

## **Development and Implementation of a Parametric Energy Tool for Building Owners**

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### **Abstract**

A building energy tool has been developed that allows users to investigate the interrelationship of multiple energy conservation measures at both macro and micro levels. The purpose of the tool is to help commercial building owners realize energy efficiency retrofit opportunities. The tool incorporates a backend database of EnergyPlus models, run parametrically using jEPlus. The tool allows users to visualize these results on the web, and matches a ‘best-fit’ baseline model and appropriate energy conservation measure (ECM) recommendations. The database of energy models and ECM’s are then paired with matching incentives and industry partners who can fund or implement the selected ECM’s.

This paper details the approach used to develop and implement the tool – i.e. running more than 300,000 parametric energy simulations using private and cloud computing clusters, extracting and post-processing simulation results, and developing the website for baseline surveying and visualization of proposed recommendations.

### **1 Introduction**

A building energy tool has been developed that allows users to investigate the interrelationship of multiple energy conservation measures at both macro and micro levels. The tool incorporates a backend database of potentially millions of individual energy models computed on an hourly basis and reporting on annual energy usage. The tool allows users to visualize these results in a series of easy-to-use web applets, placing the role of the energy modeller upfront, and giving the power to analyze and decipher the results to the owner. The tool matches a ‘best-fit’ baseline energy model drawing from industry publications specific to a particular building type and allows building owners to determine appropriate energy conservation measures (ECM’s) by filtering better performing models consistent with a user’s specifications. The database of energy models and corresponding ECM’s are then paired with matching incentives and industry partners who can design, fund or implement the recommendations, focusing specific and pointed advice at building owners.

The development workflow incorporates parametric analysis and a post-processing environment that allows standardized energy modeling outputs such as energy use intensity (EUI), peak heating and cooling loads, and carbon footprints to pair with real life implementation factors such as operational savings and incentives, build ability, capital cost. The goal of this tool is to stimulate the commercial building energy retrofit market for existing buildings by making the ECM evaluation process as straightforward and as flexible as possible in the initial stages of a property evaluation. The audience for this tool is primarily geared towards building owners and managers who require high-level guidance on the multitude of ECM’s possible and pair them with financial and technical experts who can assist with next steps. The tool covers two commercial office building types, one downtown high-rise typology, “Large Office Building” and one suburban office park typology, “Medium Office Building”.

This document details a specific example to demonstrate the implementation and functionality of the tool – i.e. running more than 300,000 parametric energy simulations using private and cloud computing clusters, extracting and post-processing simulation results, and developing the web applet for baseline surveying and visualization of proposed ECMs. In addition, this paper details how EnergyStar and Commercial Building Energy Consumption Survey (U.S. Energy Information Administration, 2003) data can integrate into the functionality of the tool.

## **2 Prototype Energy Models**

### ***Large & Medium Office Baseline Energy Models***

As the tool is focussed on existing buildings, a baseline energy model for this project was created in Energy Plus v6.0.0, by adapting the Department of Energy (DOE) Existing Commercial Reference Buildings Constructed before 1980 (U.S. Department of Energy, 2010) idf model. The modeled floor plate size and Energy Plus floor multipliers were then adapted to match average floor plate sizes for Large and Medium Office buildings as taken from the 2010 Experience Exchange Report (Building Owners and Managers Association International, 2010).

### ***Energy Modeling Definitions***

For both building types, the number of floors, envelope constructions, HVAC systems, operational schedules, set points and internal gains were adapted from the DOE Benchmark Reference building based on survey data taken from CBECS (U.S. Energy Information Administration, 2003), and the 2010 Experience Exchange Report (Building Owners and Managers Association International, 2010).

To organize the vast amount of energy modeling required for both building types, inputs were broken down into the following categories;

- **Primary Variables:** These variables include the addition and subtraction of EnergyPlus objects within the IDF file that cannot be automated through jEPlus (i.e. Changing Variable Air Volume to Constant Air Volume)
- **Secondary Variables:** These variables include EnergyPlus objects that can be easily adapted in jEPlus (i.e. Window SHGC)
- **Parameters:** These include the inputs that were varied under the secondary variables to account for different levels of performance. Poor, Code and High-Performing parameters were considered.

Input parameters were taken from manufacturer's literature, building energy codes, past design experience and technical guidance documents published by National Renewable Energy Laboratory (Leach et al. 2010) and Pacific North West Labs (Thornton et al, 2009)

## **3 Parametric Simulations**

Parametric simulations are run using the text-based idf editor for Energy Plus, an industry standard software platform developed by the U.S. Department of Energy. The pre-processing utility EP-Macro and open-source simulation automation tool jEPlus is used to run parametric analysis. A parameter tree with fifteen variables and a limited number of parameters are run on the Large & Medium Office Baseline Energy Models. These variables include high-level building properties such as air distribution systems, boiler and chiller plant efficiency curves, pump and fan efficiencies, lighting power densities (and radiant fractions) and envelope parameters. Parameters are grouped into three representative classes; Poor, Code and High-Performance. For final implementation of 300,000+ runs, a fourteen-day run requirement was

fulfilled by distributing simulations across a 96-core private cluster, and a 320-core cloud cluster in Northern California.

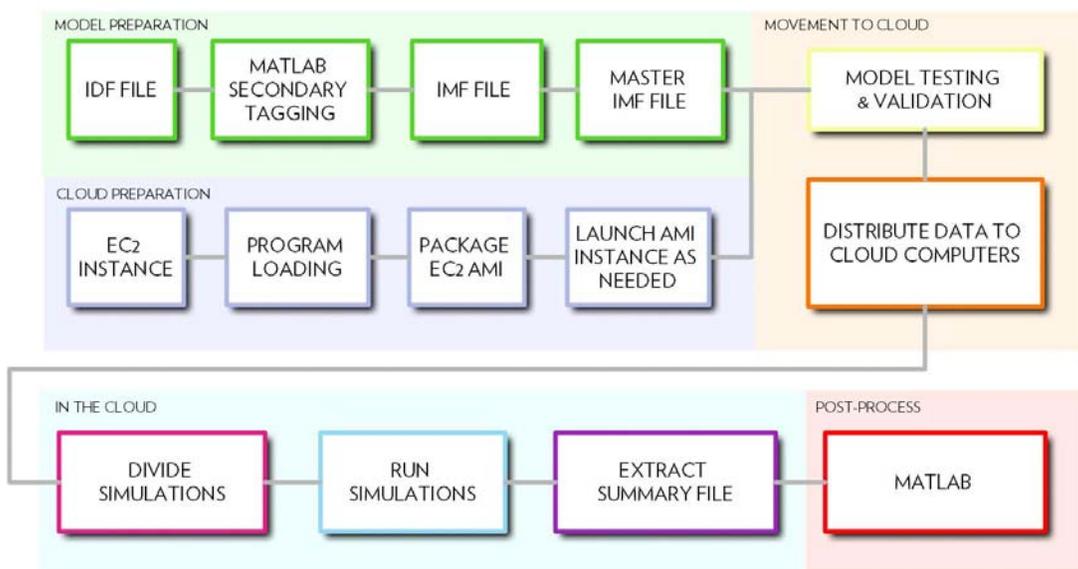


Figure 1: Simulation Process Flow Diagram

Table 1: Raw Hourly Data Output from Simulations  
(12 hours of one model is shown)

Date/Time	Electricity:Facility [J](Hourly)	Gas:Facility [J](Hourly)	InteriorLights:Electricity [J](Hourly)	InteriorEquipment:Electricity [J](Hourly)	Fans:Electricity [J](Hourly)	Cooling:Electricity [J](Hourly)
12/26 08:00:00	1,988,076,819	89,270,209	528,052,111	732,735,500	131,076,513	-
12/26 09:00:00	3,697,560,441	165,638,948	1,408,533,356	1,648,654,876	131,076,513	-
12/26 10:00:00	3,499,034,966	182,912,234	1,358,042,764	1,648,654,876	131,076,513	-
12/26 11:00:00	3,254,385,109	191,472,725	1,305,561,868	1,648,654,876	131,076,513	-
12/26 12:00:00	3,275,039,949	223,487,217	1,336,180,311	1,648,654,876	131,076,513	-
12/26 13:00:00	3,067,441,745	276,607,609	1,317,469,057	1,465,471,001	131,076,513	-
12/26 14:00:00	3,252,599,175	254,787,808	1,322,232,041	1,648,654,876	131,076,513	-
12/26 15:00:00	3,361,478,587	165,416,368	1,431,024,717	1,648,654,876	131,076,513	-
12/26 16:00:00	3,402,726,650	156,941,339	1,472,966,487	1,648,654,876	131,076,513	-
12/26 17:00:00	3,909,601,917	209,504,885	1,648,654,876	1,648,654,876	131,076,513	-
12/26 18:00:00	3,524,478,139	122,788,532	1,282,287,126	1,465,471,001	131,076,513	-
12/26 19:00:00	2,794,560,196	105,743,640	915,919,376	1,099,103,251	131,076,513	-

Table 1 shows raw data output from an EnergyPlus run compiled through jEPlus. It shows 12 hours from 1 day, where each row makes up one hour and each column is a different energy metric output. The final master spreadsheet from the 300,000+ models run includes more than 100,000,000 cells. As this volume of data requires moderate data storage, significant post processing of results data is required to establish useful performance metrics, such as total energy consumption and end use consumption, and to avoid costly online storage costs for cloud computing data transfer.

## 4 Post-Processing of Results

### Post-Processing of Results

Custom scripts were created in MATLAB to compile and post-process results. Specifically these scripts take the raw data output from jEPlus/Energy Plus (Table 1) and for each job extract summed values for annualized consumption, add certain values together for representation purposes (for example auxiliary equipment), and assign a specific model ID to each row. Each model ID is representative of one variable and parameter in the order of the simulation tree, as shown in Figure 2.

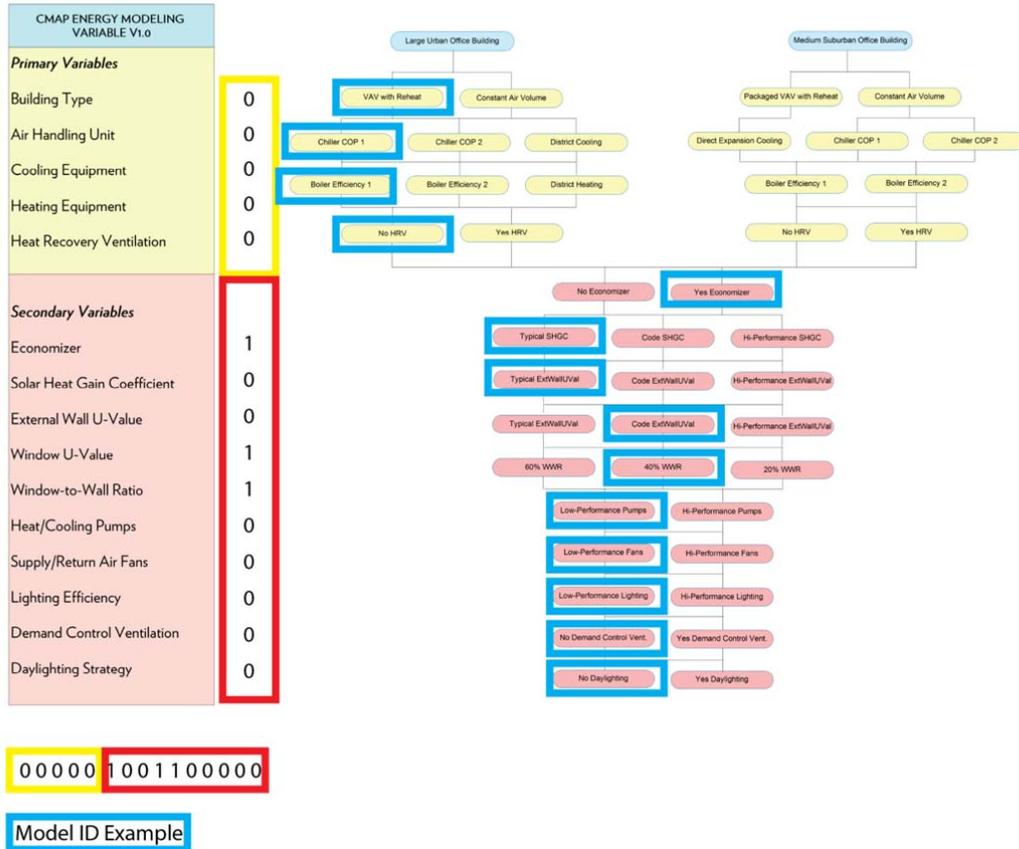


Figure 2: Variables & Parameter Breakdown – Model ID's match the order of Variables

Table 2: Post-Processed Resultant Matrix Sample  
(5000+ Rows Total all values in kBtu/sf)

Model ID	Total EUI	Lighting	Equipment	Cooling	Heating	Other	Auxiliary
000000000001000	61.6	11.3	15.9	10.0	7.3	5.2	11.9
000000000000000	61.6	11.3	15.9	10.0	7.3	5.2	11.9
000000000001010	61.5	11.3	15.9	9.8	7.5	5.2	11.8
000000000000010	61.5	11.3	15.9	9.8	7.5	5.2	11.8
00000010001000	61.4	11.3	15.9	10.0	7.1	5.2	11.9
000000010000000	61.4	11.3	15.9	10.0	7.1	5.2	11.9
000000010001010	61.3	11.3	15.9	9.8	7.3	5.2	11.8
00000010000010	61.3	11.3	15.9	9.8	7.3	5.2	11.8
000000020001000	61.2	11.3	15.9	9.9	7.0	5.2	11.9
000000020000000	61.2	11.3	15.9	9.9	7.0	5.2	11.9
000000020001010	61.2	11.3	15.9	9.8	7.2	5.2	11.8
000000020000010	61.2	11.3	15.9	9.8	7.2	5.2	11.8
000000000010000	61.0	11.3	15.9	10.0	7.3	5.2	11.3
000000000010010	60.9	11.3	15.9	9.8	7.5	5.2	11.2

## 5 User Input & Generation of Baseline

The first function of the tool is to generate a baseline, or a current representation of a building's energy use. The list of sorted post-processed models in Table 2 becomes a database for generation of baseline models (post-processed database) and subsequent recommendations of ECMs. A carefully designed survey vetted with large and medium office building owners extracts relevant information from the building owner. As the owner proceeds through the survey (Figure 3), a baseline model is dynamically matched to one row (one model) in the post-processed database.

Each answer in the survey is tagged with a specific value in the model ID. For example, if the user answers 'YES' to air-side economizer presence, the baseline model ID value for economizers (position 6) is marked as one. Additionally, an accuracy point is added to the total points answered, and a final accuracy percentage is determined by dividing the number of answered questions by the total number of questions. Results of baseline generation from MATLAB can be seen in Figure 4.

Figure 3. Building Owner Survey Functioning GUI

Baseline Index: 000001001100000      Air-Side Economizers ON – Position 6  
 Percent Accuracy: 88  
 Baseline Successfully Generated

Figure 4: Raw MATLAB GUI Output for Baseline Generation

## 6 Selection of Recommendations

Once a baseline model is matched to a model ID in the post-processed database, a set of recommendations to lower the building's energy use intensity are proposed. Since the model ID rows can be sorted in descending order by their EUI, the first step disregards all rows above the matched baseline row, as the higher EUI rows do not form part of an ECM recommendation.

The GUI backend allows users to select their ECM's via a survey checklist (Figure 3). The code scans the model ID of each row and disregards all rows other than the model ID values enabled by the recommendation checklist. This leaves a subset of rows that have model ID values changing specific to enabled ECM's, and as the list descends, energy use intensity decreases. Each change in model ID value correlates to a physical recommendation depending on character position. Results of recommendation selection and model ID filtering can be seen in Table 3 below.

**Table 3: Baseline Result and Proposed Pump, Lighting & Window Recommendations**

BASELINE		All units in kBtu/SF						
Model ID	Upgrade Strategy	Total EUI	Lighting	Equipment	Cooling	Heating	Other	Auxiliary
000000001100000	-	60.3	11.3	15.9	8.5	9.7	5.2	9.7
RECOMMENDATIONS		All units in kBtu/SF						
Model ID	Upgrade Strategy	Total EUI	Lighting	Equipment	Cooling	Heating	Other	Auxiliary
000000001110000	Pumps	59.8	11.3	15.9	8.5	9.7	5.2	9.2
000000002100000	Windows	59.3	11.3	15.9	8.6	8.6	5.2	9.7
000000002110000	Windows, Pumps	58.7	11.3	15.9	8.6	8.6	5.2	9.1
000000001100100	Lighting	57.9	9.2	15.9	8.3	9.8	5.2	9.4
000000001110100	Lighting, Pumps	57.3	9.2	15.9	8.3	9.8	5.2	8.9
000000002100100	Lighting, Windows	55.9	9.2	15.9	8.3	7.9	5.2	9.3
000000002110100	Lighting, Windows, Pumps	55.4	9.2	15.9	8.3	7.9	5.2	8.8

- Potential to be grouped as 'electricity'

## 7 Matching of Financial Incentives & Retrofit Partners

The final step of the tool is to match specific incentives and partners to the suggested recommendations. This needs to be completed in a dynamic fashion, as the incentive and partner matching will change dependent upon the baseline selected. A separate dataset of incentives and retrofit partners was built which included relevant criteria for each program. Each row of the incentives/partner database was also tagged with key words that relate to the proposed ECM's (primary and secondary variables).

## 8 Use of Cloud Computing for Simulation Scaling

Cloud computing describes a new delivery model for IT services, and typically involves the provision of dynamically scalable and virtualized resources as a service instead of using software or storage on local PCs, servers and networks. It is a by-product of easy access to remote computing sites provided by the Internet and the ubiquitous availability of high bandwidth.

Clouds have five essential characteristics: on-demand, web-based, self-service; broad network access from any location; resource pooling; rapid elasticity; and measured (pay per use) service. The majority of cloud computing infrastructure consists of data center resources enabled by a new class of software that manages application deployment across a virtualized infrastructure.

Cloud computing may allow a large number of energy simulations to be completed in a cost and time sensitive manner. Instead of purchasing hardware, all capital expenditures can be put towards running simulations. In addition, the cloud allows flexibility and scalability that cannot be seen with in-house computing solutions.

In a cloud infrastructure, multiple types of computers (or instances) can be selected depending on a user's needs. An evaluation was performed to determine an appropriate instance type for parametric EnergyPlus modeling. In preliminary testing on standard office desktop computers, a complete simulation time of approximately 16 minutes was recorded for a test file. Multiple Windows cloud instances were started using the Amazon Web Services Elastic Compute Cloud (EC2) infrastructure with Energy Plus and JEPlus installed. The control EnergyPlus input file was loaded on each instance and run for a single simulation and nine simulations, with runtimes recorded. Results from the test along with projected run times for the entire 300,000 models are shown in Table 4. It was determined for the test run that the High CPU Extra Large instance provided the highest performance for the lowest cost.

**Table 4. Cloud Computing Experiment to Determine Appropriate Computing Instance**

Instance Type	Cores	ECUs*	Number of Simulations: 315000			For 1 Computer		For 40 Computers	
			Single Runtime (Min)	Cost/Hour	Runtime Hours	Cost	Runtime Days	Runtime Days	
Baseline Desktop Computer	8	24	16.33	-	15750	-	656	16	
Standard Small	1	1	52.00	0.12	273000	\$32,760	11375	284	
Standard Large	2	4	24.80	0.48	65100	\$31,248	2713	68	
High CPU Medium	2	5	21.37	0.29	56096	\$16,268	2337	58	
High Memory Extra Large	2	6.5	14.68	0.62	38535	\$23,892	1606	40	
Standard Extra Large	4	8	22.30	0.96	29269	\$28,098	1220	30	
High Memory 2x Extra Large	4	13	14.35	1.24	18834	\$23,355	785	20	
High CPU Extra Large	8	20	18.95	1.16	12436	\$14,426	518	13	
High Memory 4x Extra Large	8	26	14.45	2.48	9483	\$23,517	395	10	

\*Elastic Compute Units (Cores X Processor Speed)

## 9 CBECS & Energy Star Integration

The Energy Star Target Finder website was queried for the target region to establish the CBECS and Energy Star EUI values for the two different building types targeted by the tool, Medium Office and Large Office. Building characteristics were taken from the BOMA Experience Report (Building Owners and Managers Association International, 2010). CBECS and Energy Star EUI's were extracted from Target Finder in increments of 1,000 sf. This data was used for comparing selected energy model EUI's against industry baseline (U.S. Energy Information Administration, 2003) and best practice performance as taken from the Target Finder service (U.S. Environmental Protection Agency, 2011).

## 10 Conclusions

Through evaluation of existing energy simulation tools, parametric modeling tools, scripting software, and available energy efficiency incentive programs the authors have identified a process that may be applied to generate a large database of energy models to represent a number of building typologies. This database can then be visualized in an online interface that allows a non-technical audience to access detailed energy modeling simulation data and "pick and choose" ECM's that match with corresponding incentives and technical and financial partners to implement the ECM's. By placing the energy model output data in a flexible and adaptable format in the hands of the client, the results of energy modeling gain a potentially more valuable life in the hands of the user.

## **11 Acknowledgements**

This process relies heavily on existing simulation tools including Energy Plus, JEPlus and existing Commercial Energy Model Benchmark files available from the Department of Energy website.

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