Portfolio-Scale Optimization of Customer Energy Efficiency Incentive and Marketing

Cooperative Research and Development Final Report

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Cooperative Research and Development Final Report

In accordance with Requirements set forth in Article XI, A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: National Grid USA Service Company, Inc.

CRADA Number: CRD-13-535

CRADA Title: Portfolio-Scale Optimization of Customer Energy Efficiency Incentive and Marketing

Joint Work Statement Funding Table Showing DOE Commitment:

Estimated Costs	NREL Shared Resources
Year 1	$150,000.00
TOTALS	$150,000.00

Abstract of CRADA Work:

North East utility National Grid (NGrid) is developing a portfolio-scale application of OpenStudio designed to optimize incentive and marketing expenditures for their energy efficiency (EE) programs. NGrid wishes to leverage a combination of geographic information systems (GIS), public records, customer data, and content from the Building Component Library (BCL) to form a JavaScript Object Notation (JSON) input file that is consumed by an OpenStudio-based expert system for automated model generation. A baseline model for each customer building will be automatically tuned using electricity and gas consumption data, and a set of energy conservation measures (ECMs) associated with each NGrid incentive program will be applied to the model. The simulated energy performance and return on investment (ROI) will be compared with customer hurdle rates and available incentives to: A) optimize the incentive required to overcome the customer hurdle rate; and B) determine if marketing activity associated with the specific ECM is warranted for that particular customer. Repeated across their portfolio, this process will enable NGrid to substantially optimize their marketing and incentive expenditures, targeting those customers that will likely adopt and benefit from specific EE programs.

Summary of Research Results:

Staff in the NREL commercial buildings group and NGrid's analytics team successfully collaborated to build an OpenStudio-based system called COFFEE (Customer Optimization For Furthering Energy Efficiency). COFFEE leveraged OpenStudio's ability to articulate detailed EnergyPlus building energy models from limited input data, perform optimization-based calibration against monthly utility bills, and evaluate the performance of multiple energy conservation measures (ECMs) using commodity cloud computing resources such as Amazon's Elastic Compute Cloud (EC2) as shown in Figure 1.

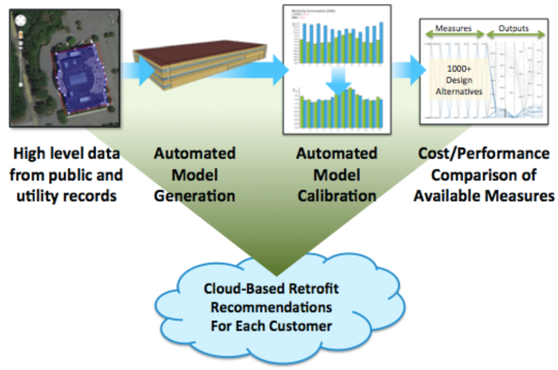

Figure 1: COFFEE Concept

Figure 2 illustrates the functional decomposition of the overall software system. Databases shown in gray are related to NGrid-specific enterprise systems, whereas the Building Component Library (BCL) shown in green is a publicly available source of "OpenStudio Measures" content. OpenStudio Measures are small self-contained scripts that can be chained together to construct or modify energy models. In the context of COFFEE, a combination of public and NGrid-specific/private Measures were used to:

- Construct the initial model, referred to as "Model 0" (red)
- Modify Model 0 via optimization to calibrate against utility data (orange)
- Apply a wide range of NGrid-specific ECMs to the calibrated model (light blue)

Financial analysis for specific customer assessment (dark blue) was performed as a post-processing activity. This was developed separately by NGrid and was not integrated into the automated system during the CRADA period of performance.

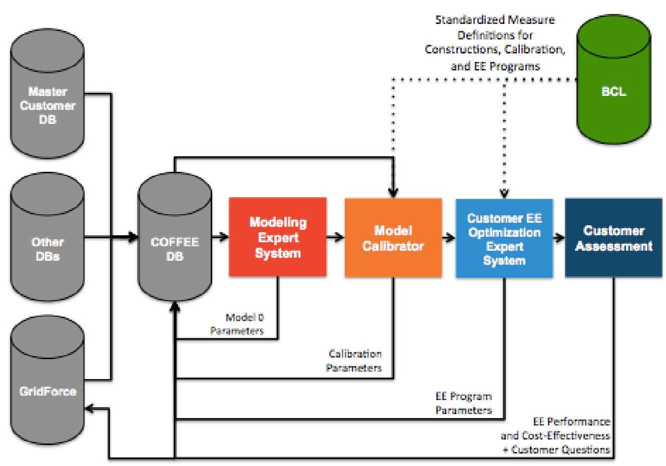

Figure 2: COFFEE Software Functional Decomposition

Input data used for the process included:

- NGrid customer data
- Consumption data
- Previously installed ECMs identified by NGrid's "In-Demand" tracking system

- Public tax records
- Actual and Typical Meteorological (AMY/TMY) data
- ECM market pricing information

The Model 0 “expert system” combined customer-specific information including North American Industry Classification System (NAICS) code for building type, vintage, square footage, and number of floors with reference data sets that included construction, load, occupancy, and schedule definitions from the Department of Energy reference building models These data sets were expanded to support building types not considered by the 16 reference building archetypes (e.g. funeral homes, movie theaters, etc.). HVAC systems were inferred from a set of ASHRAE 90.1 Appendix G systems based on building type and vintage. Finally the model was updated with any ECMs that had previously been identified via NGrid’s In-Demand system. Figures 3-5 illustrate diversity in Model 0 results produced by the expert system for three NGrid customers. Details related to building geometry, fenestration, space-type allocations, HVAC systems, and energy end-uses breakdowns are specific to each building.

Figure 3: Model 0 Results for a Small Retail Customer

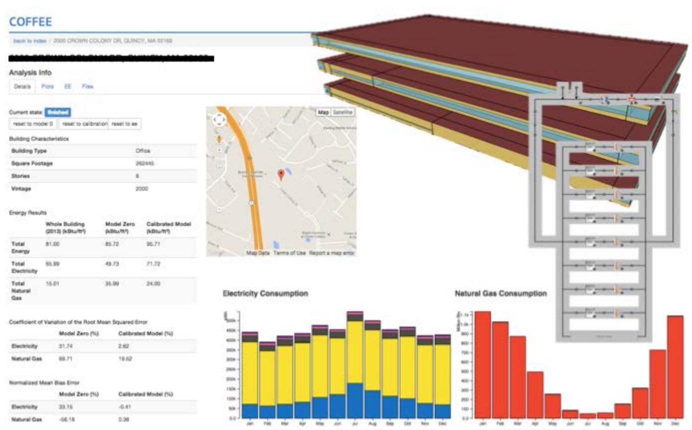

Figure 4: Model 0 Results for a Large Office Customer

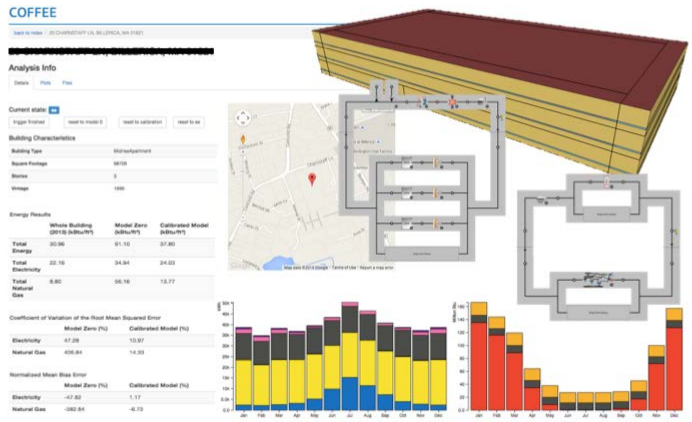

Figure 5: Model 0 Results for a Mid-Rise Apartment Customer

Automated calibration of Model 0 against monthly consumption data utilized an optimization algorithm that combined genetic and gradient methods[1]. ASHRAE guideline 14 for energy modeling was initially used to define the objective function and tolerances for optimization. Guideline 14 calls for +-5% net mean bias error and less than 15% coefficient of variation in root mean squared error against consumption data, although NGrid elected to relax these tolerances to reduce compute time while still producing acceptable solutions. Free model parameters used in the calibration process included:

- Space type ratios
- Adjust infiltration rate
- Hours of operation:
  - Adjust Length
  - Shift
- Adjust load multipliers:
  - Occupancy
  - Ventilation
  - Lighting
- Adjust equipment multipliers:
  - Electric equipment
  - Cooling coil and chiller COPs
  - Fan efficiency and pressure rise
  - Gas equipment and burner efficiency
  - Water use

Figure 6 illustrates typical calibration results for electricity and gas consumption of the mid-rise apartment example above.

[1] https://cran.r-project.org/web/packages/rgenoud/index.html

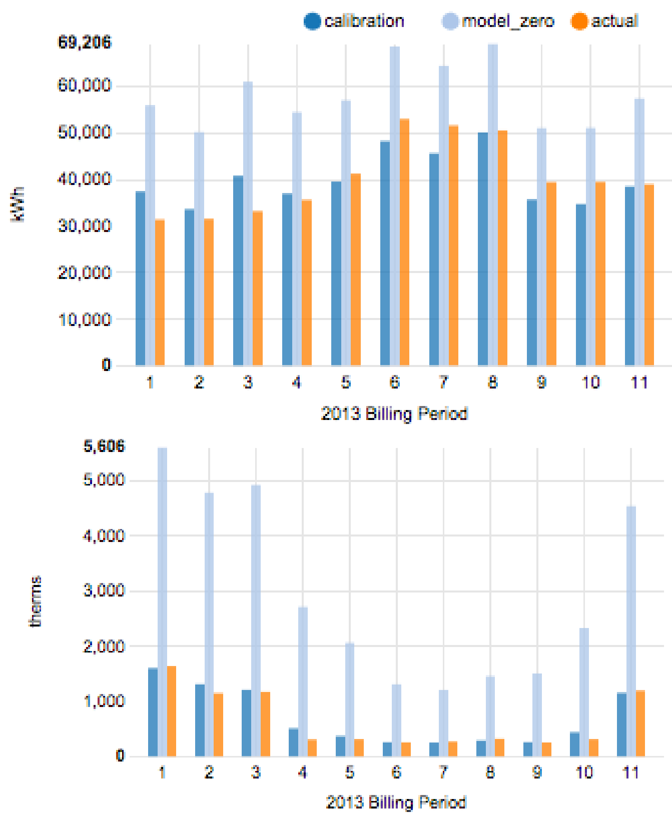

Figure 6: Comparison of Modeled Predictions with Electric and Gas Consumption Data for Mid-Rise Apartment Example

Figure 7 contains tables for this same building that summarizes model performance relative to available consumption data.

Energy Results

	Whole Building (2013) (kBtu/ft^2)	Model Zero (kBtu/ft^2)	Calibrated Model (kBtu/ft^2)
Total Energy	30.96	91.10	37.80
Total Electricity	22.16	34.94	24.03
Total Natural Gas	8.80	56.16	13.77

Coefficient of Variation of the Root Mean Squared Error

	Model Zero (%)	Calibrated Model (%)
Electricity	47.28	10.97
Natural Gas	406.84	14.33

Normalized Mean Bias Error

	Model Zero (%)	Calibrated Model (%)
Electricity	-47.82	1.17
Natural Gas	-382.84	-6.73

Figure 7: Modeled and Measured Comparison Tables Produced by COFFEE

NGrid identified 7 ECM "families" for analysis. These encompassed 87% of NGrid's incentive products, and included:

- Single package and split system unitary air conditioners
- Dual enthalpy economizer controls
- Electronically commutated fan motors
- Demand controlled ventilation
- Programmable thermostats
- Lighting system retrofits
- Lighting controls

While some of these ECMs were either applied or not (e.g. demand controlled ventilation), others had multiple options (e.g. single package and split system unitary air conditioners, which had four possible configurations). NGrid elected to generate a full design of experiments to capture every possible combination of ECMs, resulting in just over 1,100 derivative models per customer. Figure 8 shows these combinations via one of COFFEE's built in visualizations, an interactive parallel coordinate plot.

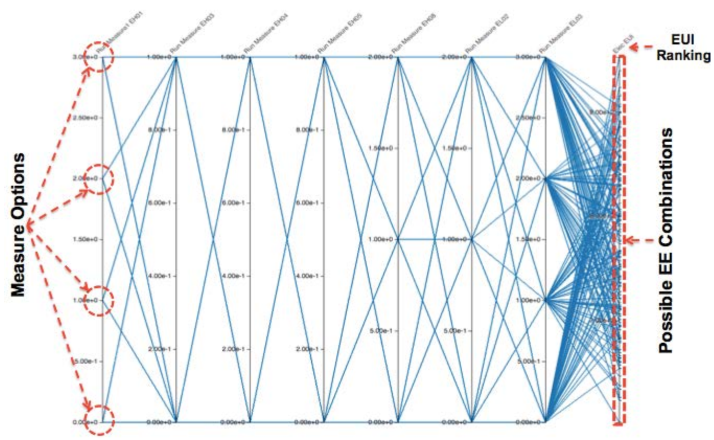

Figure 8: Parallel Coordinate Plot Depicting All Possible Retrofit Alternatives for a Customer Building

While COFFEE does provide some rudimentary tools to navigate the modeled portfolio and associated analysis results, its real purpose is to populate an analysis database that can be accessed by sales tools or other enterprise systems[2]. To that end, ECM analysis results are stored in a COFFEE NoSQL database along with the OpenStudio Measure "recipe" for reconstructing Model 0 and the calibrated model. Archiving the various models and design alternatives as references to combinations of model construction, calibration, and efficiency measures rather than discrete energy models allows for the degree of data compression that is required for COFFEE to ultimately scale to NGrid's entire service territory.

COFFEE was deployed on Amazon EC-2 in late spring of 2015, operating on a population of buildings in NGrid's Massachusetts service territory. Figure 9 shows a screenshot of the

[2] The final step in the COFFEE process, financial assessment of ECM combinations to produce ranked, recommended bundles for each customer was implemented as a post-processing system by NGrid staff. Since NREL staff were not involved in this part of the workflow, it is not within the scope of this report.

COFFEE web interface near the completion of this initial demonstration. The interactive dashboard summarizes progress broken down by analysis phase and building types. Clicking on different categories allows the user to inspect all buildings that sit in a particular analysis queue (e.g. Model 0 results that are awaiting calibration). Some rudimentary searching, sorting, reporting, and visualization capabilities were implemented in the web interface to enable development and debugging of COFFEE.

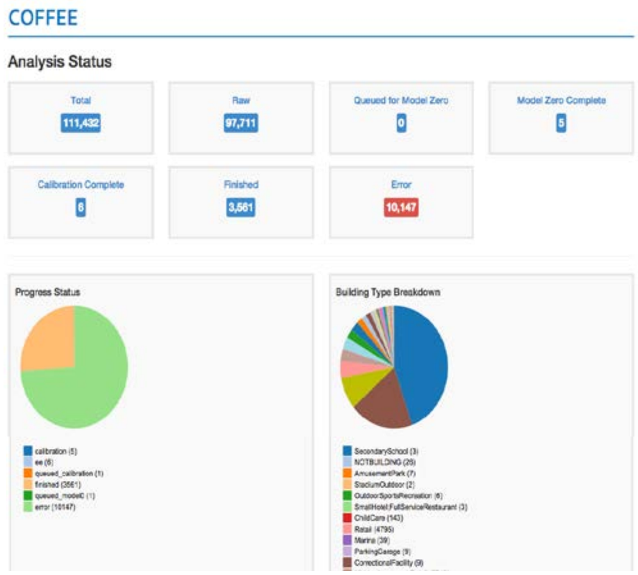

Figure 9: COFFEE Main Web Interface

Nearly 3,600 buildings were processed during this initial deployment that used on average 24 EC-2 nodes with 32 cores per node. Model 0 processing required 2-3 minutes, calibration took 25-40 minutes, and ECM analysis lasted between 70-115 minutes per building. This equated to around $10-20 of CPU time for each building analyzed.

Buildings in the overall population were either not processed or “errored out” due to a number of factors. These included:

- Invalid addresses or inactive customer account
- Incomplete customer data record
- Invalid NAICS code (e.g. NA, NotABuilding, Amusement Park, etc.)
- Missing or incomplete consumption data (e.g. customer turnover, or customer outside of NGrid gas franchise)

Opportunities to improve COFFEE include:

- Methods to proxy missing or incomplete data
- More robust error reporting and handling
- Queuing system improvements to further reduce human interaction with the system
- Integration of financial analysis with the cloud service for greater scalability and database coherence
- Development and deployment of a user interface to communicate customer opportunities and gather additional intelligence that can refine Model 0

As of this writing, NGrid staff are extending the population to Rhode Island and making additional improvements to COFFEE. NREL has granted an exclusive license for the COFFEE source code to National Grid. COFFEE-specific Measure content and the COFFEE server code are not available publicly.

Subject Inventions Listing:

None

Report Date:

12/24/2015

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