometric building properties have to be defined as well, including construction assemblies and HVAC systems. At the individual building level, this step routinely takes about a third of the modeling effort [26] and constitutes one of the main sources of discrepancies between simulated and measured energy use due to uncertainty regarding infiltration rates, equipment loads and occupant behavior [27]. While these quantities can be measured for a small group of existing buildings, such detailed data collection efforts become impractical for larger urban areas. It is therefore necessary for an UBEM to abstract a building stock into “building archetypes”, i.e. building definitions that represent a group of buildings with similar properties. The archetype approach has been extensively used in the context of national or regional bottom up building stock models to understand the aggregated impact of energy efficiency policies [28] and new technologies [29]. The generation of archetypes requires two steps: In *segmentation*, the investigated building stock is divided into groups according building shape, age, use, climate and systems [30–37]. In *characterization*, a complete set of thermal properties including construction assemblies, usage patterns and building systems have to be defined for the archetype buildings representing the previously defined groups. Depending on the scale of application and segmentation parameters chosen, an archetype

Download English Version:

<https://daneshyari.com/en/article/6699594>

Download Persian Version:

<https://daneshyari.com/article/6699594>

[Daneshyari.com](https://daneshyari.com)