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# Accelerating the energy retrofit of commercial buildings using a database of energy efficiency performance

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ABSTRACT

Small and medium-sized commercial buildings can be retrofitted to significantly reduce their energy use, however it is a huge challenge as owners usually lack of the expertise and resources to conduct detailed on-site energy audit to identify and evaluate cost-effective energy technologies. This study presents a DEEP (database of energy efficiency performance) that provides a direct resource for quick retrofit analysis of commercial buildings. DEEP, compiled from the results of about ten million EnergyPlus simulations, enables an easy screening of ECMs (energy conservation measures) and retrofit analysis. The simulations utilize prototype models representative of small and mid-size offices and retails in California climates. In the formulation of DEEP, large scale EnergyPlus simulations were conducted on high performance computing clusters to evaluate hundreds of individual and packaged ECMs covering envelope, lighting, heating, ventilation, air-conditioning, plug-loads, and service hot water. The architecture and simulation environment to create DEEP is flexible and can expand to cover additional building types, additional climates, and new ECMs. In this study DEEP is integrated into a web-based retrofit toolkit, the Commercial Building Energy Saver, which provides a platform for energy retrofit decision making by querying DEEP and unearthing recommended ECMs, their estimated energy savings and financial payback.



## 1. Introduction

Buildings consume 40% of the total primary energy in the United States [1]. Small and medium commercial buildings smaller than 50,000 $ft^2$ (4647 $m^2$) represent 95% of the number of commercial buildings, and consume 47% of the total energy of the commercial buildings excluding malls [2]. Energy efficient technologies can reduce energy use in buildings, save money, and mitigate the environmental impacts of energy use such as global climate change. More than 45% savings can be realized in small and medium commercial buildings from cost effective retrofits [2]. To improve building energy efficiency, governmental retrofit guidelines and utility incentive programs promote retrofit activities in the buildings sector. However, it is not easy for building owners and energy managers to obtain tangible information on the applicability of retrofit technologies, nor how much energy or cost can be saved. Although a wide range of technologies are readily available, Ma et al. pointed out that the main challenge still lies in how to identify the most effective retrofit measures to meet building owner's investment criteria [3].

Many building owners of large commercial buildings use ESCOs (Energy Service Companies) to conduct energy audits to identify effective energy retrofit and management strategies. Energy audits provide a summary of potential retrofit measures or operational improvements coupled with building energy performance evaluations, to improve energy efficiency. Detailed energy audits often involve elaborate data collection over long time durations, the development and calibration of an energy model, and iterative simulations for detailed analysis [4].

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Beyond energy audits, data-driven analytics enable energy retrofits to help operational improvements. The data-driven approach, powered by measured energy use data at short time intervals, enriches analysis for energy profiling and diagnostics. For example, the 5-min interval data of chiller power was used to detect cycling of chillers which would not be possible using hourly or larger interval data. Smart meters are adopted rapidly, and use of the interval electric use data fills information gaps to inform operational energy saving strategies that cannot be realized with the simulation-based retrofit analysis [5].

Unique engineering expertise is required to characterize building equipment and systems for the development and configuration of simulation models, which can require days or weeks of work depending upon model complexity and the amount of parametric simulations. Building owners and stakeholders of SMBs (small and medium-sized buildings) usually lack the resources to conduct detailed retrofit analysis. Instead they tend to rely on simple assessments, using rule-of-thumb calculations for retrofit energy and cost savings. Although initially inexpensive, this approach lacks accuracy, resulting in retrofit strategies for isolated measures without consideration of interactive effects between measures. Therefore, the potential energy savings or economic benefits may not be maximized [6].

Alternatively, a large set of packaged simulations performed by experts will provide an easy and authentic solution for quick retrofit analysis [7]. Although a pre-simulated approach comes with limitations, such as the use of prototypes to represent actual buildings which may not match the actual geometry of the buildings, it provides an immediate and reliable energy assessment. In the last five years, some of the pre-simulated databases developed include the U.S. DOE (Department of Energy)'s 179D easy calculator [8], Energy Impact Illinois' EnCompass [9], DEER (Database for Energy Efficient Resources) (CEC 2014c), and LBNL (Lawrence Berkeley National Laboratory)'s COMBAT (Commercial Building Analysis Tool) for Energy-Efficiency Retrofit [10]. The DOE's 179D energy calculator supports the tax deduction program Section 179D Energy Policy Act [11] and determines tax deduction eligibility for energy efficiency improvements to commercial buildings. Pre-simulated data are used to determine partial and interim compliance and to avoid high costs associated with simulations. EnCompass searches 278,000 energy models of large Chicago office buildings to find a best-fit baseline energy model from the pre-simulated database, and presents the energy data with energy saving opportunities and retrofit recommendations. DEER provides a list of retrofit recommendations and associated energy savings. Using batch mode analysis, data from roughly 65,000 eQuest pre-simulation runs integrates retrofit measures with a subset of the California commercial buildings. COMBAT uses prototype building models for different commercial building types in China. The prototype models using EnergyPlus were applied to a large number of ECMs (energy conservation measures) in major Chinese cities, creating a pre-simulated database. Recent advances in computing environments have enabled the execution of large scale building energy simulations for database creation, considering various energy-related analysis including model calibration, energy optimization, and zero-energy building design. Typically building owners and facility managers use the pre-simulated databases to screen potential measures as a starting point of retrofit.

HPC (High performance computing) brings new opportunities to accelerate energy retrofit assessment of commercial buildings through the development of database creation comprised of energy efficiency performance parameters derived from simulations. Existing retrofit tools allow for parametric runs to explore alternative design options. The OpenStudio PAT (Parametric Analysis Tool) [12] and jEPlus [13] provide a parametric shell to define parameter values for different design options and call EnergyPlus to conduct multiple, automated simulations. EnergyPlus, with OpenStudio SDK (Software Development Kit) and PAT, is well suited for large-scale, whole building energy simulations in an HPC environment. OpenStudio SDK enables effective EnergyPlus simulations by applying ECMs from a BCL (Building Component Library). PAT conducts cloud-based simulations of multiple OpenStudio models that are parametrically related to a baseline model. Hale et al. described a cloud-based energy simulation method that uses OpenStudio for model calibration in parallel computing using the Amazon Elastic Computer Cloud service [14]. This method highlighted multi-nodal computing architecture for model parameterizations used for calibration, which can potentially recommend combinations of retrofit energy saving measures with the calibrated model. Naboni et al. identified an open-source and cloud-based service that can be applied in architectural and engineering practices, spreading the use of parametric energy simulation [15]. A parametric shell for EnergyPlus, jEPlus handles simulation jobs executed on the VENUS-C cloud infrastructure VENUS-C (Virtual multidisciplinary EnviroNments Using Cloud infrastructures) provides a scalable and flexible virtual infrastructure empowering easy deployment [16]. The use of the cloud-based HPC reduces the computational time for parametric simulations allowing for evaluation of many more measures and their integrative effect, thus contributing to a potentially higher degree of building energy savings, relative to conventional design processes. The input to EnergyPlus can often extend to the order of a few thousand parameters that have to be calibrated manually by an expert for realistic energy modeling. This makes the process challenging and expensive thereby making building energy modeling sometimes unfeasible for smaller projects. Auto-tune research employs machine-learning algorithms to generate energy models for the different kinds of standard reference buildings in the U.S. building stock. Sanyal et al. explored the computational challenge of using supercomputers to conduct millions of EnergyPlus simulations on supercomputers that were subsequently used to train machine learning algorithms to generate parametric space and the variety of building locations and types [17].

There are other ways of conducting massive simulations using distributed computing resources such as HTCondor and CometCloud that facilitate task processing. HTC (High-throughput computing) Condor is widely used by researchers to employ the full potential of distributed computers for computational intensive tasks, such as simulations and calculations [18]. Condor is an open-source HTC workload management software for a cluster of distributed computer resources. As an example, the HTCondor system was used to optimize building energy design by exploring the computing performance of distributed computing resources [19]. Another use demonstrated by Tian and de Wilde was HTC using the Condor software package to evaluate building thermal energy performance, and they conducted simulations of many independent EnergyPlus models under probabilistic climate conditions by harnessing the processing power of idle desktop computers [20]. CometCloud [21] is an autonomic computing engine based on the Comet [22] decentralized coordination substrate, and supports highly heterogeneous and dynamic cloud or grid infrastructures. Kim and Parashar enabled the integration of public/private clouds and autonomic cloudbursts to address extreme requirements such as heterogeneous and dynamic workloads and spikes in demands [21].

With these recent advancements in the computing environment, the execution of large scale simulations for database development provides users with new resources to conduct quick and reliable retrofit assessments. In an effort to promote retrofit activities, there is a strong and growing need for the systematic