EMI report:
BESOS – an Expandable Building and Energy Simulation Platform

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Content

1 General overview

The built environment is one of the key action areas of the Pan-Canadian Framework on Clean Growth and Climate Change; in Canada using energy to heat and cool buildings accounted for about 17 percent of national GHG emissions in 2014 according to this Framework[1]. Actions concerning the built environment include making new buildings more energy efficient (including net-zero energy buildings), retrofitting existing buildings, fuel switching from fossil fuels to low-carbon electricity, and improving the energy efficiency of appliances and equipment. Because of heating electrification, actions to decrease the heating demand or to improve the heating system will have a significant impact on the electricity demand of buildings[2,3] and therefore on the low-voltage distribution electricity grid[4,5]. Vehicle electrification is also highlighted as a key action as transportation accounts for 23 percent of Canada's emissions in 2014[1]. The uptake of electric vehicles will also dramatically affect domestic electricity demand patterns[6,7,8] because of the domestic charging stations. Policy choices concerning the built environment and transportation will become highly correlated to electricity grid policies. It is important to build new decision-making tools to fill the gap between these areas and allow the formulation of holistic policies[9,10].

Core part of good decision-making tools is a set of powerful modeling and optimization algorithms. Currently several tools are employed to optimize the design of building and energy systems: simulations tools to assess the energy use of buildings, optimization techniques to derive energy and carbon reductions through cost-effective measures, surrogate models to decrease the computational cost, etc. Combining these different techniques requires sophisticated knowledge making them hard to manipulate. Moreover, constructing gateways between these tools is a time consuming process, lowering the available time and energy for actual research and development of applicable decision-making tools.

To answer this problem, our team developed the BESOS platform with funding from CANARIE to facilitate the interconnection and use of different advanced tools for buildings and energy systems

[1] Canada, Environment and Climate Change Canada. Pan-Canadian framework on clean growth and climate change: canada's plan to address climate change and grow the economy. [Internet]. 2016 [cited 2019 Jun 21]. Available from: http://www.deslibris.ca/ID/10065393

[2] Lindberg KB, Seljom P, Madsen H, Fischer D, Korpås M. Long-term electricity load forecasting: Current and future trends. Util Policy. 2019 Jun 1;58:102–19.

[3] Baruah PJ, Eyre N, Qadrdan M, Chaudry M, Blainey S, Hall JW, et al. Energy system impacts from heat and transport electrification. Proc Inst Civ Eng - Energy. 2014 Aug;167(3):139–51.

[4] Fawcett T, Layberry R, Eyre N. Electrification of heating: the role of heat pumps. 2014;13.

[5] Calvillo CF, Turner K, Bell K, McGregor P. Impacts of residential energy efficiency and electrification of heating on energy market prices. In: 15th IAEE European Conference 2017 [Internet]. Hofburg Congress Center; 2017 [cited 2019 Jul 4]. Available from: https://strathprints.strath.ac.uk/61961/

[6] Shafiee S, Fotuhi-Firuzabad M, Rastegar M. Investigating the Impacts of Plug-in Hybrid Electric Vehicles on Power Distribution Systems. IEEE Trans Smart Grid. 2013 Sep;4(3):1351–60.

[7] Deb S, Tammi K, Kalita K, Mahanta P. Impact of Electric Vehicle Charging Station Load on Distribution Network. Energies. 2018 Jan;11(1):178.

[8] Jarvis R, Moses P. Smart Grid Congestion Caused by Plug-in Electric Vehicle Charging. In: 2019 IEEE Texas Power and Energy Conference (TPEC). 2019. p. 1–5.

[9] Gu W, Wu Z, Bo R, Liu W, Zhou G, Chen W, et al. Modeling, planning and optimal energy management of combined cooling, heating and power microgrid: A review. Int J Electr Power Energy Syst. 2014 Jan 1;54:26–37.

[10] Heinen S, Turner W, Cradden L, McDermott F, O'Malley M. Electrification of residential space heating considering coincidental weather events and building thermal inertia: A system-wide planning analysis. Energy. 2017 May 15;127:136–54.

analysis. BESOS is a cloud-based open-source platform built using Python and Jupyter Notebooks, taking advantage of the numerous available tools and libraries. The design enforces its modularity and flexibility. The underlying repositories are fully tested following software development best-practices. Special attention is given to visualisation tools and user-friendly functionality. Therefore this platform can be easily expanded and form the base of numerous decision-making tools.

This report will demonstrate this ability through a description of the platform itself and three selected test cases. These test cases were chosen to show the extent of problems that can be addressed using BESOS both at research and decision stages.

2 The modeling tool: BESOS

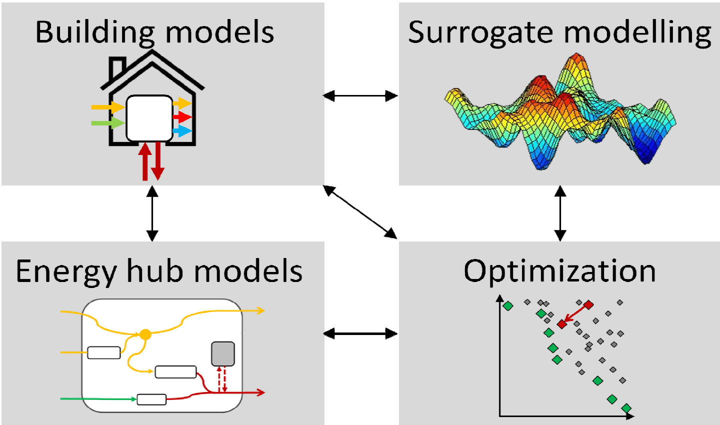

Figure 1: Main functionalities of BESOS.

The Building and Energy Simulation, Optimization and Surrogate modelling (BESOS) is a building and city modelling platform that seeks to provide a single interface to interact with traditional modelling tools and make use of novel optimization and machine learning techniques. The interface we have chosen to use are Jupyter Notebooks (JN). These JN are powered by Python code and interweave Python code, text, images, graphics, data, and tables into a single document.

Figure 1 summarizes the main functionalities, which can be used thanks to BESOS either as embedded tools or linked to. Various Python libraries have been created for the platform to ease the use of these different tools. BESOS platform links building energy simulation models, 'Energy Hub' system models, machine-learning based surrogate modelling and global optimization algorithms. Each area is detailed below:

- *Building energy simulations* calculate the hourly behaviour of a given building design over a year of weather data. This is provided by the widely-used open-source EnergyPlus software via a Python interface (EPPy).
- *The Energy Hub modelling framework* optimizes the operational energy flows between converters and storages, which can also be optimally sized in the same process. Pre-existing Energy Hub models have been ported into Python, and models are solved using the CPlex or GLPK programs.
- *Surrogate modelling* is the process of fitting a machine learning model to data generated using a detailed but computationally intensive simulation program, so that other design options can be approximated very rapidly. BESOS provides implementations of this using the standard sci-kit learn and TensorFlow libraries.

- *Optimization algorithms* (for example multi-objective genetic algorithms) can rapidly explore the space of possible designs, where design performance is evaluated using a black-box simulation. This process is provided in BESOS using the Platypus library.

Overall, the BESOS Platform provides a powerful way to couple each of these areas, for example running EnergyPlus simulations to fit a surrogate model, which is then linked to an optimizer. This integration is very straightforward using the BESOS codebase, dramatically lowering the barrier to entry to this type of holistic, integrated modelling and analysis. Combining JN and Python also give the user access to numerous libraries and ability to quickly build user-friendly interactive responsive visualizations. Finally, the particular problem of exploring the optimal design within a certain building or energy system design space can be coded in a few lines of code. JN examples of all these actions are available in the platform.

As developer of this platform, our team has a strong expertise which en able us to efficiently design and implement customized decision-making tools for specific problems concerning the built environment and/or energy systems. In the following, three test cases are proposed to highlight this diversity of problems.

3 Selected test cases

Three cases are highlighted to show possibilities of the BESOS platform.

3.1 Case 1: Modeling of remote communities

This first case is based on an academic research developed on the BESOS platform. Remote communities are at the forefront of the climate change and often deal with energy poverty. This energy poverty translates to negative outcomes and less opportunities for these communities to flourish. Renewable energy coupled with storage could provide a solution to these issues. We have pursued research to help these off-grid communities replace fossil fuel generators with photovoltaic panels and lithium ion storage systems.

BESOS is used to couple building modeling on remote communities to size renewable energy generation and storage. Building modeling makes use of EnergyPlus simulations based on a residential house archetype taking into account local weather conditions. This load is coupled into an EnergyHub, a mixed integer linear energy optimization framework, to find the optimal size of storage and photovoltaic panels. The work on this project has been presented at building simulation conference in Rome 2019[11] and will be published in a forthcoming paper.

BESOS allowed for ease of setting up the scenario matrix, coupling together EnergyPlus with the EnergyHub and running the model. Furthermore, JN using Python libraries pandas and matplotlib support analysis of input data and results. The input data and results from this work are analyzed by tabling the data and constructing high quality visualizations in line with the methods.

3.2 Case 2: STEP Code new build electricity use estimation application for HES PV

Two new recent developments, the BC Building STEP Code combined with BC hydro's new net metering requirements led to a collaboration between the Energy in Cities group and a local PV company HES PV. The local utility BC-Hydro introduced new net-metering plan restrictions requiring buildings in the plan to produce no more electricity than they consume over the course of a year. Before a PV system is installed under this net-metering program, applicants provide an estimate of their yearly electricity use by submitting the electricity bill from previous year, or for new construction based on a calculation of a

[11] Azin Rahimzadeh, Ralph Evins "The Effect of Fuel and Storage System Price on the Economic Analysis of Off-grid Renewable Energy Systems" *Proceedings of Building Simulation 2019: 16th Conference of IBPSA*

typical building. BC step code changes this paradigm of a typical building as new constructions are subjected to more stringent energy requirements and therefore use less electricity.

We developed a modeling tool to estimate electricity use at the design stage for new residential buildings. These estimates are used to justify PV array size to BC Hydro for approval. The tool was developed on BESOS to allow HES-PV to streamline and refine these estimates for the BC hydro application and improves the company's ability to efficiently and effectively deliver PV solutions to their clients. BESOS JN allowed for quick development of the underlying software and calculations. Moreover, an interface was quickly built using ipywidgets for ease of use of the application by HES PV.

3.3 Case 3: Clustering Energy Signatures to Identify Characteristics of a Building Stock

This case is based on an academic research developed on the BESOS platform[12]. We developed a method to extract thermal characteristics of buildings using smart meter data and high-level outside air temperature data only. We applied clustering methods, including dynamic time warping (DTW), to group buildings by their energy signature (a visual representation of the dependency of energy consumption on outside air temperatures) and we showed that the resulting groups help to differentiate each building by type (apartment or free-standing building) and heating system type. This research constitutes a first step toward a decision-tool to target buildings which must be priority for a retrofit in a building stock.

Three core features of BESOS were essential for the successful termination of the research:

- *Collaboration*. This research happened in close collaboration with a chair at ETH Zurich. A webhosted Jupyter environment allowed interacting smoothly. Especially, having access to running codes from multiple parts of the world, accelerated the research
- *Code base*. We could leverage existing methods implemented in the BESOS library to avoid "reinventing the wheel".
- *Publishing of codes*. By hosting our scripts on BESOS readers of the paper will have direct access to the research work stream and will be able to build upon our work.

4 The future of BESOS

The first version of the platform was launched in July 2019. All the member of Energy Systems and Sustainable Cities group currently work with BESOS.

The platform is maintained and will continue to be extended to respond to specific issues and feature requests, to better meet the needs of both current and future users. Envisioned features include new interfaces to facilitate the development as long as new modules to easily design interactive applications and tools. We also plan to enlarge machine learning possibilities to enable the use of these powerful tools.

Beside the development of the platform, we are continuing our research about optimal design and retrofit of buildings and energy systems to mitigate climate change and to take account of societal changes. We are always in search of opportunities to apply the results of our research to real test cases.

[12] Paul Westermann, Chirag Deb, Arno Schlueter, Ralph Evins "Clustering Energy Signatures to Identify Characteristics of a Building Stock" *submitted to Applied Energy*