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Auto-Calibrated Urban Building Energy Models as Continuous Planning Tools

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ABSTRACT

Owners of large building portfolios, such as university campuses, increasingly rely on physics-based building energy models, calibrated to historic energy data, to explore energy efficiency retrofits. These calibrated models, which require substantial effort to originally set up, are then typically only used once for analyzing a series of upgrade options. This paper presents a methodology for the development of a continuous energy performance tracking system that expands the point-in-time analysis capabilities of conventional urban energy modeling platforms. The goals are to enable university campuses to manage their building energy-use over time by automatically tracking their actual performance against earlier defined targets, updating individual building energy models following the implementation of any upgrades and evaluating potential future retrofit strategies. A key innovation is the development of easy to implement workflows that are cognizant of current flows of information and that allow the mapping and display of changes and their consequences.

Author Keywords

building energy simulation; automatic energy model calibration; energy efficiency retrofits; urban energy modeling; continuous performance tracking

1 INTRODUCTION

Along with a societal obligation to commit to a low carbon economy, established university campuses typically have a portfolio of aging buildings with a significant opportunity for energy efficiency retrofits but a limited implementation budget. To reduce their building energy use, long identified as a key contributor to global greenhouse gas emissions [1], university administrations require a prioritization plan for upgrades with a high degree of certainty in expected greenhouse-gas emission reductions. To better understand costs and benefits, decision makers frequently rely on a simulation-based assessment of a building retrofit strategy, based on well-established whole building energy modeling programs [2] that simulate heat and mass flows in and around buildings, and calculate energy use for different end-uses required to meet the building's programmatic requirements.

Given the considerable time and financial efforts required to collect data and setup an energy model for even a single building [3], it is typically not feasible to scale this traditional whole building energy simulation approach to the scale of a campus that may include hundreds of buildings. Over the past few years, a new genre of urban building energy models (UBEM) [4] has been utilized by municipalities and utilities to develop suitable energy-efficiency policy measures and to assess broad-scope carbon-emission reduction strategies. Similar urban modeling approaches can be employed by owners of large building portfolios, such as university campuses, to develop an understanding of the existing energy use [5], and to assess the energy saving potential of possible energy efficiency measures.

A common trait of this methodology, however, is that the engagement with the stakeholders is limited to a single moment in time and the analysis of results is limited to evaluating static proposals. This type of analysis can help university administrations to understand what is technically feasible and to ground aspirational greenhouse-gas emission reduction targets on scientific realities. However, campus level transformations have a built-in inertia that may stretch over decades, from retrofitting and solarizing programs for buildings to streetscape and façade renewal efforts. Campus conditions are also in constant flux as building uses change and student populations fluctuate.

This paper proposes a methodology for the development, implementation, and validation of a campus-level energy performance tracking system that complements the point-in-time analysis capabilities of current urban energy modeling platforms. The immediate goal is to help a university campus to document and manage the development of their building energy-use portfolio over time and to track its performance vis-à-vis a set of earlier defined targets. A key innovation is the development of easy to implement workflows that are cognizant of current flows of information and that allow the mapping and display of changes and their consequences. Using metered energy data from 100 MIT campus buildings, the authors have worked with the Institute's Office for Sustainability to implement the proposed framework for the MIT campus.

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2 FLOW OF INFORMATION

The foremost goal of the proposed continuous planning tool is to provide information on the historic energy use breakdown and predict potential changes in energy use with any identified building retrofits, at the campus and individual building scale. Collecting historic and current energy use data for all buildings is, therefore, at the core of the tool. In addition, location-specific weather data is collected regularly from an on-site weather station and automatically processed to generate up-to-date EnergyPlus [6] Weather (EPW) files.

Using accurate energy use and weather information, detailed EnergyPlus building energy models, developed using established UBEM data input and model generation techniques, are automatically calibrated to reflect individual building performance characteristics using previously developed surrogate model driven auto-calibration methods [7]. The resulting calibrated building-by-building energy models incorporate existing parameters for envelope configuration, internal loads and usage profiles across the building stock, and therefore, can reasonably simulate the effects of a large range of energy conservation measures, from campus level strategies to specific building retrofits.

Finally, a web-based user interface presents the aggregated building energy-use data and associated useful statistics at the campus and individual building levels. In addition, the interface allow users to select potential upgrades at the campus level, specific building measures, or even partial building retrofits; runs the energy models in the background, and presents in real-time the predicted energy-use and greenhouse-emissions impact of evaluated upgrades on building and campus energy use. Figure 1 schematically illustrates this flow of information.

2.1 Data Collection

There are a few key components interacting in the backend of the tool that ultimately result in the finished product. The driver and central component of the project is the server set up for data handling. The server, an Amazon Web Services EC2 instance running Ubuntu 16.04.3 LTS [8], is responsible for data aggregation, data conversion, and data delivery to the user interface.

Measured Energy Data

Currently, there are two different sources for energy use data for the MIT campus. MIT provides the breakdown of energy use, by building and by energy type (chilled water, steam, and electricity) in monthly intervals through PostgreSQL [9] tables, and 5-minute interval OSISoft [10] data maintained by the MIT Office of Sustainability. The server queries both datasets directly and the information is automatically converted into consistent units before further processing.

Weather Data

MIT has a weather station installed on campus that records weather data in 5-minute intervals using a system called Hobolink [11]. This data is accessed through automatic once-daily transfers of comma separated value (CSV) files from Hobolink via a file transfer protocol (ftp) setup on the server. The collected global horizontal solar radiation is then post-processed using the Daysim program [12] and converted into equivalent direct normal and diffused radiation for each recorded hour. Finally, a scalar vector average of wind direction using wind speed as the length of the vector calculates average wind speed and direction for the hour. These conversions are set to run automatically every day to create an EPW hourly format file, which is then saved into a sqlite [13] database on the server.

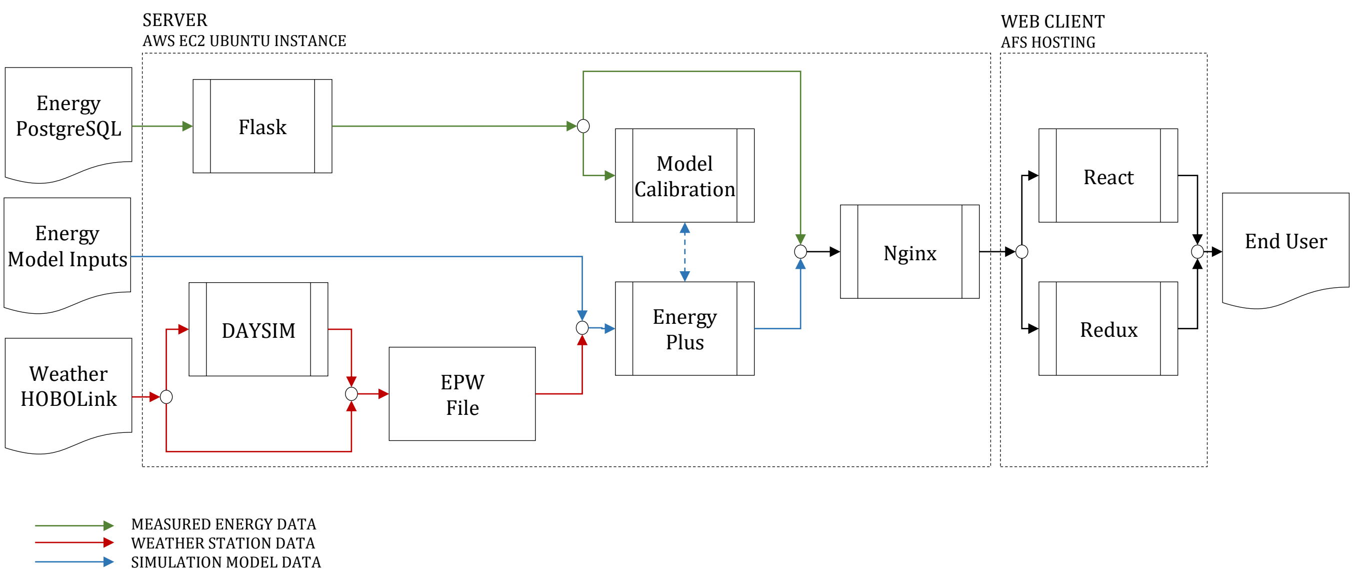

Figure 1. Schematic diagram illustrating the flow of information protocols employed to collect actual measured energy use and weather data, to develop and auto-calibrate urban building energy models, and to deliver processed data to a web client

2.2 Auto-Calibrated UBEM

The UBEM incorporates a combination of several datasets including climate data, building geometry, construction standards, usage schedules, and loads and systems parameters to simulate individual building energy use. A campus-wide Geographic Information Systems (GIS) database was utilized to automatically generate extruded massing models of the campus. Additional envelope data, which consisted of floor heights, fenestration configuration, window opening ratios, and construction assemblies, was based on architectural drawings or on visual inspection where drawings were not available. The building stock was then abstracted into four predominant programmatic archetypes that represent a group of buildings with similar non-geometric properties. Figure 2 presents a graphic rendering of the campus energy model showing distribution of academic, laboratory, ancillary and residential archetypes. The UBEM is developed for EnergyPlus whole building energy simulation program using the Urban Modeling Interface (UMI) [14].

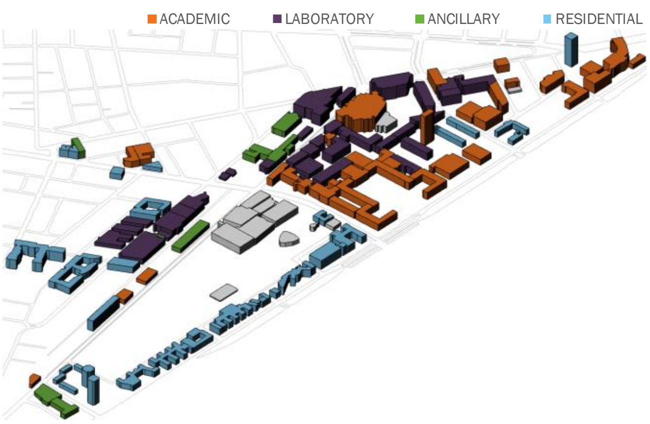

Figure 2. Graphic rendering of MIT campus UBEM showing distribution of programmatic archetypes

Variations for envelope configuration, lighting and mechanical systems, and occupant behavior are incorporated at an individual building scale where this information is available. When detailed information regarding some performance characteristics is not easily accessible, the input parameters are fitted based on the local weather data and known measured energy use for each building. Surrogate models [7], a class of machine learning algorithms, are employed to create mathematical approximations of the physical behavior of building systems based on the known performance characteristics and measured energy use data.

These approximation models are then used in combination with optimization routines to estimate the properties of unknown building performance parameters, without the need for computationally expensive iterative energy simulations. This auto-calibration procedure regularly monitors the collected data and updates EnergyPlus input parameters to maintain up-to-date energy models.

2.3 Data Delivery

The collected as well as simulated energy use data, and all relevant statistics, are delivered by the server to a web client using a RESTful API [15] coded with the web micro-framework Flask [13]. In production, the server uses nginx [16] to reverse proxy and serves all web requests to the Flask web server for handling. The static historical data is saved for each year in a JSON [17] file and shipped to the web client. The web client allows users to evaluate upgrades to buildings, and displays model predicted output for those upgrades. The web app is built using React [18] and Redux [19], in addition to Babel [20] to build the bundle. The components heavily rely on flex-boxes, or the display: flex property of CSS [21]. There are three main components in related to data display:

Campus Map

The Campus Map shows a map of all buildings built using Leaflet.js [22] and GeoJSON. By default each building is colored based on its current energy use intensity. An alternate display changes the color gradients to compare energy use based on the building type. Additionally, the colors can be filtered by individual energy type to compare only the electricity, chilled water, or steam use of buildings.

Campus Overview

The campus overview displays a bar graph showing campus wide historical energy use data for past years. The displayed data can be broken down by month, or by energy type, based on user selection. Additionally the campus overview filters based on the filters selected in the campus map, and allows for interactions like hovering over months, or select groups of months to see total energy use of the selected months.

Building Overview

Finally, when a user clicks on a specific building on the campus map, the overview pane switches to data specific to that building. Additionally, it displays metadata on the building including building id, floor area, etc. The building overview compares the measured energy use data to the predicted results from the EnergyPlus simulations, and allows users to compare results for various upgrade scenarios.

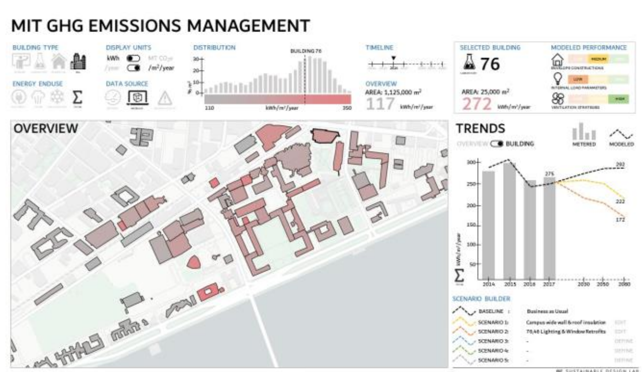

Figure 3. Screenshot of web user interface mock-up showing the campus map (left), and the overview pane (right)

3 DISCUSSION AND OUTLOOK

The development of campus-wide building energy models currently requires substantial effort and expertise for detailed geometric model building, and considerable amount of information and time for setup and calibration of individual building models. Once developed, however, the models are traditionally used only for a single point-in-time analysis, to evaluate static proposals. While this analysis can help to evaluate potential future scenarios for the unique set of existing conditions, the models are not designed to evolve as the retrofit programs are implemented, as new buildings are added, or as building use or occupancy changes over time.

In principle, these urban energy models, which incorporate performance parameters in extensive detail, have the potential to be easily updated by simply modifying the relevant inputs as campus condition change. This paper presents a data workflow that automatically tracks new energy use and updates the models, allowing the resulting tool to serve as a facility planning and maintenance platform for the assessment of ongoing comprehensive building level retrofitting programs. The methodology capitalizes on previous research that significantly reduced the time and effort required to calibrate building energy models by developing high fidelity auto-calibration routines based on computationally inexpensive surrogate modeling techniques.

An important next step for the project is the development of a data-flow infrastructure that facilitates the mapping of campus developments over time; specifically the entering and interpretation of this data by the university campus administration to modify specific energy model input parameters as individual buildings systems are upgraded. Particular challenges arise for example when the university adds new building to their portfolio.

The proposed tool will provide an effective way of combining measured building energy data with simulation results to automatically, and continuously, track whether a given retrofitting measure has led to expected outcomes, and to determine the actual financial payback of implemented measures. Over time, this type of analysis can demonstrate which upgrade strategies lead to the most greenhouse gas emission reductions per dollar invested. The procedures outlined in this document would help set up a "living" campus-wide urban energy model, which would in turn empower campus administrators and facilities to assess the effectiveness of their greenhouse-gas emission reduction policies in real-time.

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