Policy and Market Macro Modeling

Mid-Sized Offices in the GPIC Region

January 2012

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1 Introduction

A key objective of GPIC is to design more impactful policies that will affect the market uptake of energy efficient solutions that conform to the overall goal of the GPIC Hub. As such, a macro-modeling effort was undertaken to analyze and forecast the regional impact of policies and programs that might be put forward by GPIC's Policy, Market, and Behavior (PMB) and cross-task researchers.

A Policy and Market Macro-Modeling collaborative working group was formed under PMB (Task 4) to create analytical methods and tools to quantify the effects of policies (inclusive of policies and programs implemented by government, utilities, financial institutions, and others), on the adoption of energy conservation measures in commercial buildings. The approach addresses a broad array of building owner decision factors that determine the uptake of such measures, and how those decision factors are affected by policies. The Group's initial focus was on conducting an assessment of the existing stock of Class A mid-sized office buildings in the GPIC area, which serves as an illustration of the capability and usefulness of policy models in the GPIC Hub and regional context.

This report describes the methodology developed by the Policy and Market Macro-Modeling working group, including:

- collection and synthesis of data for existing buildings within a submarket,
- reducing the population to a manageable number of representative buildings,
- specification of available energy conservation measures for buildings in the submarket,
- completion of whole building energy simulations, and
- application of a building stock model to compute energy efficient technology adoption levels and changes in energy consumption based on micro-economic investor stakeholder decisions.

The application of the methodology is demonstrated through an analysis of existing Class-A office buildings in the GPIC region, providing estimates of the uptake of energy efficiency measures in these buildings over a 40-year period and the impacts this has on energy consumption. The model allows these outputs to be generated under different scenarios, including business-as-usual and implementation of several potential policy options, such as incentives on equipment, modified energy pricing, and enhanced building codes. From these results, we can compare and contrast the effectiveness (or ineffectiveness) of policy options.

As a foundation-building activity, the analysis discussed in this report does not represent our final assessment of the Class A office building market, although some instructive findings are portrayed with respect to policy impacts. Using what was learned in applying the methodology, however, we are positioned to evaluate multiple building submarkets in the coming year.

2 Objective

The first year of macro-modeling work focused on developing a foundation of data, methods, and tools from which to launch analyses of policies and markets in the GPIC region. In support of this objective, the group concentrated on an initial assessment of the Class A mid-sized office buildings in the GPIC area, which represents a submarket that can illustrate the capability and usefulness of policy models in the GPIC Hub and regional context. In addition, the initial assessment would help identify any obstacles in implementing the approach, such as data availability. Therefore, one objective was to develop credible GPIC-HUB regional baseline market and building data statistics – from building stock to policy structures – using a variety of applicable methods from data mining to regional stakeholder workshops. Another objective was to map decision making methods, identify key adoption barriers, develop market asset value metrics, and quantify behavior characteristics' impact on energy efficient buildings uptake and operation. The first year focused on completing this work for the Class A mid-sized office segment and, in collaboration with GPIC researchers at Drexel and Penn, making estimates and approximations as necessary pending completion of data acquisition agreements and execution.

3 Baseline Characteristics of GPIC Class A Mid-Sized Office Building Stock

The GPIC Hub is focused on average-sized commercial and multi-family residential buildings.[1] In the first year's analysis, we approximated "average size" to fall between 20,000 and 100,000 ft^2. This range will be revisited as more information about the GPIC's building stock becomes available. To analyze these buildings within the GPIC region, the CoStar database of properties was acquired, which contains a comprehensive population listing of every commercial property, exclusive of certain government and multi-family residential properties. CoStar data is not sample data; it is the population of buildings for which it covers (e.g., commercial buildings). Within the GPIC region, 9,100 commercial buildings are in this range, representing a total of 400

[1] See Econsult Corporation. 2011. The Market for Commercial Property Energy Retrofits in the Philadelphia Region. GPIC Policy, Markets and Behavior Task Team.

million square feet of mostly small urban properties. From CoStar, Figure 1 shows how these buildings are spread geographically across the region, and Figure 2 shows the distribution of building square footage among different building types and building sizes. Offices account for 100 million square feet. Within this set are many different system configurations as well as ownership types. Analysis and simulation required clustering of the office sector into refined homogeneous subsets. To that end, the 100 million square feet were divided into Class A and non-Class A properties to reflect different ownership decision making criteria, and initially focused the analysis on Class A. Next, one must identify the characteristics of the existing stock of Class A mid-sized office buildings, which then serve as the baseline from which predictions of changes in the building stock are made at different points in the future. The data needed to conduct a simulation is not readily available from any single source, and in some cases a source for a particular piece of data does not currently exist. For example, CoStar does not contain energy related equipment or operating schedule information. The CBECS sample database does not contain sufficient granularity for analysis at or within the GPIC region. Consequently, the use of multiple data sources is required, and professional judgment must be applied to make estimates when necessary. As more data becomes available, it is possible to make comparisons between data sets to validate the data set that is used.

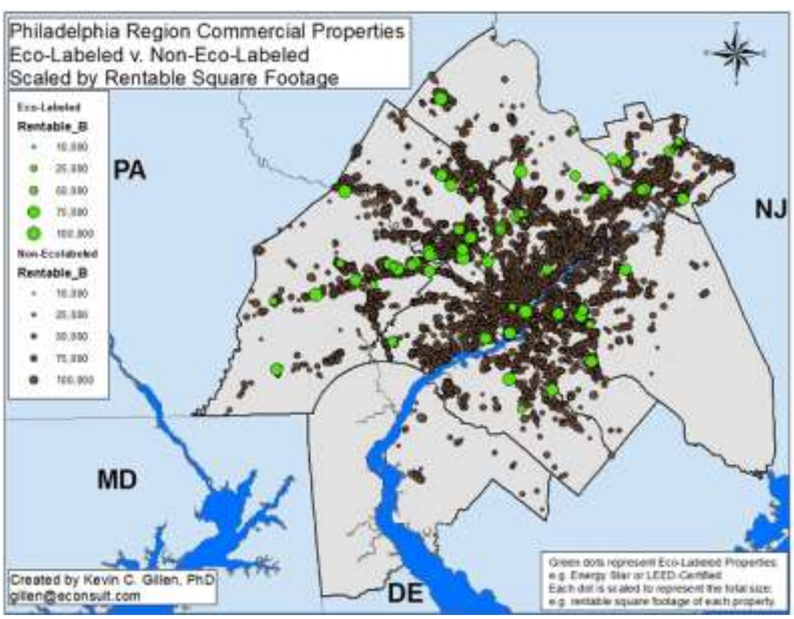

Figure 1. Commercial property locations in the GPIC region

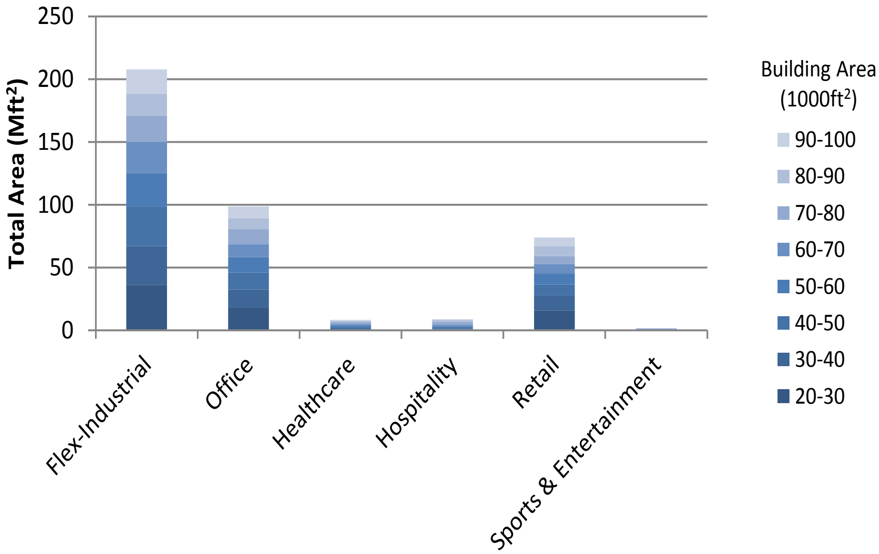

Figure 2. Distribution of total floorspace by building type

For this work, we relied primarily on CoStar for a listing of properties, ownership types, area and construction material characteristics. For all other information, we supplemented this with data collected by the U.S. Department of Energy (DOE) for its Commercial Buildings Energy Consumption Survey (CBECS), from which we formed representative but complete property-level information on the region's stock of commercial buildings between 20,000 and 100,000 square feet.

3.1 CoStar Group Data Set

The population data from CoStar identified 2,250 office buildings between 20,000 and 100,000 square feet in the GPIC region. As a check, this list compared precisely with tax record population data acquired for Montgomery County, one of the 13 counties in the GPIC region. Further such data checks will be completed as the project moves forward. We filtered this population further down to 1,512 office buildings with two to four floors. Of these, there were 451 Class A properties. These buildings are generally all 25,000 square feet per floor, incur an average of $7/ft^2 in operating expenses, and have all been renovated in the last 20 years. The differences among these buildings included the following:

- Tax rate $0 to $12/ft^2, average $4/ft^2
- Zero or two elevators
- Masonry or steel construction

- 20% have an atrium
- 20% have an on-site property manager
- 10% have added amenities (retail, bank, day care, etc.)

A histogram of buildings according to rentable building area revealed a unimodal distribution, with a mean of 60,000 square feet.

3.2 Commercial Buildings Energy Consumption Survey

The DOE's CBECS database contains sample based information on building energy related systems not found in other available databases (e.g., CoStar). There are several aspects of the CBECS data, however, that place certain limitations on its accuracy. First, the CBECS sample is meant to represent U.S. averages and is therefore not ideal for a regional filtered analysis. As more buildings are filtered, the error bars grow correspondingly. Professional judgment is necessary to assess the impacts of these error bars. Second, the CBECS sample data is becoming dated. The latest available data are from the 2003 CBECS. However, until a comparable CBECS survey is performed for the GPIC area, this is the best information available from the federal government.

Two data sets were extracted from the CBECS database:

- Set 1 - the Northeast census region intersected with mid-Atlantic climate zone and
- Set 2 - the East census region intersected with the mid-Atlantic climate zone.

Buildings in Set 1 are approximately within the GPIC area, but form a small sample. There are 77 office building samples, and of these 26 are between 20,000 and 100,000 square feet. Nine of the entries are two to four floors and privately owned. Buildings in Set 2 form a larger sample, yet have energy systems comparable to buildings in the GPIC area. There are 144 office building samples, with 41 of these between 20,000 and 100,000 square feet. This set is useful as a backup data set should Set 1 contain outliers.

The mid-sized offices were filtered to those with two to four floors. In general, roughly all such office buildings in this refined sample had gas heat, electric air conditioning systems, fluorescent lighting, thermostat controls and basic light switches, and plastic/rubber/synthetic sheeting roofs. The operating schedule was typically 7:00 a.m. to 7:00 p.m. Monday through Friday, and 9:00 a.m. to 2:00 p.m. on Saturday. Buildings differed, however, in the amount of window area

(20% or 60%), single- or double-pane tinted windows, the wall construction (brick or steel/concrete), and the HVAC equipment.

3.3 Reduction to Representative Building Typologies

Table 1 lists the nine mid-sized office buildings in the northeast mid-Atlantic that represent the filtered data set. These represent 5,800 buildings, of which 50% are small bank branch offices.

Table 1. Representative mid-sized office buildings

# Bldgs	Area (ft^2)	Principle Building Activity	Owner	Complex Type	Built	Owner Occupied	# Businesses	# Business Categories
81	65,000	Admin-prof office	Property mgmt company	Office complex	1990	No	3	3
869	26,000	Admin-prof office	Property mgmt company	Office complex	1962	Yes	1	2
81	95,000	Admin-prof office	Property mgmt company	Office complex	1985	No	1	2
2740	20,000	Bank-othr financial	Individual owner		1977	No	1	2
81	100,000	Bank-othr financial	Individual owner		1955	No	1	2
869	20,000	Mixed-use office	Othr corp-partnership	Office complex	1988	Yes	2	3
117	35,000	Mixed-use office	Othr corp-partnership	Office complex	1964	Yes	1	2
81	60,000	Mixed-use office	Othr corp-partnership		1958	Yes	12	5
869	22,000	Mixed-use office	Property mgmt company		1940	Yes	6	4

In terms of parameters related to energy consumption, the following characteristics were identified.

- Operating schedule: Information on the hours of operation for these nine buildings indicates that a weekday schedule of 7 a.m. to 7 p.m. and a weekend schedule of 9 a.m. to 1 p.m. on Saturday provides a reasonable representation.
- Occupancy: The number of workers for these nine buildings suggests that occupancy of 100 workers is fairly typical.
- Wall construction: An analysis of construction data identified two basic wall constructions - brick and steel/concrete.
- Roof construction: Rubber sheeting is the typical roof material.
- Fenestration: the two worst-case baseline window configurations were 20% of wall area, tinted single-pane and 60% of wall area, tinted single pane.
- Heating: Electricity and natural gas are the two main fuels for heating. We ignored the 3% of the population with steam heat, and there were no indications of oil as a fuel in this mid-sized Class A office property segment. The worst-case baseline equipment is gas or electric –resistance unit heaters and packaged unit ACs.

- Lighting: All nine buildings could be well represented with a single lighting configuration, consisting of fluorescent lighting, electronic ballasts, and no building management system (BMS) or occupancy sensors. The worst-case baseline lighting had no skylights and no daylighting.

Taking into consideration the CoStar data augmented with the CBECS data, nine statistical clusters were formed, each represented by a set of given characteristics, as shown in Table 2. These align with the same nine clusters of Table 1. Among these buildings, we defined two baseline building types for building simulation purposes. Baseline I buildings all have brick facades and 25% window area, whereas Baseline II buildings use a steel and concrete façade and have 60% window area. The first column lists the percent of the building stock represented by any particular buildings. Forty percent of the buildings have Baseline I construction while 60% are Baseline II.

Table 2. Characteristics of nine representative buildings to emulate the current stock

% Stock	Baseline	Window Type	Glass Percent	Awnings	Heating System	AC System	VAV	Econ-omizers	BMS	Usage
3%	I	Single	≤ 10	Yes	Gas Space heaters	Packaged AC units	No	No	No	Mixed-use office
16%	I	Double	11-25	Yes	Gas Packaged units	Packaged AC units	Yes	Yes	No	Admin-prof office
12%	I	Double	11-25	Yes	Gas + Heat pumps	Heat pumps for cooling	Yes	Yes	No	Mixed-use office
6%	I	Double	11-25	No	Gas Boilers inside	Central chillers inside	Yes	Yes	No	Bank-othr financial
3%	I	Double	≤ 10	No	District steam-HW	Central chillers inside	Yes	Yes	No	Mixed-use office
38%	II	Single	51-75	No	Gas Packaged units	Packaged AC units	No	No	No	Bank-othr financial
13%	II	Single	51-75	Yes	Gas Furnaces hot air	Resid-type central AC	No	No	No	Mixed-use office
4%	II	Double	51-75	No	Gas + Heat pumps	Heat pumps for cooling	No	No	Yes	Admin-prof office
5%	II	Single	51-75	No	Elec Space heaters	Packaged AC units	Yes	Yes	Yes	Admin-prof office

4 Modeling Approach

The model implemented for this project is based on modeling work developed by the World Business Council for Sustainable Development (WBCSD) to evaluate how different policy options could influence (or not) the uptake of energy efficiency measures in buildings. This helps identify the actions that would be required of industry, construction, financing, trade organizations and governments to significantly reduce energy consumption by buildings. To quantify these considerations, a model of how the building stock changes due to the micro-economic decisions of building owners and stakeholders was necessary. This differs from other broadly applied energy models (e.g., MARKAL, NEMS) in that it addresses not only the building sector end use, but also more realistically reflects the capital investment decisions than assuming complete adoption of all technologies with higher payback than others.

4.1 Model Structure

The model developed is a conglomeration of separate submodels, as shown in Figure 3. The three key submodels are (1) the building energy simulation (implementation described in Section 6), (2) the cost submodel, and (3) the decision-making submodel. For the set of energy conservation measures relevant to the Class A mid-sized office buildings, whole building energy simulation was used to technically assess the energy impact of adopting these measures individually or in combination on the building stock in the GPIC area (based on the nine representative building types). The cost submodel produces estimates of capital and operational costs for the different construction options. The decision-making submodel considers the costs of construction option packages (combinations of individual construction options) and corresponding energy consumption costs, compares these to a baseline, and applies an algorithm that represents the likely outcomes assuming a variety of stakeholders and range of stakeholder behaviors. The resulting changes in the building stock are computed at 5-year increments that are repeated until the end of the desired simulation period (e.g., 40 years) is reached.

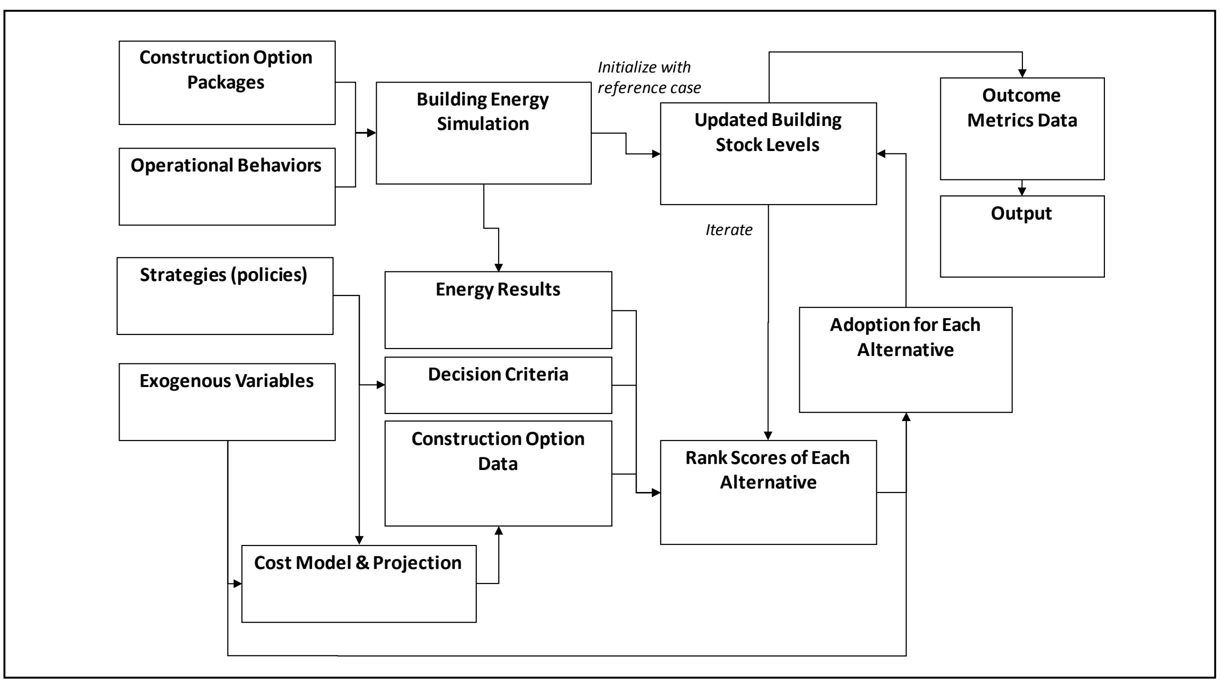

Figure 3. Model structure

4.2 Representation of Buildings and Energy Subsystems

The analysis operates on a submarket basis, which in this case is the mid-sized office submarket in the GPIC region. A homogenous set of buildings is needed for the analysis, in terms of provided service levels, to represent the building stock within the submarket. The model represents a building as 23 energy related subsystems and materials, including wall insulation, roof insulation, fenestration selections, lighting systems, daylighting levels, primary heating equipment, primary cooling equipment, thermal distribution systems, ventilation systems, passive thermal measures, renewable generation systems, etc. For each such subsystem, various technology options are defined with energy efficiency and first cost parameters. A building alternative is a selection of one technology option for each of the 23 energy related subsystems, defining a very large space of available building configurations.

The year 2010 was chosen as the baseline reference year, and a representative set of buildings was defined in terms of energy related subsystem selections. In the model, each building alternative has a (possibly zero) level of building stock.

Further, each energy-related subsystem has an age, from new to end of useful life. For example, most HVAC equipment has a useful life of 20 years. With this representation, every year a percentage of the building stock in the model is refurbished and decisions over new subsystems selections made. In addition, a fraction of the building stock is destroyed and removed from the stock model, and a fraction of new construction also occurs, adding new subsystems and building alternatives into the stock. These three modes of building stock change are used in the model, defining a year-over-year differential equation of the building stock. For the purposes of this study, we kept the building stock fixed to focus in on retrofits to existing buildings.

4.3 Micro-Economic Decision Submodel

The refurbished building stock is determined through a rank ordering of alternatives according to the micro-economic decisions of a modeled set of stakeholders. That is, each building alternative is simulated using a whole building energy simulation such as EnergyPlus (DOE 2010). These results provide the synergistic energy savings of different subsystem technology combinations for a building. The energy savings then provide a payback against the incremental first cost, where we also have a first cost model of materials and installation for each technology alternative. Using these figures, a rank ordering can be defined. This can substantially vary according to macro-economic conditions such as the price of energy, technology learning curves, and also due to government policy incentives or taxes. We further model the impact of building codes by eliminating from consideration alternatives that do not meet different building energy codes at different levels of code.

The micro-economic decision submodel accounts for the various stakeholders who influence capital equipment selection, depending on the decision dynamics of the submarket. This is represented by allowing different economic criteria to be the objective function and other decision criteria to be filtering constraints on the selection decision.

For example, owner-occupiers tend to make capital purchase decisions based on simple economic payback. Owners of owner-tenant buildings, however, do not, since they likely pay the first cost whereas the tenant would receive the benefit of lower monthly energy costs. In such arrangements, the link between an owner's decision over first costs and perceived benefits is tenuous. In our model, we represent these situations with a multi-stakeholder decision filtering method. That is, we assign one of the stakeholders as the decision maker, such as the owner. An owner likely has an objective of minimizing first costs. On the other hand, the tenants may prevent this unilateral choice because they will not accept systems with annual costs higher than a certain level. This situation would define one possible owner-tenant decision model. In our research with stakeholders, we found the typical case is where the owner will accept a maximum first cost increment over the lowest cost alternative, while minimizing the annual operating costs for the tenants. However, this varies by submarket.

Whatever the specific microeconomic objective criteria and filtering constraints, the year-after-year result is a sorted list of the most preferred alternative building configurations. This rank ordering is then converted to a distribution of building stock alternative increments for that year. If an alternative has a high ranking, it is assigned a higher percentage of building stock increment in that year. Thereafter, the building stock alters year after year according to the micro-economic decisions being made. These incremental calculations on the building stock are made iteratively from 2010 to 2050. With the building stock level projections calculated to 2050, the associated energy consumption projections and carbon emission projections are also aggregated. It is also possible to observe changes in the use of energy conservation measures over time.

5 Energy Conservation Measures

For each energy related subsystem, various technology options are defined with energy efficiency and first-cost parameters. A building alternative is a selection of one technology option for each of the 23 energy related subsystems, defining a very large space of available building configurations. Implementation costs were based primarily on data compiled by R.S. Means.

The following table shows the ECMs that were included in the simulation of Class A office properties, with separate columns for Baseline I and Baseline II buildings. The large bold X's denote ECMs that exist in the current stock , while the small x's indicate ECMs that are not currently present, but that are available to be adopted should they be selected under the decision criteria applied within the model.

Table 3. ECMs available to be selected within the model.

	Building type	
	Type I	Type II
Fenestration		
Single pane	x	**X**
Double pane low E, Argon fill, thermal break	x	**X**
Envelope Insulation		
1999 code walls	x	**X**
2010 code walls	x	x
Roof Insulation		
1999 code roof	x	**X**
1999 + white surface paint	x	x
White super-insulated	x	x
Space Heating Equipment		
Heat Pump COP4-ACRated	x	
Ground Source Heat Pump COP6-ACRated	x	
Central Boiler 83% AFUE	**X**	x
Central Boiler 95% AFUE	**X**	**X**
83% AFUE RTU Gas		**X**
95% AFUE RTU Gas		**X**
RTU Heat Pump COP4-ACRated		x
RTU Ground Source Heat Pump COP6-ACRated		x
CHP Reclaim	x	
Space Cooling Equipment		
Ducted AC COP3-Rated	**X**	
Ducted RTU COP3-Rated		**X**
Ducted AC COP5-Rated	x	
Ducted RTU COP5-Rated		**X**
Heat Pump Ducted COP5-Rated	x	
Heat Pump RTU COP5-Rated		x
VS Chiller COP6-Rated	**X**	**X**
Absorption Chiller	x	x
GS Heat Pump Ducted COP6-Rated	x	
GS Heat Pump RTU COP6-Rated		x
Fresh Air ECMs		
Ducted, high leakage	**X**	**X**
Ducted with OA Economizers, low leakage	**X**	**X**
Ducted DCV with OA Economizers, low leakage	x	x

	Building type	
	Type I	Type II
Heating and Cooling Distribution ECMs		
Ducted CAV, high leakage	**X**	**X**
Ducted CAV, low leakage	**X**	**X**
Ducted VAV w Econ, low leakage	**X**	**X**
Radiators	x	x
Chilled beams	x	x
Lighting		
90% T8 Fluorescent, 10% Incandescent	**X**	**X**
100% T5 equivalent Fluorescent	**X**	**X**
100% LED equivalent	x	x
HVAC Controls		
Thermostats	**X**	**X**
BMS	**X**	**X**
BMS + Temperature Reset Strategy	**X**	**X**
Power limit Smart Grid (BMS + Power limit sh	x	x
Passive Lighting		
None	**X**	**X**
Light shelves	x	x
Lighting Controls		
Switches	**X**	**X**
Occupancy sensors	x	x
Smart grid lighting ECMS+occupancy sensors	x	x
Water heating		
Standard hot water heating & piping	**X**	**X**
Reclaim from CHP	x	x
Elevators & Large Electric Loads		
Std large plugs+power dist, std elevators	**X**	**X**
Smart grid large plugs+power dist, high eff ele	x	x
Small Plug Loads		
Standard plugs and distribution	**X**	**X**
Smart grid plugs and distribution	x	x

The costs of each ECM were derived from a cost model based on data from R.S. Means.

6 Energy Model Implementation

As mentioned in Section 4, two fundamental building designs were used as the basis for the simulations. The starting point for both of these was the DOE mid-sized office EnergyPlus template, which is a building of 54,000 ft^2, 3 stories, rectangular shape, 33% glazing area, a typical office operating schedule from CBECS, one air handling unit per floor, and five zones per floor. The footprint of this building was scaled up to a total square footage of 60,000 to match that of the baseline building. Baseline I used this template with brick façade and 25% window area and Baseline II used this template with steel and concrete façade and 60% window area. Renderings of these two baseline buildings are shown in Figure 2.

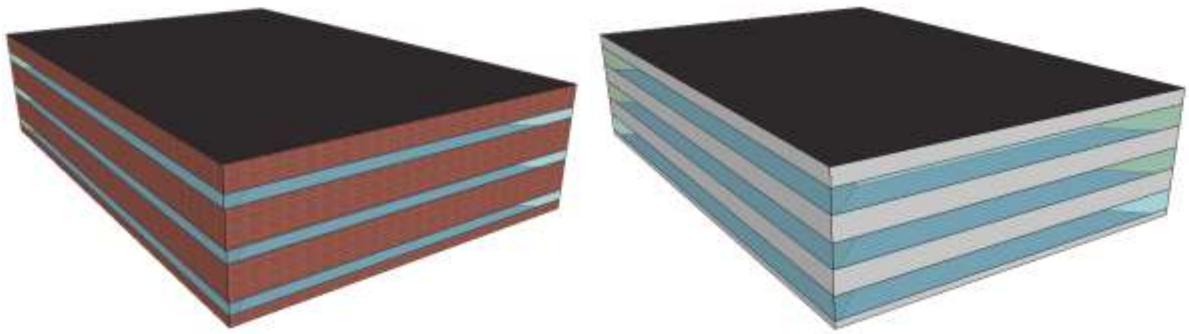

Figure 2. Baseline I building (left) and Baseline II building (right)

The nine building types incorporate six different configurations of HVAC systems. The three HVAC configurations for Baseline I (Figure 3) are (1) constant air volume (CAV) system, (2) variable air volume (VAV) system, and (3) central chiller system with VAV. Baseline II (Figure 4) is represented by (1) CAV roof-top units, (2) packaged VAV units, and (3) heat pumps with VAV.

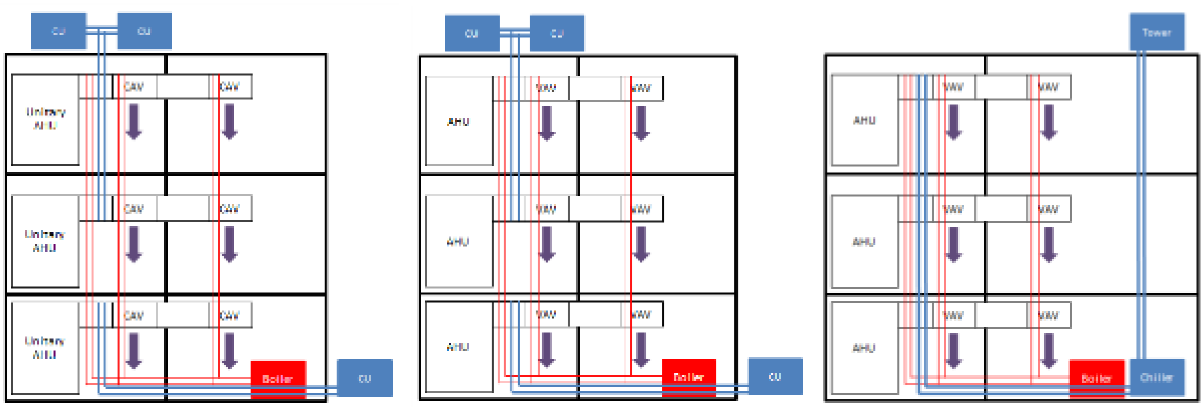

Figure 3. Baseline I showing HVAC configurations (left: CAV, center: VAV, right: central chiller)

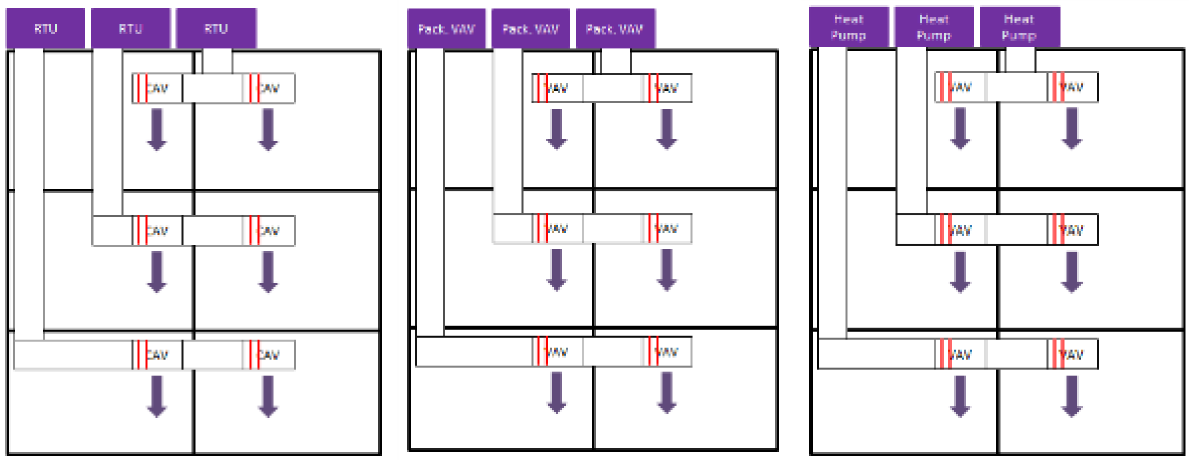

Figure 4. Baseline II showing HVAC configurations (left: CAV RTU, center: packaged VAV, right: heat pump)

The two baseline buildings were modeled using EnergyPlus. In addition, ECM upgrades to these two buildings (either individual ECMs or combinations of ECMs) were simulated in EnergyPlus to generate a family of model results representing potential building retrofit outcomes from the existing building stock. Specifically, 13 additional building simulations were performed for each baseline building, for a total of 28 simulations including the two baselines. A detailed account of the building energy modeling work is available in a separate report prepared by researchers from Drexel University (Hendricken, 2012).

7 Model Results

7.1 Business-As-Usual Case

To define a baseline for comparison purposes, the model was run assuming no policies were in place, which we define to be business as usual (BAU) (even though a variety of policies are currently in use within the GPIC Region). The results (Figure 5) indicate that energy consumption is anticipated to fall 12% from 2010 to 2050 without any policy intervention. The primary reason for this result is that as equipment comes up for replacement over time (i.e., reaches the end of its useful life) building owners adopt new ECMs that have the best economic return, which in some cases will also have higher energy efficiencies. Figure 6 plots the EUI versus first cost for all construction option packages in a Baseline II building, where it's

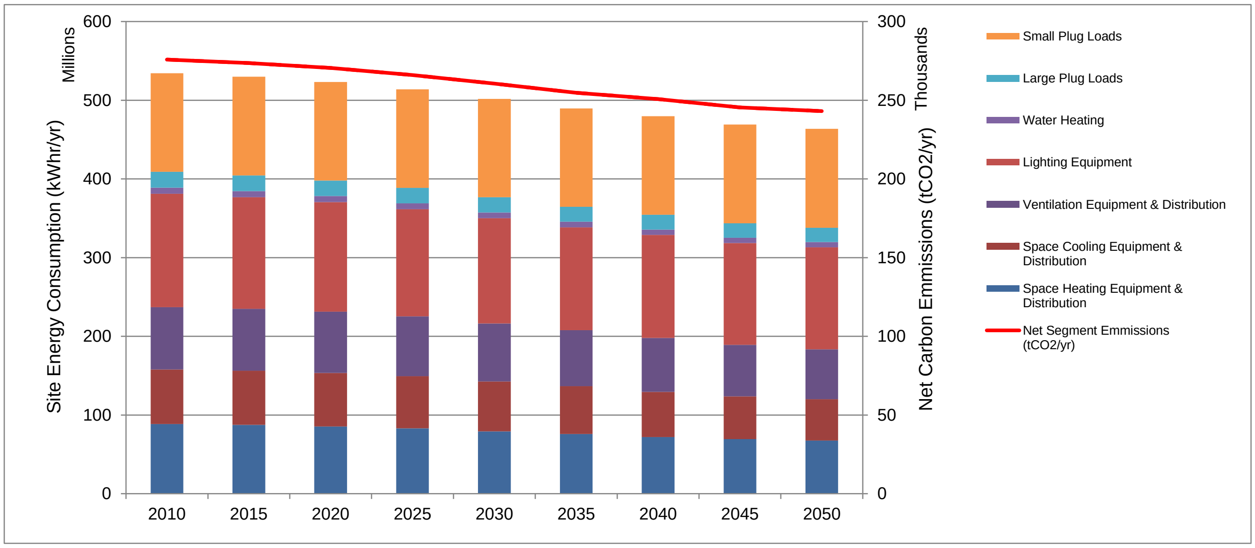

Figure 5. BAU - Projections of site energy consumption

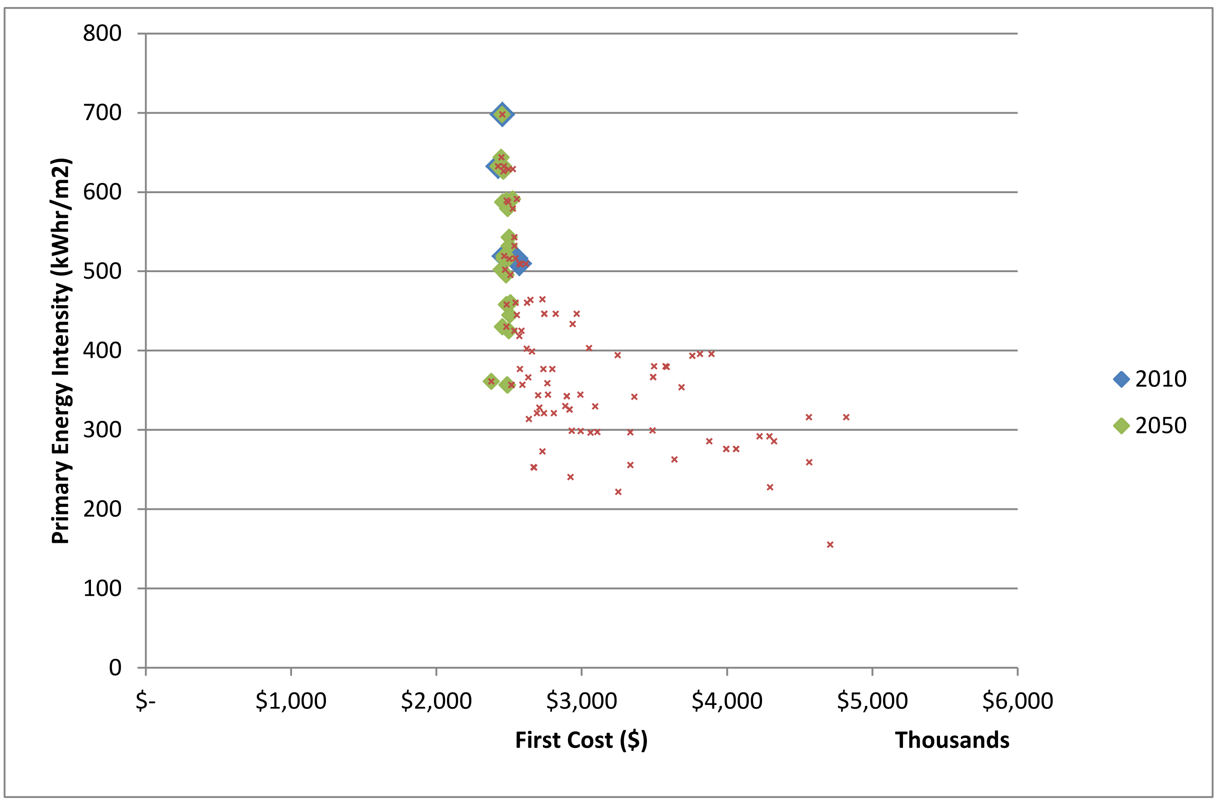

Figure 6. BAU - Current vs. future outcomes based on first cost and energy intensity (shown for Baseline II buildings only)

apparent that in 2050 the selected options (green diamonds) all fall on the left-most edge of the possible options (red x's). As shown in Figure 5, the greatest reductions occur in ventilation equipment and distribution and in space heating equipment and distribution. This also is shown in the subsystems stock table for Baseline I buildings (Figure 7), where there is a shift to higher efficiency HVAC equipment. Some of this change is also due to the adoption of better building controls. Further, the adoption of commissioning, though not included in Figure 7, contributes improvements to the operation of HVAC equipment.

		2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
Fenestration											
Single Pane	$170,564	0.140	0.145	0.151	0.152	0.153	0.153	0.146	0.141	0.138	0.136
Double Pane Low E, Argon Fill, Thermal Break	$207,114	0.040	0.035	0.029	0.028	0.027	0.027	0.034	0.039	0.042	0.044
Envelope											
1999 Code Walls	$535,161	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180
2010 Code Walls	$805,914	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Roof											
1999 Code Roof	$129,136	0.180	0.179	0.178	0.177	0.175	0.173	0.171	0.171	0.171	0.171
1999 + White Surface Paint	$131,836	0.000	0.001	0.002	0.003	0.005	0.007	0.009	0.009	0.009	0.009
White Super Insulated	$271,830	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heating											
Heat Pump COP4-ACRated	$392,499	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ground Source Heat Pump COP6-ACRated	$443,070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Central Boiler 83% AFUE	$184,933	0.140	0.144	0.149	0.150	0.148	0.146	0.133	0.127	0.121	0.118
Central Boiler 95% AFUE	$194,865	0.040	0.036	0.031	0.030	0.032	0.034	0.047	0.053	0.059	0.062
CHP Reclaim	$0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AC											
Ducted AC COP3-Rated	$168,866	0.140	0.144	0.149	0.150	0.147	0.143	0.130	0.123	0.118	0.116
Ducted AC COP5-Rated	$166,542	0.000	0.006	0.010	0.017	0.028	0.037	0.050	0.057	0.062	0.064
Heat Pump Ducted COP5-Rated (Priced in Heating	$0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VS Chiller COP6-Rated	$311,023	0.040	0.030	0.021	0.013	0.005	0.000	0.000	0.000	0.000	0.000
Absorption Chiller	$413,773	0.000	0.000	0.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.000
GS Heat Pump Ducted COP6-Rated (Priced in Hea	$0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Distribution											
Ducted, high leakage	$575,345	0.070	0.068	0.070	0.068	0.066	0.061	0.053	0.048	0.042	0.039
Ducted with OA Economizers, low leakage	$612,845	0.110	0.112	0.110	0.112	0.114	0.119	0.127	0.132	0.138	0.141
Ducted DCV with OA Economizers, low leakage	$650,345	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lighting											
90% T8 10% Inc	$201,776	0.110	0.106	0.102	0.099	0.101	0.099	0.109	0.109	0.111	0.111
100% T5	$220,483	0.070	0.074	0.078	0.081	0.079	0.081	0.071	0.071	0.069	0.069
100% LED	$279,356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lighting Controls											
Switches	$28,825	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180
Occupancy Sensors	$44,223	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Smart Grid Lighting ECMS + Occupancy Sensors	$59,658	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Building Controls											
Thermostats	$24,225	0.070	0.068	0.070	0.068	0.066	0.061	0.053	0.048	0.042	0.039
BMS	$30,142	0.040	0.032	0.023	0.017	0.011	0.007	0.011	0.013	0.017	0.018
BMS + Temperature Reset Strategy	$35,342	0.070	0.080	0.087	0.095	0.103	0.112	0.116	0.119	0.121	0.123
Power limit Smart Grid (BMS + Power limit shut of	$46,859	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Higher efficient HVAC systems are adopted due to wearout replacement

Figure 7. BAU – Changes in subsystems stock (Baseline I buildings)

7.2 *Policy Scenarios*

While the number of policy and program scenarios could be exhaustive, the first year's effort was designed to demonstrate insights on how the model could be used to test various policy and program structures. It is expected that as GPIC policy designers become familiar with the modeling capability, new scenarios will emerge for evaluation. The following policy scenarios were examined for model demonstration purposes only, representing of a range of actions that could be taken by government to stimulate the uptake of energy efficient building technology and reduce the energy footprint of buildings:

1. Equipment incentives: Incentives on equipment and materials are commonly offered as a way to stimulate the adoption of more energy efficient measures. In the scenario analyzed here, the incentives are 25% on improved insulation, windows, and HVAC equipment.
2. Higher energy costs: In theory, higher prices for electricity or natural gas will improve the value proposition for more costly higher efficiency options, since the energy savings are more valuable to a building owner under these conditions. The simulation of this scenario used energy prices 3 times higher than prevailing rates.
3. Incentives for retrofit combinations achieving 30% improvement over ASHRAE 90.1-2004. In this scenario building owners would receive an incentive of 25% on the combination of efficiency upgrades that reduces their energy use intensity (EUI) to 400 $kWh/ft^2/yr$, which represents an energy savings approximately 30% below ASHRAE 90.1-2004. Otherwise an owner is not eligible for any incentives.
4. All retrofits must result in a building meeting ASHRAE 90.1-2004. This proscriptive approach forces improvement in energy efficiency to occur over time as equipment upgrades naturally take place.
5. Policy scenarios 3 and 4 combined. In this case, retrofits are forced to meet ASHRAE 90.1-2004, and in addition, owners are incentivized to go even further by meeting an EUI that's better than what would be achieved by meeting ASHRA 90.1-2004 alone.

The following table shows a summary of the site energy reductions for these policy scenarios for the period 2010 to 2050.

Scenario	Total Site Energy Reduction	Site Energy Reduction Compared to BAU
BAU	14	0
Policy 1	16	2
Policy 2	14	0
Policy 3	33	19
Policy 4	32	18
Policy 5	49	35

These results suggest that a package of policies is necessary to attain deep energy reductions approaching 50%. The results for the five policy scenarios are presented in greater detail below.

7.2.1 Equipment Incentives Scenario

Incentives on individual pieces of equipment improve the economics, shortening paybacks and increasing IRRs. For example, in the modeled scenario, if a furnace wears out, the price of a high efficiency model to replace it would be decreased 25%, which might be sufficient to induce a higher efficiency replacement. Upgrading individual building systems in isolation produces incremental benefits, but the absence of an integrated approach leaves a lot of savings on the table. As shown in Figure 8, the change in energy consumption over time is nearly identical to the BAU case; by 2050 there is only a 2 percentage point improvement over BAU.

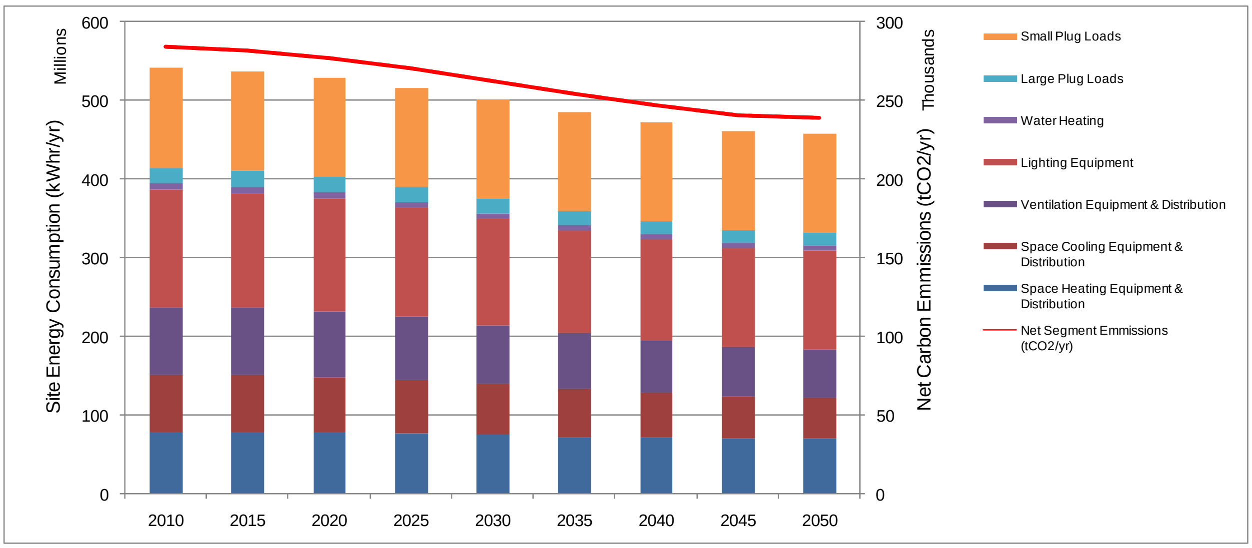

Figure 8. Equipment incentives - projections of site energy consumption

7.2.2 Higher Energy Costs Scenario

We tested a hypothesis that substantially higher energy costs – 3 times current prices, for example – would drive building owners toward more efficient equipment. Figure 9 shows the results of this simulation, which indicates that increasing energy prices 3-fold does little to stimulate energy efficiency improvements compared to BAU. Figure 9 shows the results for this scenario, which show only minor differences compared to BAU (e.g., a slightly more rapid decrease after 2030), while reaching nearly the same end point in 2050.

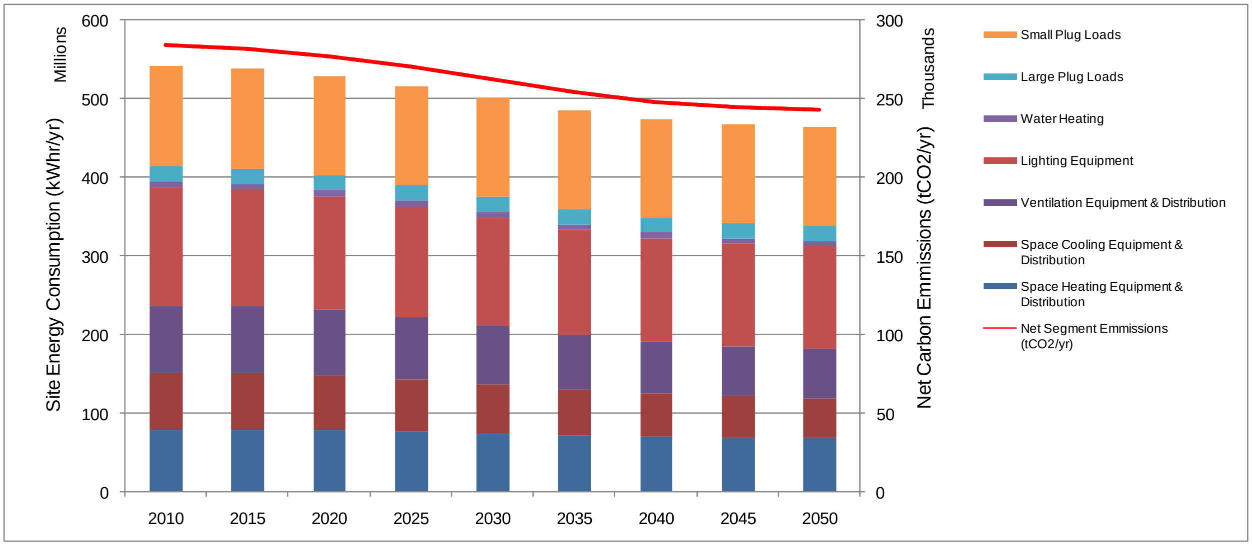

Figure 9. 3X Energy prices - projections of site energy consumption

7.2.3 Incentives for Retrofit Combinations Achieving 30% Improvement over ASHRAE 90.1-2004

Rather than incentivize individual pieces of higher efficiency equipment, we postulated that offering incentives for packages of ECMs (construction option packages) that result in energy consumption below some threshold is more effective policy approach. We modeled a case with a 25% incentive on packages of ECMs if they produce an EUI 30% better than the EUI for a 90.1-2004 code-compliant building. If this level of improvement is not realized, then no incentive is received. This policy produces a relatively steep drop in energy consumption in the 20 years from 2010 to 2030, with a plateau beyond this, resulting in a 31% reduction by 2050 (Figure 10). Figure 11 shows where Baseline II buildings end up in 2050 with respect to EUI and first cost. The buildings represent the lowest cost options that meet the improvement threshold for EUI, indicated by the horizontal red line.

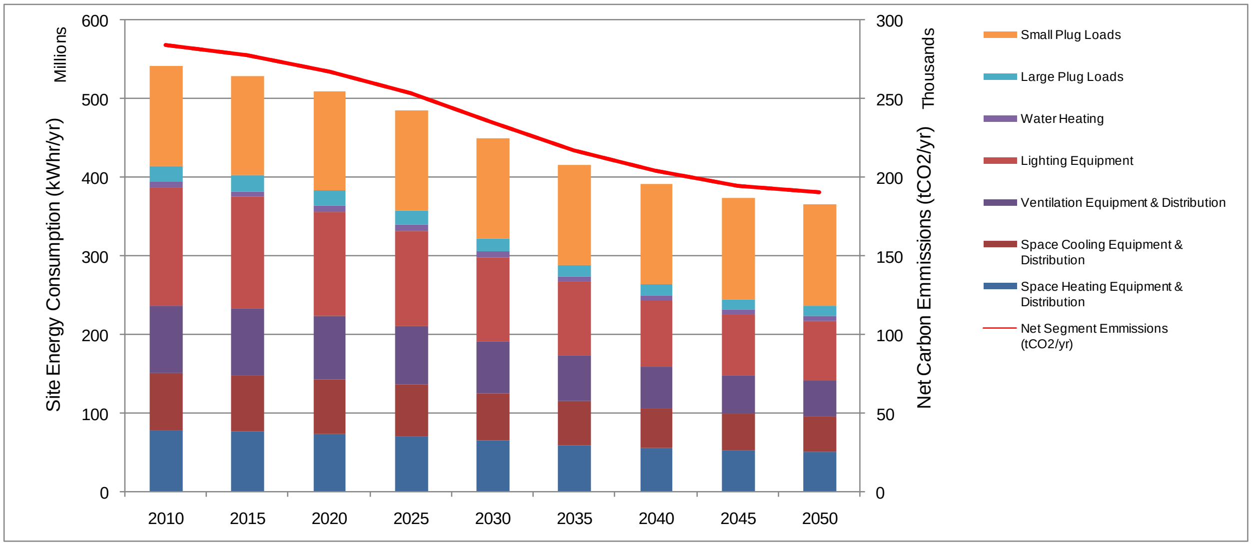

Figure 10. 90.1-2004 Incentive - projections of site energy consumption

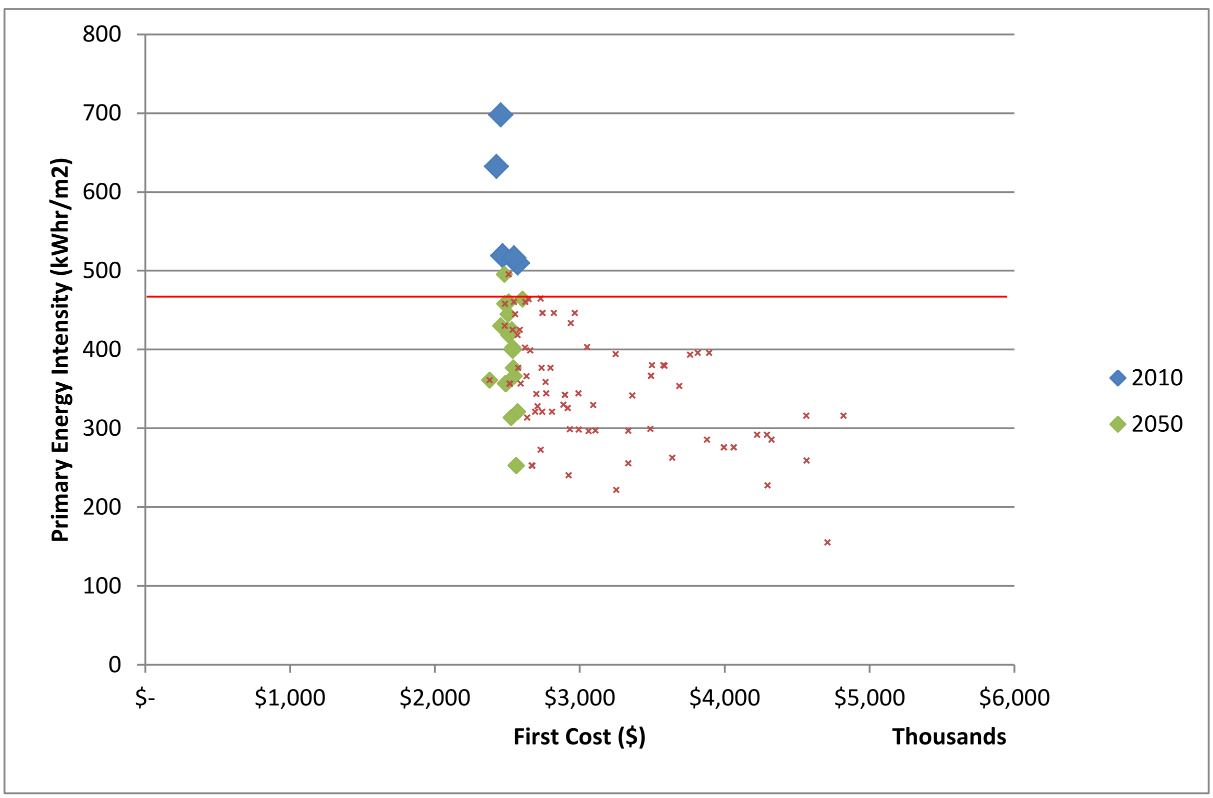

Figure 11. 90.1-2004 Incentive - current vs. future outcomes based on first cost and energy intensity (Baseline II buildings only; horizontal red line indicates the improvement threshold)

7.2.4 All Retrofits Must Result in a Building Meeting ASHRAE 90.1-2004

In this scenario we modeled a policy dictating that all retrofit events must result in an entire building upgrade to ASHRAE 90.1-2004 standards. This produces a degree of certainty in a strong result, yielding a 35% reduction in energy consumption by 2050 (Figure 12). An interesting feature to the final building stock is that one segment gravitates toward the lowest cost solutions and doesn't achieve significant energy reductions, while another segment shoulders higher costs but reduces EUIs to low levels; behavior presumably motivated by the availability of incentives is such low EUIs are achieved. This result is illustrated in Figure 13 for Baseline II buildings only.

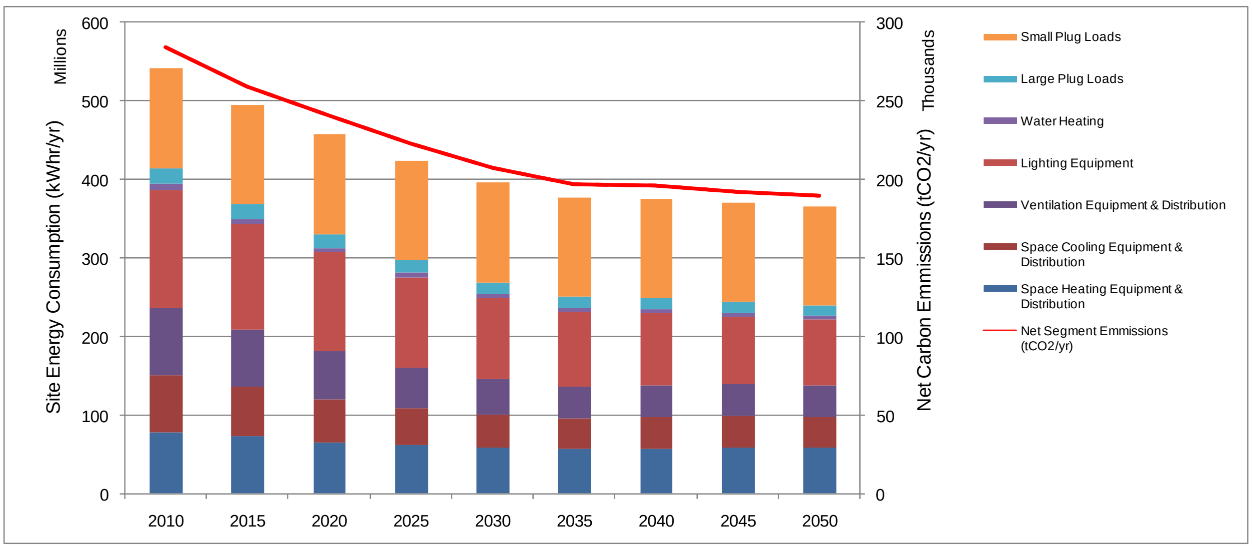

Figure 12. 90.1-2004 Requirement - projections of site energy consumption

Figure 13. 90.1-2004 Requirement - current vs. future outcomes based on first cost and energy intensity (shown for Baseline II buildings only)

7.2.5 Retrofits Trigger ASHRAE 90.1-2004 Requirement, with Incentives for Going Beyond

Combining the previous two policy scenarios produces an end result of a 46% reduction in energy consumption from 2010 to 2050. This carrot-and-stick approach may ultimately be needed to achieve energy reductions on the order of 50%. As shown in Figure 14, essentially all of the building stock has received deep retrofits by 2030, and beyond this no further reductions are seen. Unlike the result for the previous scenario, the buildings by 2030 and beyond are using packages of ECMs that represent the lowest EUI; there is no segment of the population taking the BAU approach (Figure 15). Figure 16 shows which subsystems are being adopted under this policy scenario in Baseline II buildings. There is a 100% changeover to double-paned windows, a modest shift to 2010 code walls, adoption of white roofs, movement to high efficiency heating and cooling systems, 100% adoption of ducted VAV with economizer, 100% adoption of LED lighting (note that cost curves are used for technologies such as LED in the model), all occupancy sensor lighting controls and all BMS building controls.

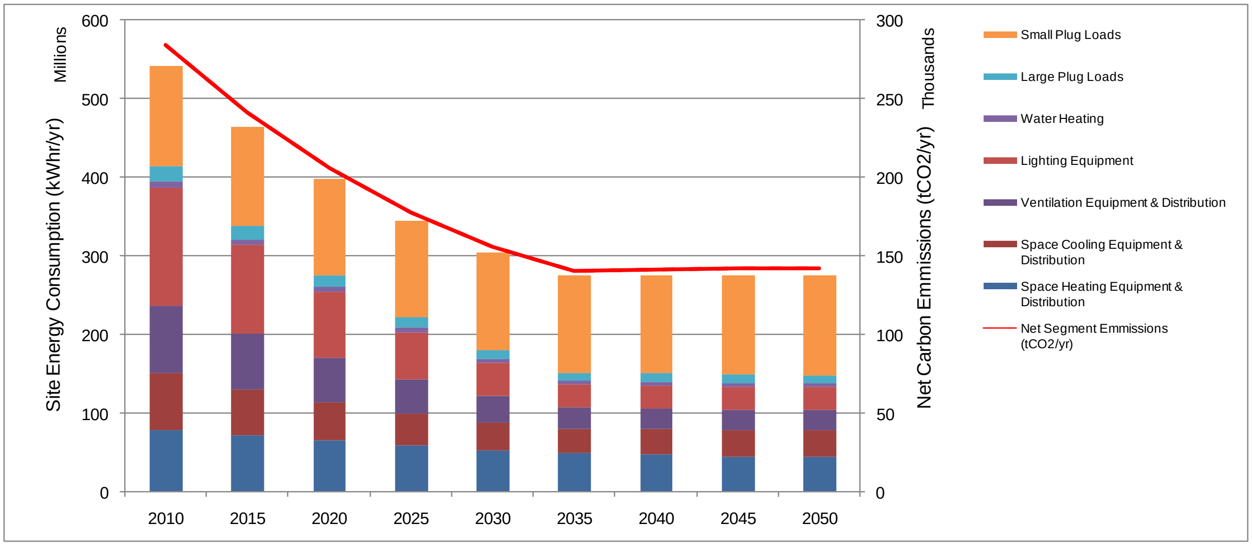

Figure 14. 90.1-2004 + Performance incentives - projections of site energy consumption

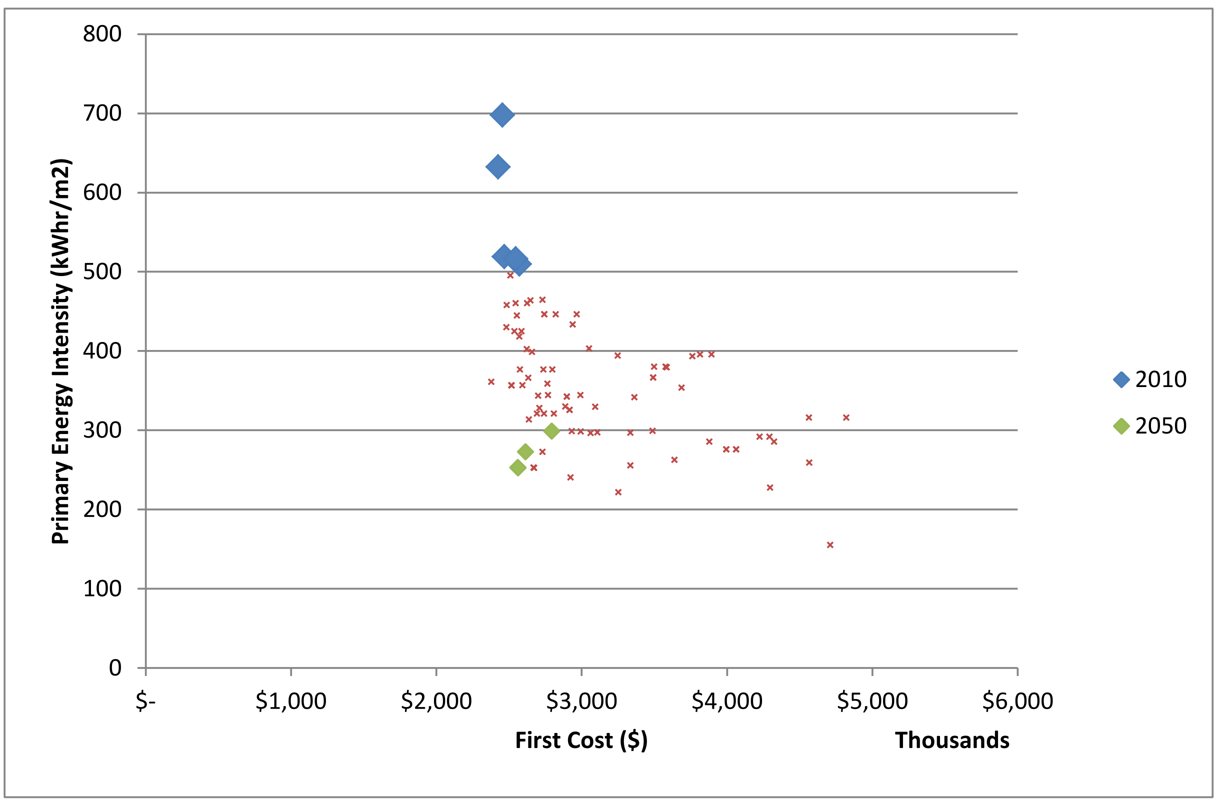

Figure 15. 90.1-2004 + Performance incentives - current vs. future outcomes based on first cost and energy intensity (shown for Baseline II buildings only)

		2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
Fenestration											
Single Pane	$170,564	0.249	0.172	0.114	0.066	0.027	0.000	0.000	0.000	0.000	0.000
Double Pane Low E, Argon Fill, Thermal Break	$207,114	0.021	0.099	0.157	0.206	0.244	0.271	0.271	0.271	0.271	0.271
Envelope											
1999 Code Walls	$535,161	0.271	0.271	0.271	0.258	0.245	0.237	0.225	0.214	0.212	0.210
2010 Code Walls	$805,914	0.000	0.000	0.000	0.013	0.026	0.034	0.046	0.057	0.059	0.061
Roof											
1999 Code Roof	$129,136	0.271	0.245	0.223	0.196	0.174	[illegible]	[illegible]	[illegible]	[illegible]	0.141
1999 + White Surface Paint	$131,836	0.000	0.026	0.048	0.075	0.097	0.113	0.121	0.128	0.129	0.130
White Super Insulated	$271,830	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heating											
Central Boiler 83% AFUE	$149,237	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Central Boiler 95% AFUE	$193,224	0.020	0.015	0.011	0.007	0.003	0.000	0.000	0.000	0.000	0.000
83% AFUE RTU Gas	$177,019	[illegible]	[illegible]	0.103	0.058	0.024	0.000	0.000	0.000	0.000	0.000
95% AFUE RTU Gas	$199,717	0.029	0.044	0.050	0.068	0.073	0.077	0.072	0.069	0.067	0.065
RTU Heat Pump COP4-ACRated	$292,428	0.000	0.054	0.099	0.125	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RTU Ground Source Heat Pump COP6-ACRated	$390,376	0.000	0.000	0.000	0.013	0.026	0.034	0.046	0.057	0.059	0.061
AC											
Ducted RTU COP3-Rated	$169,452	[illegible]	[illegible]	0.103	0.058	0.024	0.000	0.000	0.000	0.000	0.000
Ducted RTU COP5-Rated	$171,691	0.025	0.044	0.050	0.068	0.073	0.077	0.072	0.069	0.067	0.065
Heat Pump RTU COP4-Rated (Priced in Heating)	$0	0.000	0.054	0.099	0.125	0.140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VS Chiller COP6-Rated	$291,644	0.020	0.015	0.011	0.007	0.003	0.000	0.000	0.000	0.000	0.000
Absorption Chiller	$437,007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GS Heat Pump RTU COP6-Rated (Priced in Heating)	$0	0.000	0.000	0.000	0.013	0.026	0.034	0.046	0.057	0.059	0.061
Distribution											
Ducted CAV, high leakage	$0	[illegible]	0.116	0.075	0.042	0.017	0.000	0.000	0.000	0.000	0.000
Ducted CAV, low leakage	$0	0.060	0.042	0.028	0.016	0.007	0.000	0.000	0.000	0.000	0.000
Ducted VAV w Econ, low leakage	$70,000	0.041	0.113	[illegible]	0.213	0.247	0.271	0.271	0.271	0.271	0.271
Radiators	$0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lighting											
90% T8 10% inc	$201,776	[illegible]	[illegible]	0.098	0.056	0.023	0.000	0.000	0.000	0.000	0.000
100% T5	$220,483	0.060	0.042	0.030	0.018	0.007	0.000	0.000	0.000	0.000	0.000
100% LED	$279,356	0.000	0.080	[illegible]	0.199	0.241	0.271	0.271	0.271	0.271	0.271
Lighting Controls											
Switches	$28,825	0.271	[illegible]	[illegible]	0.072	0.030	0.000	0.000	0.000	0.000	0.000
Occupancy Sensors	$44,223	0.000	0.080	[illegible]	0.199	0.241	0.271	0.271	0.271	0.271	0.271
Smart Grid Lighting ECMS + Occupancy Sensors	$59,658	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Building Controls											
Thermostats	$24,225	[illegible]	0.116	0.075	0.042	0.017	0.000	0.000	0.000	0.000	0.000
BMS	$30,142	0.041	0.113	[illegible]	0.213	0.247	0.271	0.271	0.271	0.271	0.271
BMS + Temperature Reset Strategy	$35,342	0.060	0.042	0.028	0.016	0.007	0.000	0.000	0.000	0.000	0.000
Power limit Smart Grid (BMS + Power limit shut off logic	$46,859	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 16. 90.1-2004 + Performance Incentives: Changes in Subsystems Stock (Baseline II buildings)

7.2.6 A Note on Existing GPIC-Region Programs to Increase Building Energy Efficiency

Some of the scenarios that were modeled are comparable to existing energy efficiency programs in the GPIC region. Rebates on many kinds of equipment, for example, are available in both New Jersey under its SmartStart Buildings program and in Pennsylvania under PECO Energy's Smart Equipment Incentives (currently a waiting list). Whole-building energy efficiency incentives, analogous to the policy scenario #3, are also found in New Jersey and Pennsylvania. New Jersey recently put in place the Pay for Performance program, applicable to existing commercial, industrial and multifamily buildings (1) with peak demand over 100 kW in any of the preceding months and (2) that are customers of a New Jersey investor-owned utility. The total package of measures presented in the project's Energy Reduction Plan must have at least a 10% internal rate of return, and an energy savings of 15% or more must be achieved in order to receive any incentives. As of November 2011, 284 projects had filed for incentives under this program. In Pennsylvania, PECO offers Smart Construction Incentives for new construction and substantial rehabilitation projects (currently a waiting list) based on a whole building design approach. Future work may take a closer look at these and other existing policies using the macro-modeling approach presented in this report. A detailed description of existing policy measures in the GPIC region is found in the report by Cozen and O'Connor prepared in Year 1 under the Policy, Markets and Behavior Task.[2]

8 Future Work

In year 2 of the policy and market macro-modeling effort, we will create and further develop analytical methods and analysis tools, based on both theoretical understanding and empirical studies, to quantitatively assess market mechanisms and policy impact on energy efficient buildings market adoption for the GPIC region. The work will be informed by input from regional stakeholders in the building retrofit industry, which will be convened by Task 6 (Demonstration and Deployment) under "platforms" representing (1) owners and operators, (2) occupiers and tenants, (3) building design and delivery firms, (4) suppliers, and (5) financing institutions, as well as from policy designers and conveners in the region. United Technologies, Drexel University, Carnegie-Mellon University, and the University of Pennsylvania will coordinate closely on executing the second year's work scope.

The analysis will be primarily used in a forward looking context for assessing the impact and effectiveness of measures in the GPIC region. The developed model methodology is expected to be scalable to other regions. The team will undertake a series of field and laboratory experiments to better understand the demand side of this market so it is then possible to propose concrete ways to significantly increase the number of consumers (individuals and firms) who will switch to cost-effective EEB technologies. This will include modeling the broad array of decision heuristics that determine uptake, and how those decisions are affected by policies.

Furthermore, this project seeks to develop strategic energy buying, selling and storage strategies for buildings powered by existing and renewable energy resources, identify the role of energy efficiency improvements in enabling building retrofit financing, examine the role of aggregators and identify the optimum pricing strategies they can use to facilitate the large scale deployment of energy efficient solutions and characterize the maximum possible energy efficiency attainable under different organizations of aggregators. This project seeks to

[2] Shapiro, S. and C. O'Connor. 2011. Policy and Process Factors Impacting Commercial Building Energy Efficiency in Pennsylvania and New Jersey. GPIC Policy, Markets and Behavior Task Team.

demonstrate the components and systems for retrofits and to incorporate these benefits within a multi-media decision support tool. In addition to opportunities, the project will also identify barriers to implementation of measures aimed at increased energy efficient building retrofit. Given the broad set of related efforts to characterize market impact, this project will establish broader collaboration with DOE's on-going empirical data gathering initiatives so that macro-modeling GPIC researchers can both inform the empirical efforts as well as benefit from DOE's empirical studies.