United Technologies Research Center

Transforming the Building Market: Modelling Approach

June 23, 2014

Russell Taylor, Ph.D.
United Technologies Research Center
East Hartford, CT
USA

Projection of Paths to Transformative Change in the Built Environment through Quantitative Modeling of Policies, Market Mechanisms and Behavior

Russell Taylor [1]
+1 (860) 610-7485
taylorrd@utrc.utc.com

Liam Hendricken [2]
+1 (301) 910-7895
lth23@drexel.edu

Patrick Casey[3]
+1 (508) 361-3518
patrick.casey@s-p-insight.com

William Sisson[1] Michael Hamilton[2], Patrick Gurian[2], Jin Wen[2], Vivian Loftness[4], Erica Cochran[4], Alex Waegel[5],
[1]United Technologies Research Center, 411 Silver Lane, East Hartford, CT 06118
[2]Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104
[3]SP Insight, 29 South Street, Medfield, MA 02052
[4]Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA
[5]T.C. Chan Center for Building Simulation and Energy Studies, 220 S 34th Street, Philadelphia, PA

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Market Analytics Model Development Timeline

wbcsd business solutions for a sustainable world

2007-2009: World Business Council for Sustainable Development

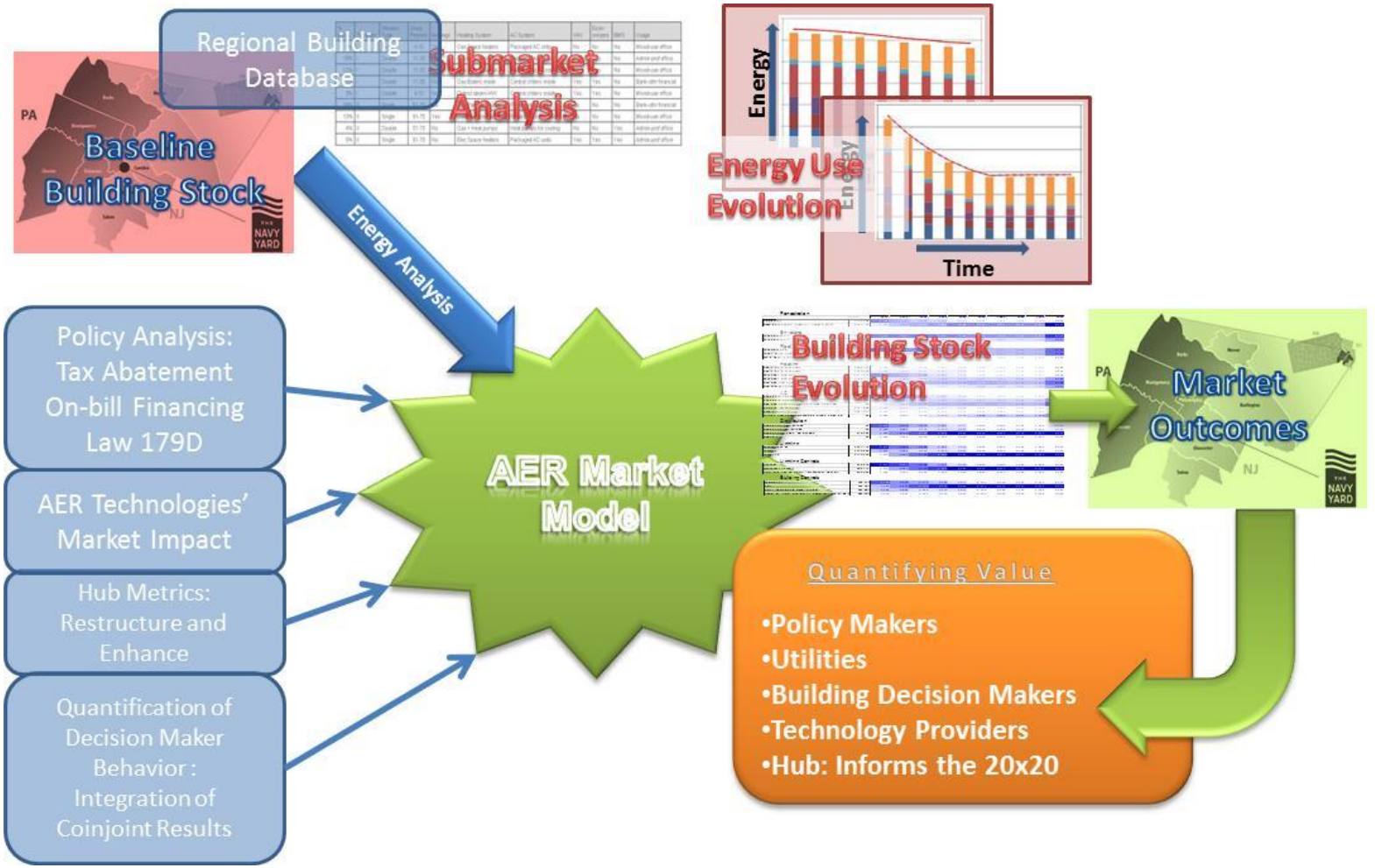
- http://www.wbcsd.org/transformingthemarketeeb.aspx
- Understand how market mechanisms can be used to transform the World's building stock
- Develop a path to 50% energy reduction by 2050

eebHUB Energy Efficient Buildings Hub
Re-energizing buildings for the future.™

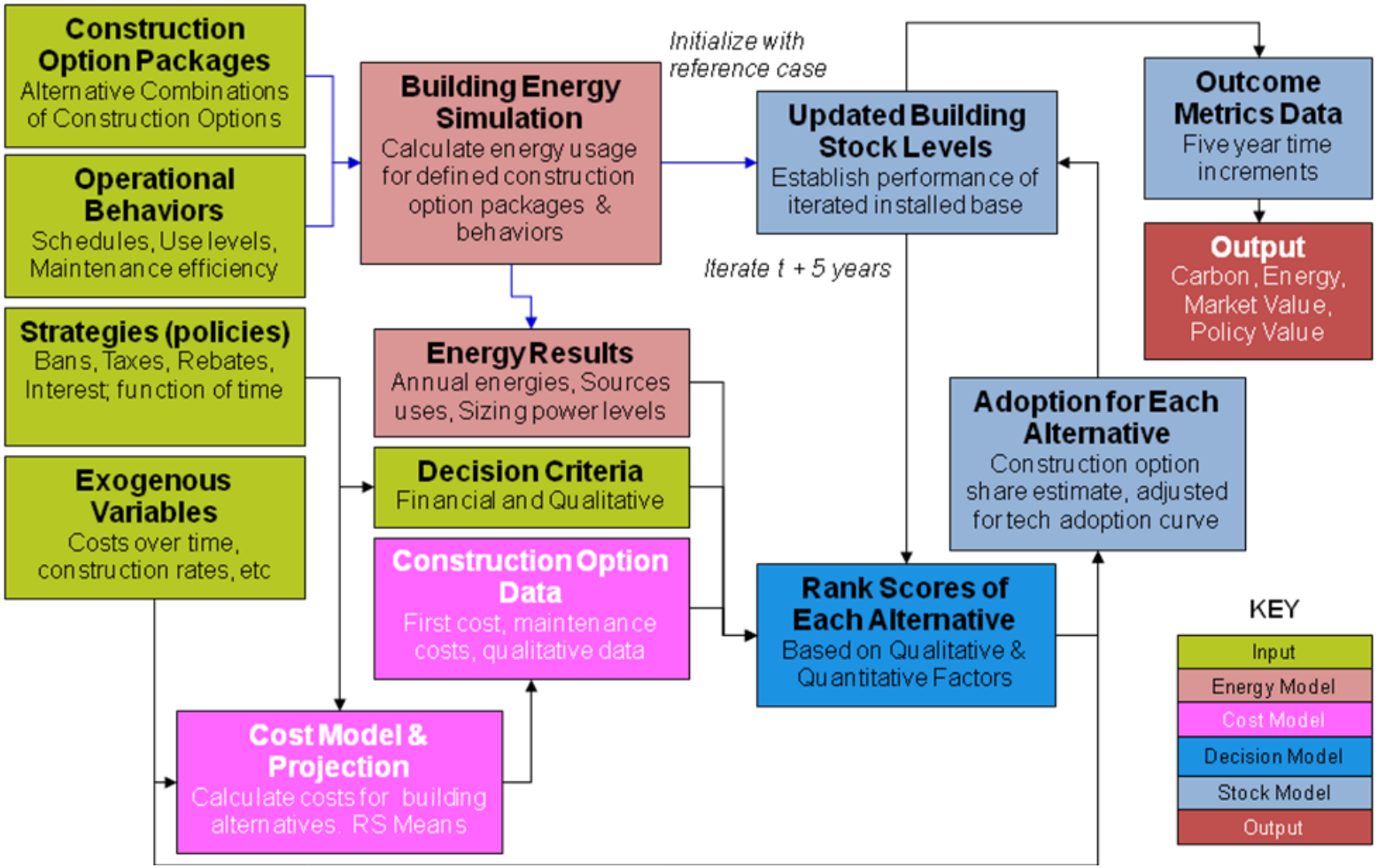
2011-2013: Energy Efficient Buildings HUB

- http://eebhub.org/
- Refine and Apply Market Analytics Model to Philadelphia Region
- Develop policy and market based pathways to 20% energy reduction by 2020 and 50% by 2030

Market Analytics Model Integration with EEB Hub Activities



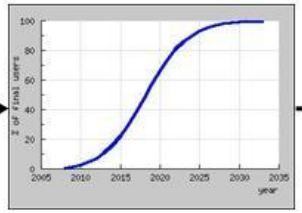
Market Analytics Model Computational Structure



Share and Diffusion Calculation

Decision Maker Weights

- Present Value of Costs
- Present Value of Enhancements
- Qualitative Factors

Set of COPs (time t) → Stakeholder Filters → Qualifying Set → Overall Rank → Saturation Share of COPs →  → Set of COPs (time t + delta)

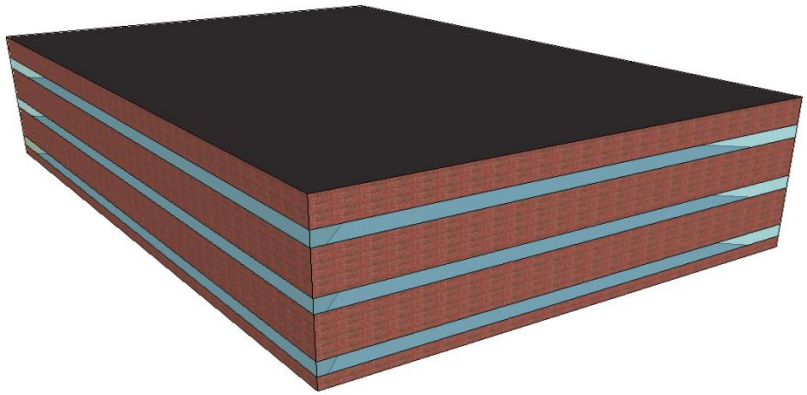
Bass Diffusion Model

Stakeholder(s) Thresholds

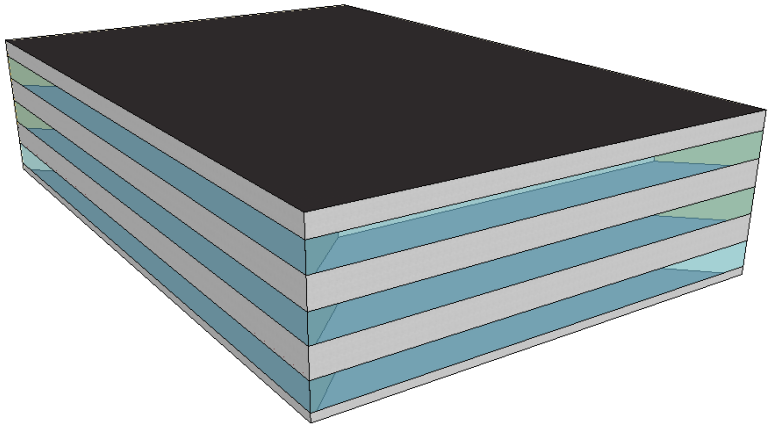
- Present value of costs
- First cost
- NPV
- BET
- Operating costs
- Value Enhancement Rank
- Carbon Emissions
- Energy Consumption
- Indoor Environmental Quality (IEQ) Rank
- Reliability and Predictability Rank
- Ease of Use & Installation Rank
- Appearance Rank
- Energy and Atmosphere
- Materials and Resources Usage Rank

Building Baselines

- Baseline I: 60,000 ft^2, 25% window area, brick façade



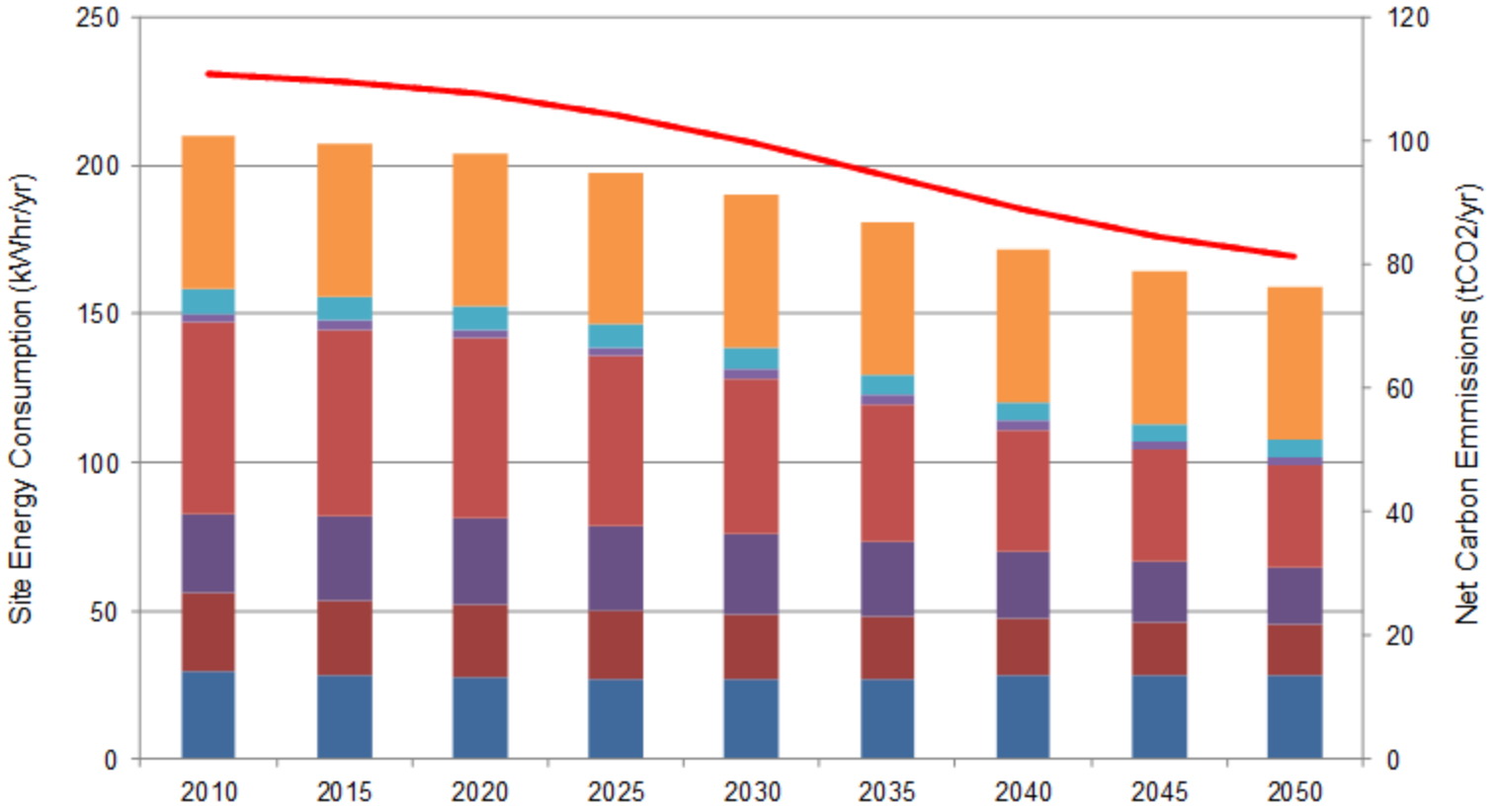
- Baseline II: 60,000 ft^2, 60% window area, Steel + Concrete façade



Model Projections: Business-as-Usual

Owner-Occupier

~20% Reduction in Energy and Emissions



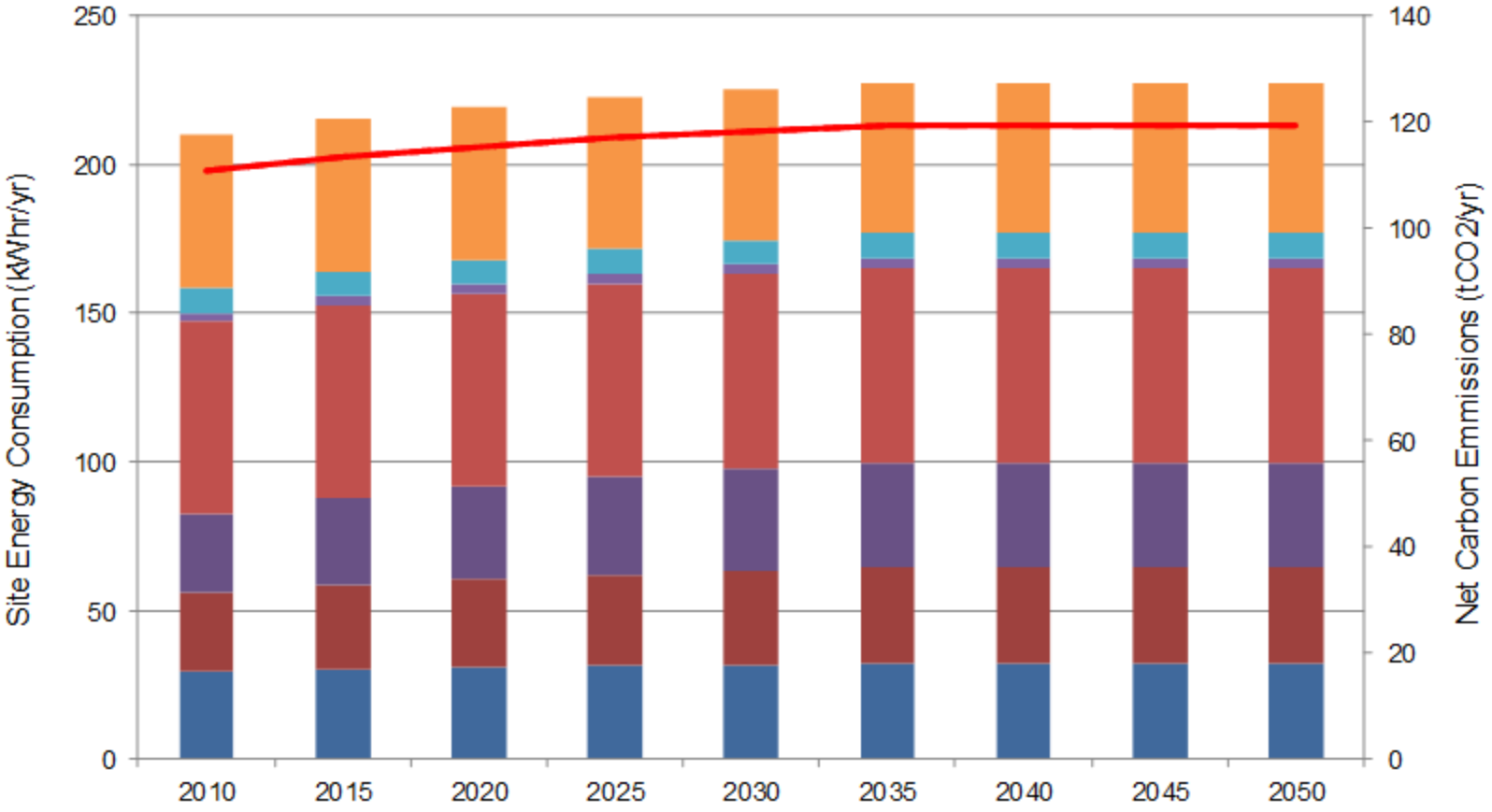
Building Stock Subsystem Evolution

		2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
Fenestration											
Single Pane	$170,564	0.246	0.173	0.114	0.065	0.027	0.000	0.000	0.000	0.000	0.000
Double Pane Low E, Argon Fill, Thermal Break	$207,114	0.025	0.098	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	0.158	0.150	0.143	0.142	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	0.000	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	0.226	0.158	0.103	0.058	0.024	0.000	0.000	0.000	0.000	0.000
95% AFUE RTU Gas	$199,717	0.025	0.044	0.059	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	0.098	0.125	0.145	0.160	0.153	0.145	0.145	0.145
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	0.226	0.158	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	0.059	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	0.098	0.125	0.145	0.160	0.153	0.145	0.145	0.145
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	0.166	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	0.045	0.113	0.168	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	0.211	0.149	0.098	0.056	0.023	0.000	0.000	0.000	0.000	0.000
100% T5	$220,483	0.060	0.042	0.028	0.016	0.007	0.000	0.000	0.000	0.000	0.000
100% LED	$279,356	0.000	0.080	0.145	0.199	0.241	0.271	0.271	0.271	0.271	0.271
Lighting Controls											
Switches	$28,825	0.271	0.191	0.126	0.072	0.030	0.000	0.000	0.000	0.000	0.000
Occupancy Sensors	$44,223	0.000	0.080	0.145	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	0.166	0.116	0.075	0.042	0.017	0.000	0.000	0.000	0.000	0.000
BMS	$30,142	0.045	0.113	0.168	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

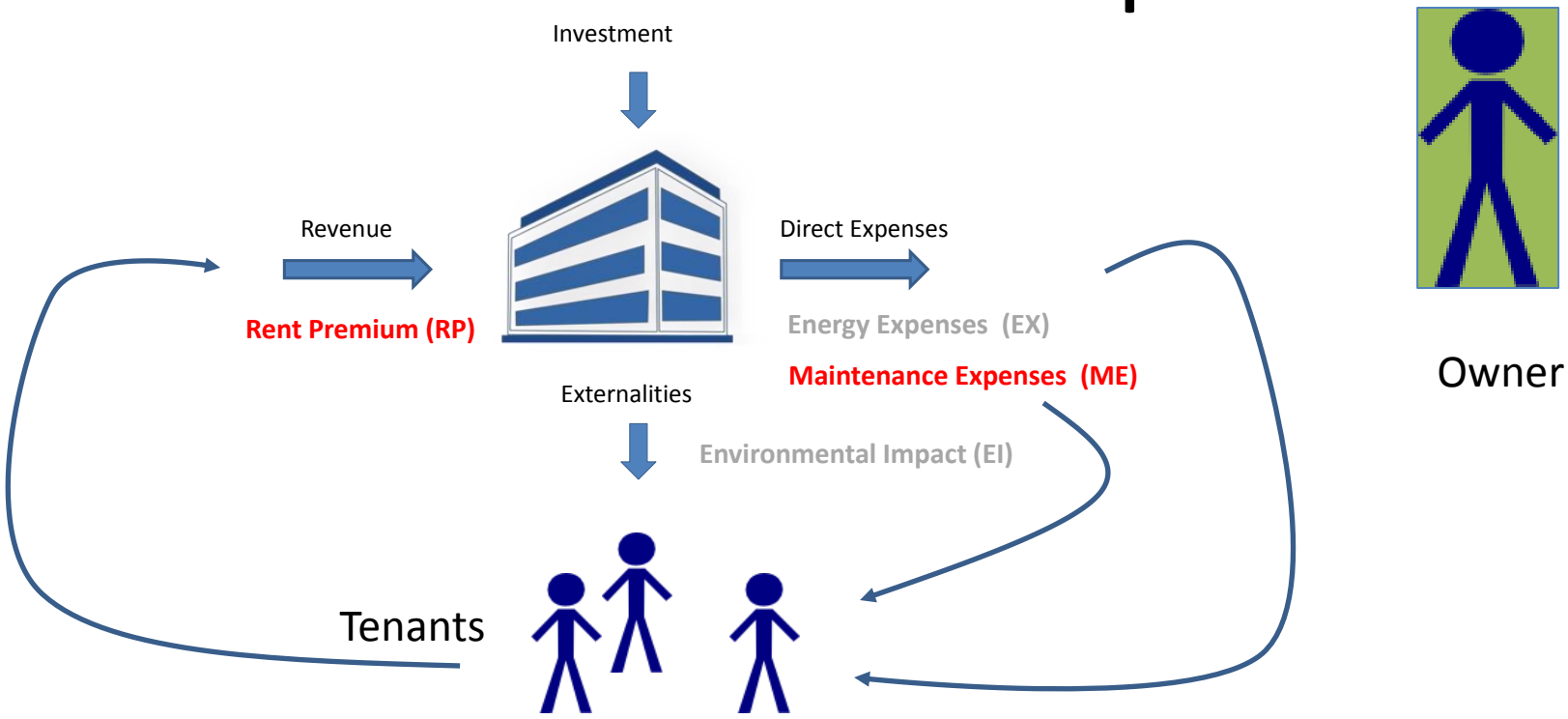
Model Projections: Business-as-Usual

Split-Incentive

~5% Increase in Energy and Emissions



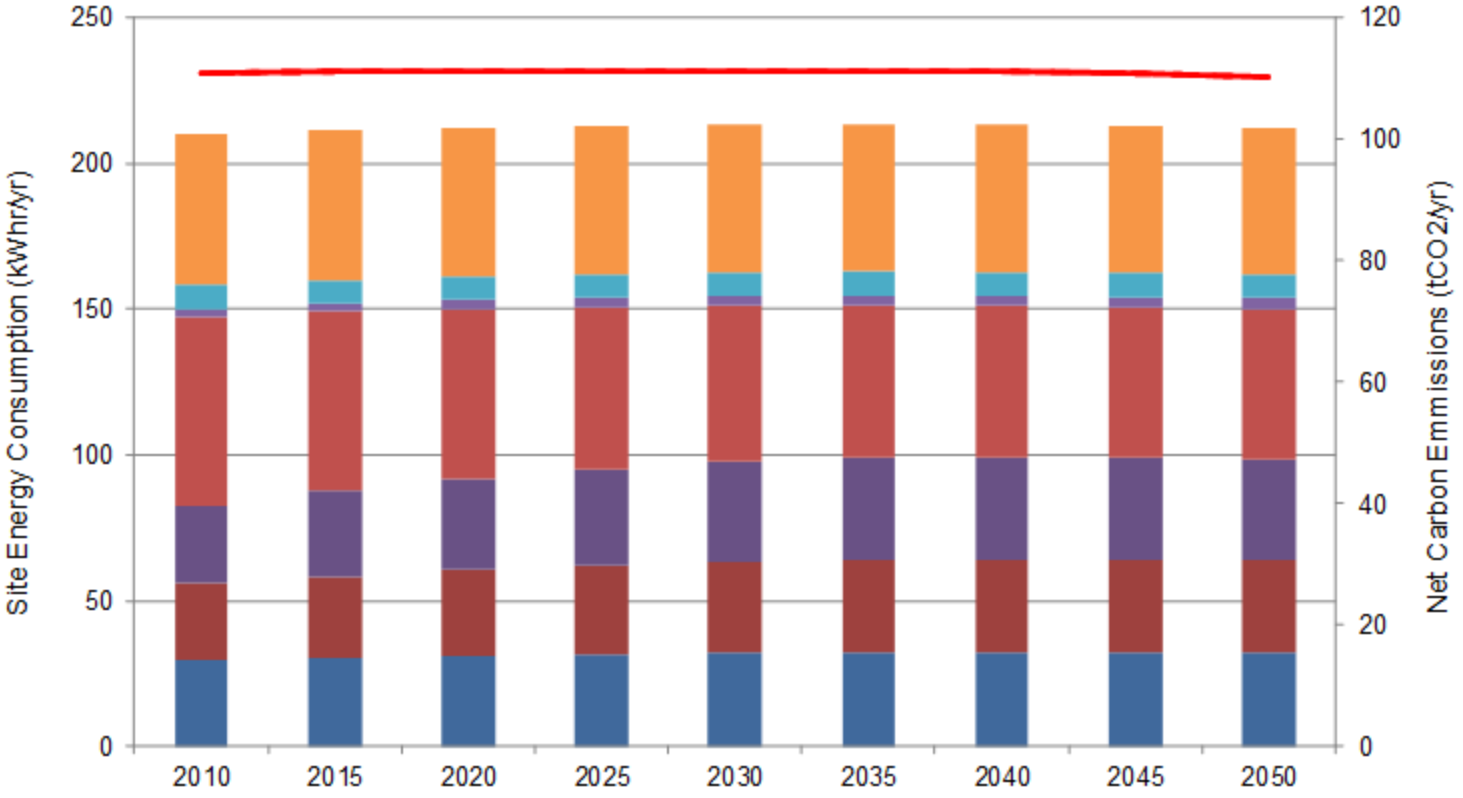
Disclosure: Owner Perspective



- An owner-landlord will not directly recoup energy savings resulting from investments in more efficient building systems
- They will (may), however, see a rent premium corresponding to the value renters place on:
  - Energy savings
  - Environmental impact
- The rent premium will be a function of:
  - Fidelity of information regarding prospective energy consumption of potential lessor
  - Potential lessor attention to, and comprehension of, available information

Model Projections: 50% Effective Disclosure

Landlord can recoup 50% of the energy savings as increased rent for financing energy efficient retrofits



Carbon Tax

Assumptions:

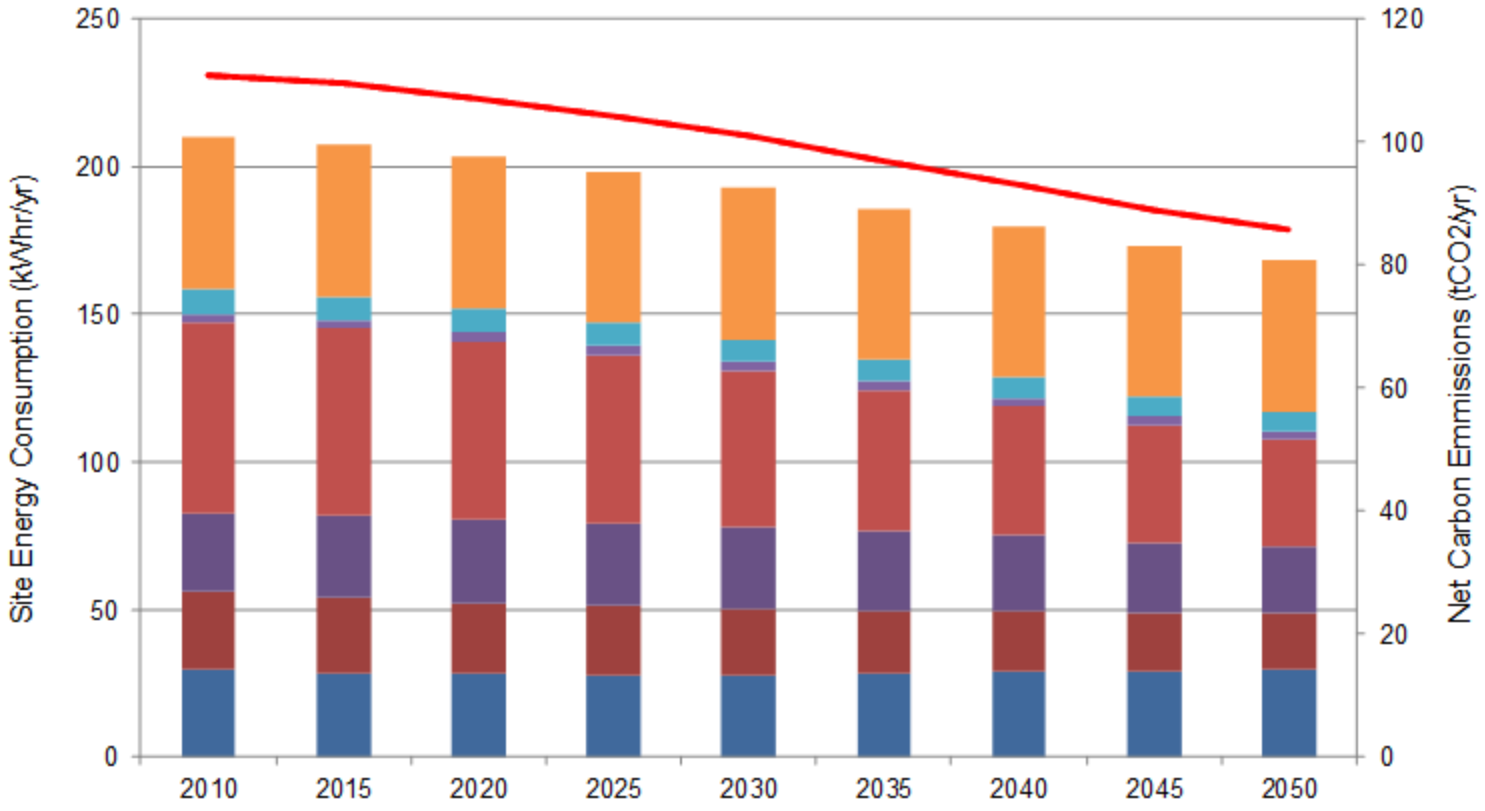
- Cost of Carbon = $30/ton
- Emissions for electricity based on typical Philadelphia generation mix: Coal, Natural Gas, Nuclear
- No switching to renewables (but natural gas is less carbon intensive than electricity in the Philadelphia region)

Likely Outcome: Carbon tax acts as a general tax on energy and encourages heating fuel switching from electric to natural gas

- Modeling objectives: Impact of price of carbon on energy efficiency retrofit rates

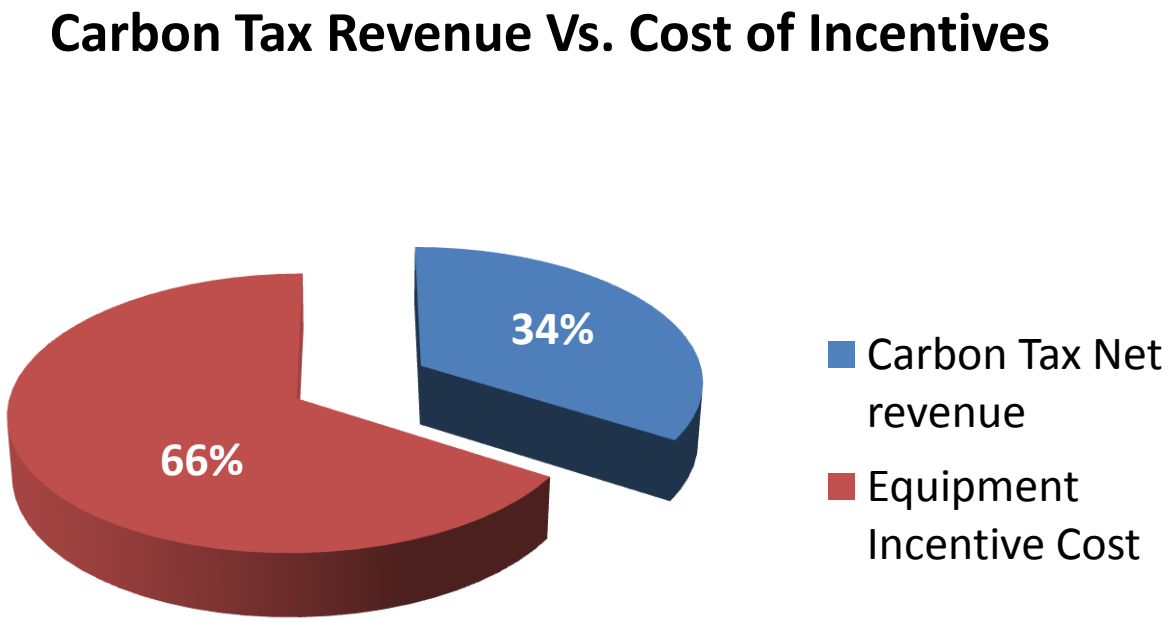
Model Projections: On-Bill Repayment with 50% Effective Disclosure and Carbon Tax

Modest improvement over disclosure alone: 22% energy savings and 25% carbon emission savings by 2050 compared to the initial state in 2010



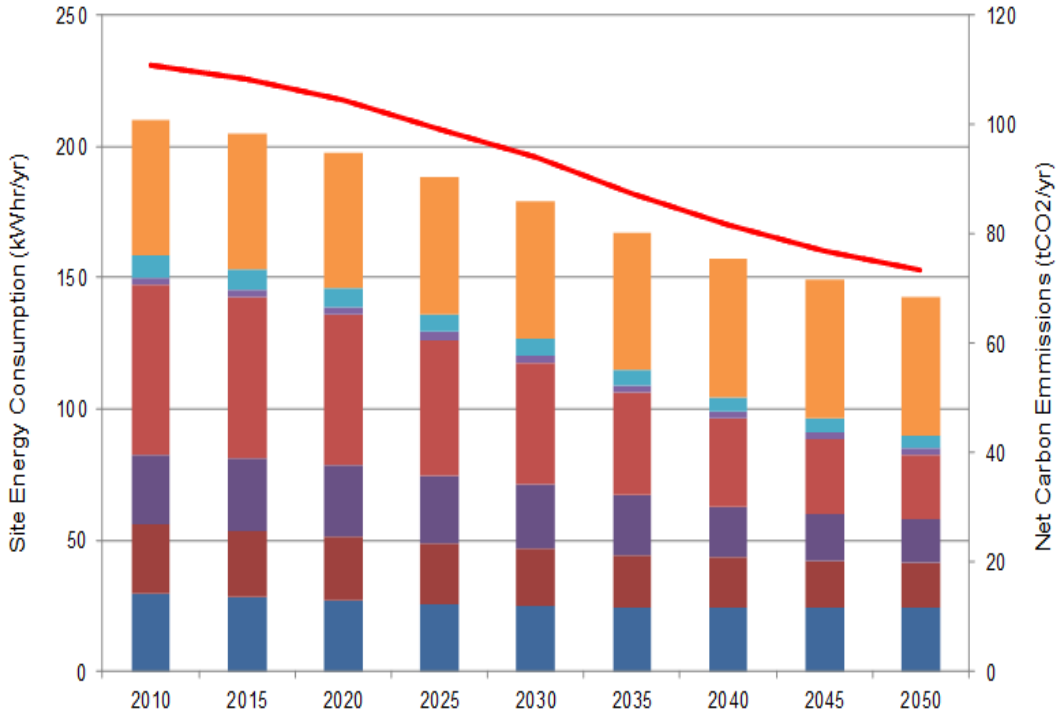
Carbon Tax Revenue and Cost of Incentives

- Near 50% increase in energy savings
- Carbon tax revenue substantially exceeds cost of incentive program



Model Projections: On-Bill Repayment with 50% Effective Disclosure, Carbon Tax, Equipment and Whole Building Incentives

- 35% reduction in energy consumption by 2050
- Policy cost increases by 10X
- Carbon tax revenue could offset 25% of the cost of incentives



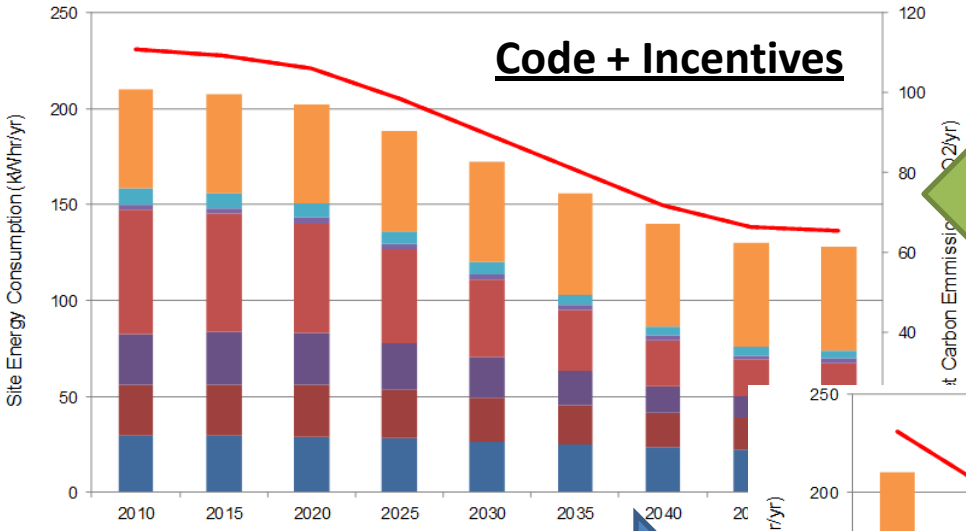
Energy Conservation Codes

Assumptions:

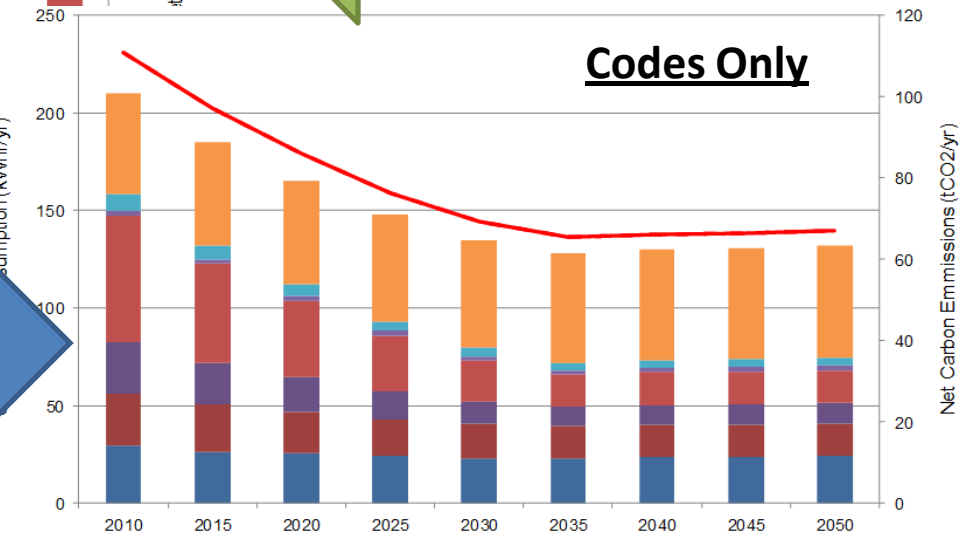
- Progressively bans technologies that don't meet minimum standards i.e. incandescent lights, HVAC with low COP, non-condensing boilers, etc
- Buildings must meet new codes when retrofit occurs

- Modeling objectives: Impact of price of carbon on energy efficiency retrofit rates

Model Projections: On-Bill Repayment with 50% Effective Disclosure, Carbon Tax, Equipment and Whole Building Incentives, Code Enforcement



- 39% reduction in energy consumption
- Minor increase in lifecycle costs
- More adoption of measures that exceed maximum BET hurdle



- 40% reduction in energy consumption
- All costs borne by building owner
- 30% increase in life-cycle costs

CONCLUSIONS

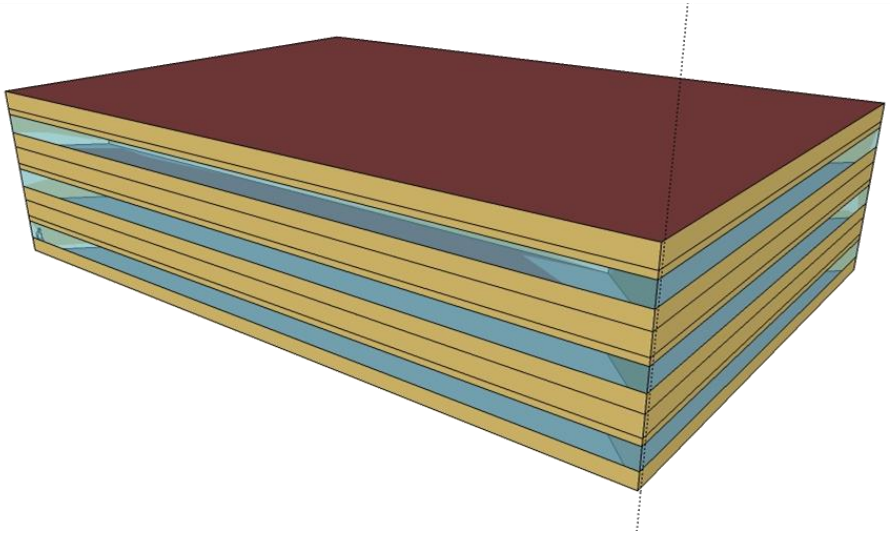
Plausible policy solutions are available that could achieve significant building energy conservation given sufficient time:

- Market-based solutions can be as effective as a strictly regulatory approach
- Market-based approach works by socialization of some of retrofit costs to reduce the total investment required by the building decision maker behavior
- Effectiveness of code-based approach will depend on compliance
- Carbon tax will have little impact on building energy consumption over time unless it is much larger than anything currently proposed.

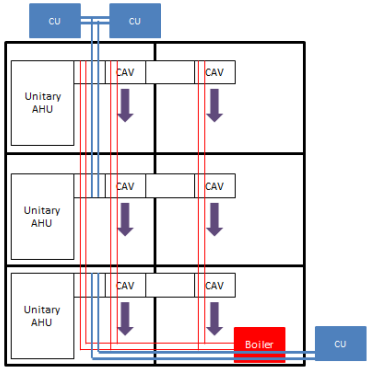
Back-up Slides

Energy Modeling Template

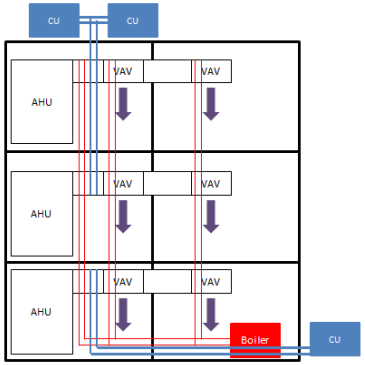
- DOE Mid-Sized Office EnergyPlus Templates
- Adjustable defaults:
  - 50,000 ft^2, 3 stories
  - Rectangular shape
  - Typical office operating schedule from CBECS
  - One AHU per floor
  - 5 zones per floor



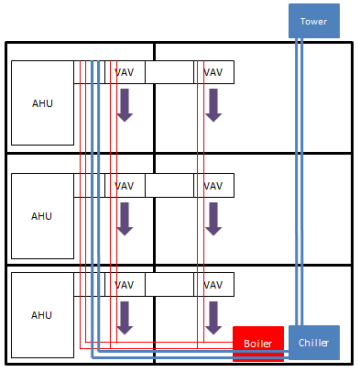
2010 Representative Stock Models



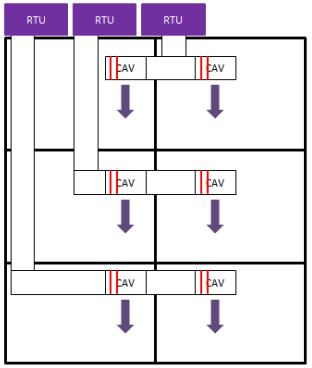
Baseline I CAV



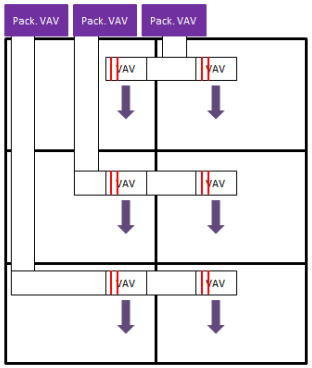
Baseline I VAV



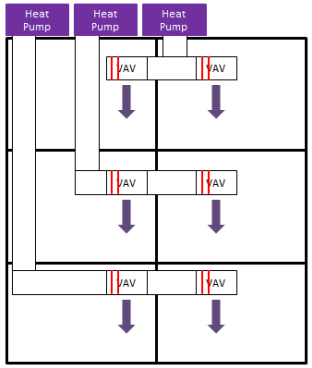
Baseline I Central Chiller



Baseline II CAV RTU



Baseline II Packaged VAV



Baseline II Heat Pump

Equipment Incentives

Assumptions:

Energy efficient subsystems subsidized with an incentive of 20-35% of the individual first costs

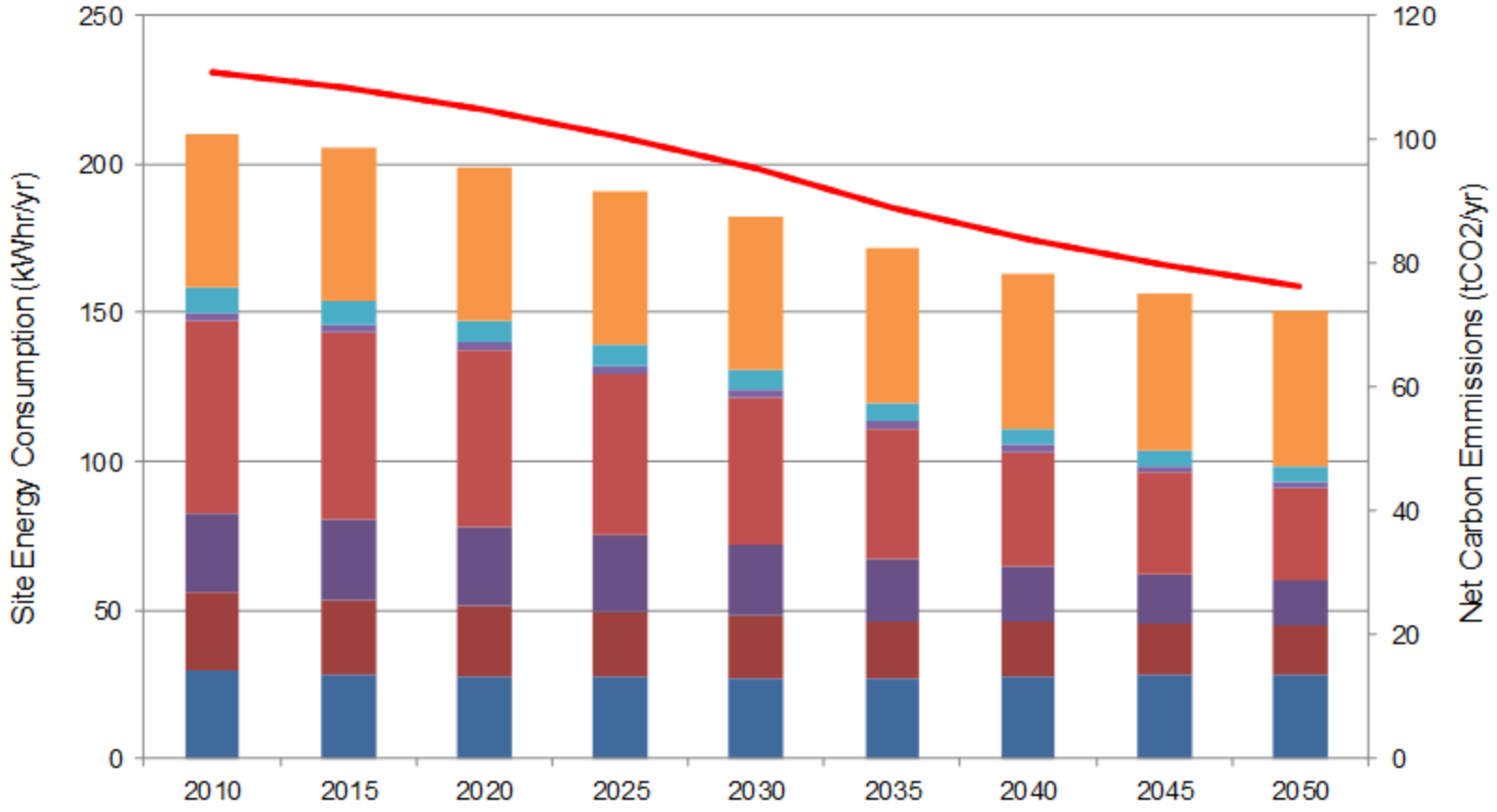
Likely Outcome:

Increased uptake of efficient equipment in retrofits due to increase in efficient equipment that meets the maximum BET hurdle

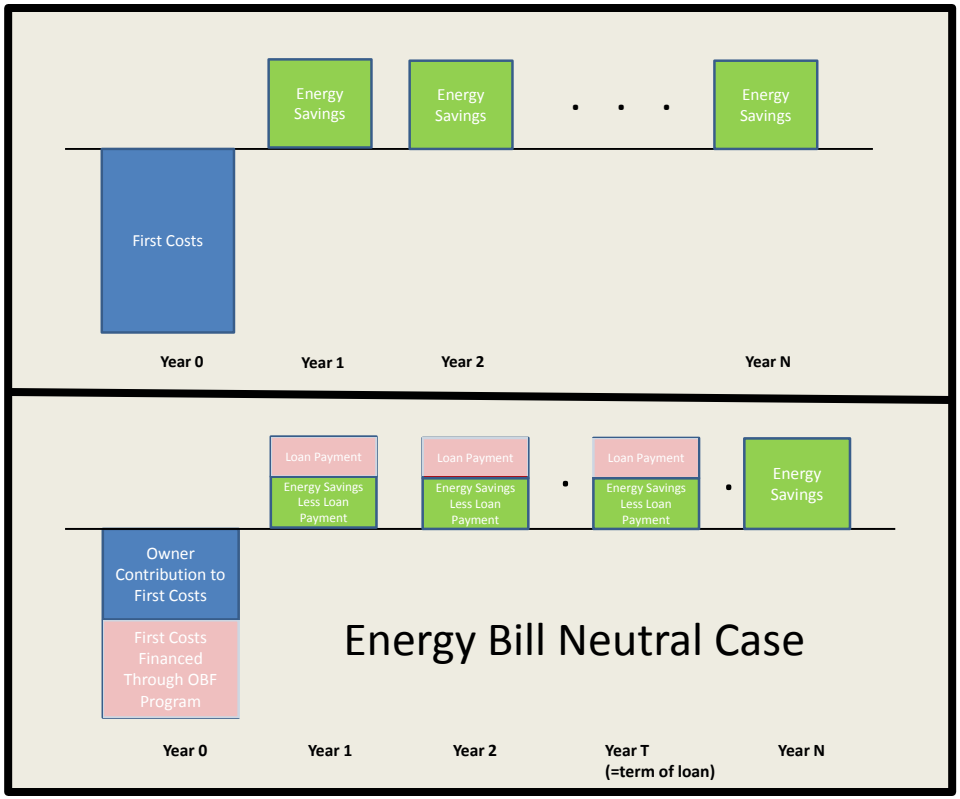
- Modeling objectives: Impact of price of carbon on energy efficiency retrofit rates

Model Projections: On-Bill Repayment with 50% Effective Disclosure, Carbon Tax and Equipment Incentives

Additional modest improvement in energy savings: 31% energy savings by 2050 compared to the 2010 baseline



On Bill Repayment Owner Perspective



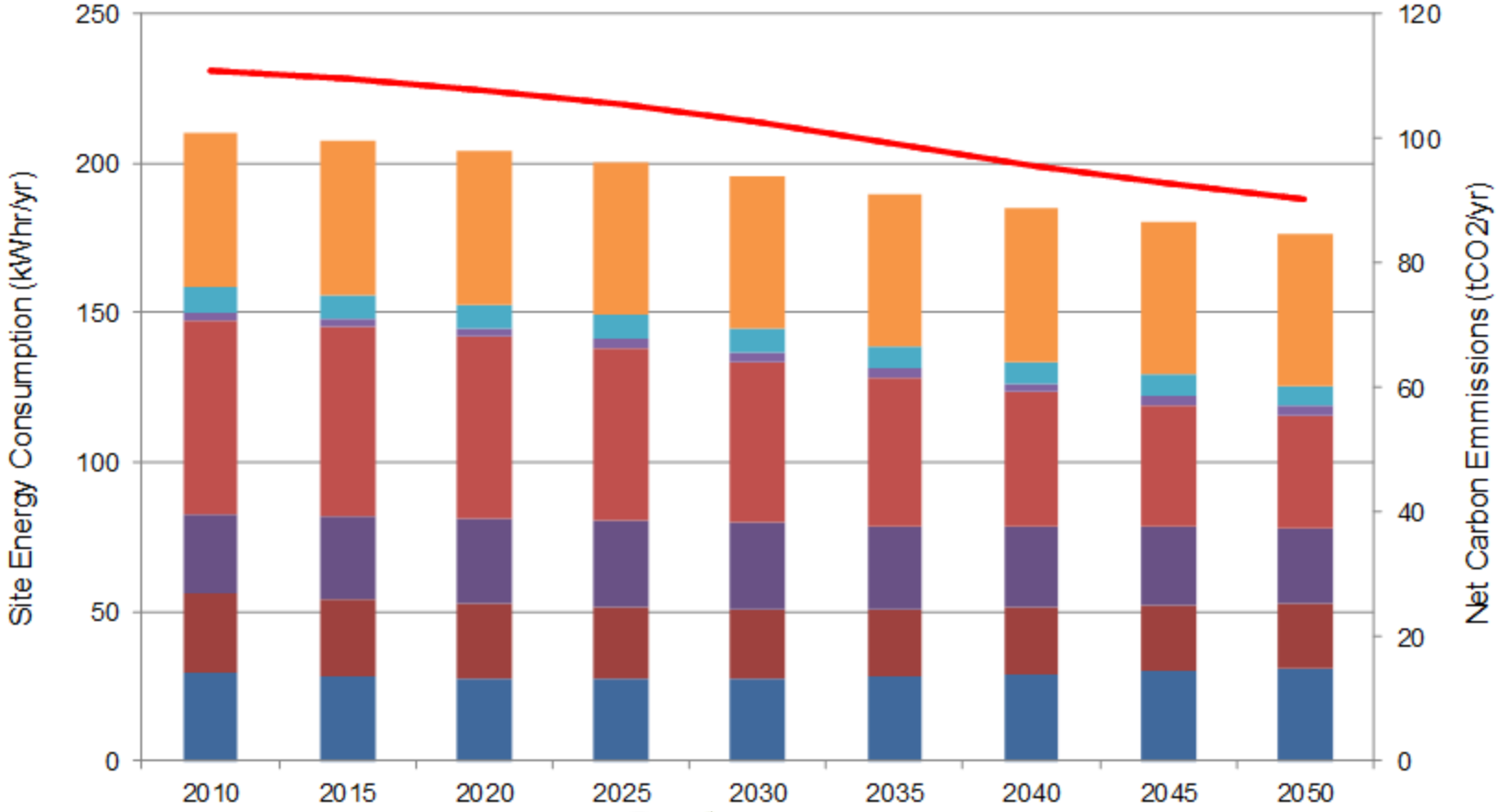
A typical AER investment is modeled as an upfront investment which yields a stream of energy savings

On-Bill repayment reduces owner contribution to first costs…..and offsets energy savings with loan payments for the duration of the loan

- Modeling objectives: Impact of qualification criteria, financing terms, bill neutrality

Model Projections: On-bill Repayment with 50% Effective Disclosure

Landlord can recoup 50% of the energy savings as increased rent for financing energy efficient retrofits



Whole Building Incentives

Goal:

Encourage broader adoption of whole building solutions that achieve greater reduction in energy consumption than piecemeal measures

Assumptions:

- EUI < 50 kWh/m^2-yr: 50% of the total retrofit cost
- EUI > 50 kWh/m^2-yr but < 90 kWh/ m^2-yr : 25% of the total retrofit cost

- Modeling objectives: Impact of price of carbon on energy efficiency retrofit rates