Energy Savings of Heat-Island Reduction Strategies for the Kansas City Area

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leidos

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Background

The Greater Kansas City Clean Air Action Plan, originally adopted in 2005 and updated in 2011, outlines voluntary measures for reducing ground-level ozone in the Kansas City metro area. Strategies for implementing the Plan include heat-island reduction (HIR) strategies like high albedo surfaces and shade trees. The heat island effect is known to increase ambient temperatures in urban areas and contribute to increased ozone formation. The Mid-America Regional Council (MARC) funded this study, which focuses on building energy impacts of HIR measures specific to the Kansas City region. Specifically, this study analyzed the direct building energy impacts of high albedo roofs, nearby high albedo ground cover, and nearby tree shading measures on commercial and residential building energy consumption.

Methodology

Leidos used a parametric energy model approach to determine the energy impacts of the HIR measures. The U.S. Department of Energy developed energy models for several commercial and residential prototype buildings. Leidos adapted a set of these prototype models to represent prevalent building types in the Kansas City region. In addition to the building type, several other significant building features were also varied in the parametric study. Tables 1 & 2 show the parameters and values that were varied in order to represent the Kansas City area building stock in this study. Many other building model inputs were used as developed for the prototypes and were not varied parametrically (e.g., building geometry, schedules). Appendices C & D include further details about the building characteristics of each energy simulation model used in this study. Tables 3 & 4 show the HIR measures that were analyzed for commercial and residential buildings, respectively.

The parametric energy model results provide energy impacts for every combination of the model input parameters. Recent average Missouri utility rates and emissions factors for electricity and natural gas were applied to determine utility cost and emissions impacts of each measure for each building. Leidos also estimated implementation costs and put together a simple payback and cost-benefit analysis for each measure. Tables 5 & 7 show the values of important calculation inputs that can be varied interactively as needed. Default values are included along with associated references.

The parametric results have been put together as interactive spreadsheets for both commercial and residential building types. The spreadsheets include dynamic pivot charts to display results, which can be filtered as needed. Appendices A & B include versions of these pivot charts that represent results for each measure using building characteristics that could be considered typical. Tables 6 & 8 indicate the building characteristic combinations that correspond to the charts displayed in Appendices A & B.

The spreadsheets that were developed through this project present the results in several ways. All of the measures are included in a spreadsheet that normalizes results on the basis of conditioned floor area. This provides a convenient way to compare results across building types. This database can also be used in combination with a breakdown of building types in the Kansas City region to determine the aggregate impact of any or all of these measures for the region. The results of the ground cover

Table 1. Commercial Building Parametric Variable Assignments

Parameter	# of Iterations	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6
Building Type	6	Medium Office	Large Office	Primary School	Hospital	Stand-Alone Retail	Mid Rise Apartment
Construction Vintage Roof R-Value	10	Pre-1980 10, 15, 20, 25	Post-1980 15, 20, 25	New Construction 15, 20, 25	- -	- -	- -
Window Solar Reflectance[1]	2	~0.15	~0.3	-	-	-	-
Economizer	2	Fixed (No Economizer)	Dry Bulb	-	-	-	-
Roof Material Emissivity (ε) & Reflectance (ρ)[2]	4	Light Gravel on Built-Up Roof $\varepsilon = 0.9$ $\rho = 0.34$	Black EPDM Membrane or Smooth Bitumen $\varepsilon = 0.86$ $\rho = 0.06$	White EPDM Membrane $\varepsilon = 0.9$ $\rho = 0.64$	Paint-On Reflective Coating $\varepsilon = 0.86$ $\rho = 0.55$	-	-
Ground Cover Material Emissivity (ε) & Reflectance (ρ)[2]	2	Asphalt $\varepsilon = 0.9$ $\rho = 0.1$	Portland Cement Concrete or Vegetation $\varepsilon = 0.9$ $\rho = 0.25$	-	-	-	-
Exterior Shading[3]	4	None	25% Tree Cover	50% Tree Cover	75% Tree Cover	-	-
Total Runs:	**7,680**						

Notes

1. Windows were chosen from the window library to meet IECC code requirements and approximate reflectance value of interest. Glass reflectivity is ~0.15 for clear glass and ~0.3 for reflective glass.
2. Infrared emissivity and solar reflectance represent 3 year aged values.
3. The % Tree Cover indicates what percentage of the building South, East, and West walls have seasonal tree coverage as represented by representative trees as described in the methodology section.

Table 2. Residential Building Parametric Variable Assignments

Parameter	# of iterations	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
Building Type	4	Single Family Gas Furnace DX Cooling	Single Family Heat Pump	Multi Family Gas Furnace DX Cooling	Multi Family Heat Pump	-
Construction Vintage Attic R-Value	10	Pre-1980[1] 10, 20, 38, 49	Post-1980[1] 20, 38, 49	IECC 2006 38, 49	IECC 2012 49	-
Window Solar Reflectance[2]	2	~0.15	~0.3	-	-	-
Roof Material Emissivity (ε) & Reflectance (ρ)[4]	5	Composition Shingles Standard - Black ε = 0.91 ρ = 0.04	Composition Shingles Standard - Tan ε = 0.91 ρ = 0.14	Composition Shingles CRCM Material[3] ε = 0.92 ρ = 0.3	Metal Roof Standard - Dark ε = 0.85 ρ = 0.1	Metal Roof CRCM Material[3] ε = 0.87 ρ = 0.43
Ground Cover Material Emissivity (ε) & Reflectance (ρ)[4]	2	Asphalt ε = 0.9 ρ = 0.1	Portland Cement Concrete or Vegetation ε = 0.9 ρ = 0.25	-	-	-
Exterior Shading[5]	4	None	25% Tree Cover	50% Tree Cover	75% Tree Cover	-
Total Runs:	**3,200**					

Notes
1. Values for Pre-1980 and Post-1980 construction based on engineering judgment.
2. Windows were chosen from the window library to meet IECC code requirements and approximate reflectance value of interest. Glass reflectivity is ~0.15 for clear glass and ~0.3 for reflective glass.
3. CRCM = cool roof color material; engineered for higher solar reflectance.
4. Infrared emissivity and solar reflectance represent 3 year aged values.
5. The % Tree Cover indicates what percentage of the building South, East, and West walls have seasonal tree coverage as represented by representative trees as described in the methodology section.

Table 3. Commercial HIR Measures

Measure Code	Component	Baseline	Revised	Measure Type[1]	Measure Life (yrs)[2]	Cost	Cost Basis	Cost Note
CR-1	Roof	Light Gravel on Built-Up Roof	Applied Coating	Retrofit	30	$ 2.10	per SF Roof Area	4
CR-2		Smooth Bitumen Roof	Applied Coating	Retrofit	30	$ 1.83	per SF Roof Area	5
CR-3		Black EPDM	White EPDM	New Upgrade	30	$ 0.13	per SF Roof Area	6
CG-1	Ground Cover	Asphalt	Concrete	New Upgrade	50	$ 1.60	per SF Covered Area	7
CS-1	Exterior Shade	None	25% Tree Cover	Retrofit	50	$ 100	per Tree[3]	8
CS-2		None	50% Tree Cover	Retrofit	50	$ 100	per Tree[3]	8
CS-3		None	75% Tree Cover	Retrofit	50	$ 100	per Tree[3]	8

Notes

1. Retrofit measures can be applied to existing buildings at any time; retrofit cost is the cost to apply the retrofit. New upgrade measures represent use of the revised building component instead of the baseline building component in new construction or at the end-of-life for an existing building; incremental cost for the revised component over the baseline component applies to this measure type.
2. Roofs: Based on median manufacturer's warranty seen in CRCC products database (by product type); Concrete: https://www.fanniemae.com/content/guide_form/4099f.pdf; Trees: Engineering judgement.
3. Each tree is assumed to have a canopy that begins five feet from the ground, extends to fifteen feet above ground, and is fifteen feet in width.
4. Average of the range (1.45-2.75) found by Lawrence Berkeley National Laboratory (LBNL-49638).
5. Average of the range (1.25-2.40) found by Lawrence Berkeley National Laboratory (LBNL-49638).
6. Average of the range (0.10-0.15) found by Lawrence Berkeley National Laboratory (LBNL-49638).
7. RS Means Incremental Cost of Concrete (320610100310) over Asphalt (321216140500 & 321216140900).
8. Tree cost estimates range from approximately $1 to $1000 per tree depending on many factors; especially initial tree size.

Reference Report LBNL-49638: "Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City)", S. Konopacki and H. Akbari, Heat Island Group - Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory - University of California, February 2002.

Table 4. Residential HIR Measures

Measure Code	Component	Baseline	Revised[1]	Measure Type[2]	Measure Life (yrs)[3]	Cost	Cost Basis	Cost Note
RR-1	Roof	Black Composition Shingles	CRCM Shingles	New Upgrade	50	$ 0.55	per SF Roof Area	4
RR-2		Tan Composition Shingles	CRCM Shingles	New Upgrade	50	$ 0.55	per SF Roof Area	4
RR-3		Standard Dark Metal Roof	CRCM Metal Roof	New Upgrade	35	$ 0.50	per SF Roof Area	5
RG-1	Ground Cover	Asphalt	Concrete	New Upgrade	50	$ 1.60	per SF Covered Area	6
RS-1	Exterior Shade	None	25% Tree Cover	Retrofit	50	$ 100	per Tree[4]	7
RS-2		None	50% Tree Cover	Retrofit	50	$ 100	per Tree[4]	7
RS-3		None	75% Tree Cover	Retrofit	50	$ 100	per Tree[4]	7

Notes

1. CRCM = Cool Roof Color Material.
2. Retrofit measures can be applied to existing buildings at any time; retrofit cost is the cost to apply the retrofit. New upgrade measures represent use of the revised building component instead of the baseline building component in new construction or at the end-of-life for an existing building; incremental cost for the revised component over the baseline component applies to this measure type.
3. Roofs: Based on median manufacturer's warranty seen in CRCC products database (by product type); Concrete: https://www.fanniemae.com/content/guide_form/4099f.pdf; Trees: Engineering judgement.
4. Each tree is assumed to have a canopy that begins five feet from the ground, extends to fifteen feet above ground, and is fifteen feet in width.
5. Average of the range (0.35-0.75) found by Lawrence Berkeley National Laboratory (LBNL-49638).
6. Average of the range (0.00-1.00+) found by Lawrence Berkeley National Laboratory (LBNL-49638).
7. RS Means Incremental Cost of Concrete (320610100310) over Asphalt (321216140500 & 321216140900).
8. Tree cost estimates range from approximately $1 to $1000 per tree depending on many factors; especially initial tree size.

Reference Report LBNL-49638: "Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City)", S. Konopacki and H. Akbari, Heat Island Group - Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory - University of California, February 2002.

Table 5. Commercial Building HIR Measure Analysis Inputs

Value	Default Value	Units	Description	Default Reference
0.093	0.093		Commercial Electricity ($/kWh)	http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a
0.86965	0.86965		Commercial Gas ($/therm)	http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm
2.1	2.1	$/SF of Roof	Applied Coating over Smooth Surface	Average of the range (1.45-2.75) found by Lawrence Berkeley National Laboratory (LBNL-49638)
1.825	1.825	$/SF of Roof	Applied Coating over Rough Surface	Average of the range (1.25-2.40) found by Lawrence Berkeley National Laboratory (LBNL-49638)
0.125	0.125	$/SF of Roof	Incremental Cost of Cool EPDM vs Black EPDM	Average of the range (0.10-0.15) found by Lawrence Berkeley National Laboratory (LBNL-49638)
1.6	1.6	$/SF of Cover	Incremental Cost of Concrete vs Asphalt	RS Means Incremental Cost of Concrete (320610100310) over Asphalt (321216140500 & 321216140900)
100	100	$/Tree	Deciduous Tree[1]	Tree cost estimates range from approximately $1 to $1000 per tree depending on many factors; especially initial tree size
5%	5%		Discount Rate[2]	
1758	1758	lb/MWh	CO2 Emissions for Electricity Generation	2013 KCP&L figure
1.9186	1.9186	lb/MWh	NOx Emissions for Electricity Generation	http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf
2.5511	2.5511	lb/MWh	SOx Emissions for Electricity Generation	http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf
11.639	11.639	lb/therm	CO2 Emissions for Natural Gas	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002, EPA430-R-04-003, U.S. EPA, Washington, DC, April 2004.
0.009126	0.009126	lb/therm	NOx Emissions for Natural Gas	http://www3.epa.gov/ttnchie1/conference/ei12/area/haneke.pdf
5.83E-05	5.83E-05	lb/therm	SOx Emissions for Natural Gas	http://www3.epa.gov/ttnchie1/conference/ei12/area/haneke.pdf

Notes

1. Each tree is assumed to have a canopy that begins five feet from the ground, extends to fifteen feet above ground, and is fifteen feet in width.
2. Discount rate is used to determine the present value of utility cost savings over the life of the measure.

Reference Report LBNL-49638: "Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City)", S. Konopacki and H. Akbari, Heat Island Group - Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory - University of California, February 2002.

Table 6. Commercial Building "Typical" Values Chosen for Overall Results Presentation (Appendix A)

Building Type	Window Reflectivity	Reference	Economizer	Reference
Hospital	High	Engineering Judgement	Dry Bulb	Engineering Judgement
Large Office	High	Engineering Judgement	Dry Bulb	Engineering Judgement
Medium Office	Both	Engineering Judgement	Dry Bulb	Engineering Judgement
Mid Rise Apartment	Low	Engineering Judgement	Fixed	Engineering Judgement
Primary School	Both	Engineering Judgement	Dry Bulb	Engineering Judgement
Stand-Alone Retail	Low	Engineering Judgement	Both	Engineering Judgement

Construction Vintage	Roof R-Value	Reference
Pre 1980	10	Engineering Judgement
Post 1980	15	Commercial IECC 2006
New Construction	25	Commercial IECC 2012

measures (CG-1 and RG-1) are presented on the basis of conditioned building area (expressed in units of kSF or thousand square feet of conditioned floor area) in Appendices A & B.

In addition to the spreadsheets that normalize results based on conditioned area, two other normalization bases are provided. For the roof measures, spreadsheets are provided that normalize results on the basis of roof area (in units of kSF or thousand square feet of roof area). For the tree shading measures, spreadsheets are provided that normalize results per tree.

Table 7. Residential Building HIR Measure Analysis Inputs

Value	Default Value	Units	Description	Default Reference
0.1186	0.1186	$/kWh	Residential Electricity	http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a
1.027237	1.027237	$/therm	Residential Gas	http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm
0.55	0.55	$/SF of Roof	CRCM[1] Composite Shingle	Average of the range (0.35-0.75) found by Lawrence Berkeley National Laboratory (LBNL-49638)
0.5	0.5	$/SF of Roof	CRCM[1] Metal Roof	Average of the range (0.00-1.00+) found by Lawrence Berkeley National Laboratory (LBNL-49638)
1.6	1.6	$/SF of Cover	Incremental Cost of Concrete vs Asphalt	RS Means Incremental Cost of Concrete (320610100310) over Asphalt (321216140500 & 321216140900)
100	100	$/Tree	Deciduous Tree[2]	Tree cost estimates range from approximately $1 to $1000 per tree depending on many factors; especially initial tree size
5%	5%		Discount Rate[3]	
1758	1758	lb/MWh	CO2 Emissions for Electricity Generation	2013 KCP&L figure
1.9186	1.9186	lb/MWh	NOx Emissions for Electricity Generation	http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf
2.5511	2.5511	lb/MWh	SOx Emissions for Electricity Generation	http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf
11.639	11.639	lb/therm	CO2 Emissions for Natural Gas	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002, EPA430-R-04-003, U.S. EPA, Washington, DC, April 2004.
0.009126	0.009126	lb/therm	NOx Emissions for Natural Gas	http://www3.epa.gov/ttnchie1/conference/ei12/area/haneke.pdf
5.83E-05	5.83E-05	lb/therm	SOx Emissions for Natural Gas	http://www3.epa.gov/ttnchie1/conference/ei12/area/haneke.pdf

Notes

1. CRCM = Cool Roof Color Material.
2. Each tree is assumed to have a canopy that begins five feet from the ground, extends to fifteen feet above ground, and is fifteen feet in width.
3. Discount rate is used to determine the present value of utility cost savings over the life of the measure.

Reference Report LBNL-49638: "Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Aslt Lake City)", S. Konopacki and H. Akbari, Heat Island Group - Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory - University of California, February 2002.

Table 8. Residential Building "Typical" Values Chosen for Overall Results Presentation (Appendix B)

Building Type	Window Reflectivity	Reference
Single Family	Low	Engineering Judgement
Multi Family	Low	Engineering Judgement

Construction Vintage	Roof R-Value	Reference
Pre 1980	10	Engineering Judgement
Post 1980	20	Engineering Judgement
IECC 2006	38	Residential IECC 2006
IECC 2012	49	Residential IECC 2012

Measure Descriptions

Roof Measures

The urban heat island effect is reduced when any building exterior surface is high albedo; meaning that it reflects a higher percentage of solar energy back away from the surface. Since roofs face generally upward, they receive solar energy directly, and high albedo roofs can effectively reflect a higher portion of that energy back into space than more conventional options. Also, in an urban environment the building roof area can represent a significant fraction of total area.

ENERGY STAR keeps a database of certified roof products[1]. This database lists roofing products in several categories along with initial and 3-year aged solar reflectance, emissivity, and warranty. For the purposes of this study, the 75th percentile aged solar reflectance and emissivity were used to represent high albedo roof products. A spreadsheet file of the ENERGY STAR product database that was current at the time of this study has been provided to accompany the report.

Baseline roof reflectance ranges from 0.04 to 0.34, and high albedo roofing reflectance ranges from 0.3 to 0.64. For commercial roofing, high albedo coatings can be applied over an existing roof in good repair as a retrofit. Measures CR-1 and CR-2 examine the impacts of applying such a coating over a light gravel covered built-up roof and a smooth bitumen roof, respectively. Measure CR-3 examines the incremental cost and energy impact of choosing a high albedo EPDM membrane roof instead of a conventional black EPDM roof. Residential roof measures examine the use or cool roof color material (CRCM) shingles instead of either black (measure RR-1) or tan (measure RR-2) composition shingles. Measure RR-3 examines the use of CRCM metal roofing instead of conventional dark metal roofing. Cool roof color materials are specially engineered to provide high solar reflectance even with a visual color that may appear relatively dark. The need for CRCMs arises in part from a consumer acceptance perspective; medium or darker colors are preferred over white roofing in residential applications.

In addition to reflectance, a secondary surface property that relates to the urban heat island effect is emissivity. Emissivity is a measure of how efficiently a surface emits thermal energy. A so-called "black body" is a perfect emitter with an emissivity of 1. Most non-metallic surfaces have thermal emittance between 0.80 and 0.95. All of the roofs considered in this analysis have emissivity ranging from 0.85 to 0.92.

Ground Cover Measure

High albedo ground cover is another heat island reduction measure. The urban hardscape often consists of relatively dark asphalt pavement (reflectance of 0.1) that absorbs solar energy. Lighter ground cover options exist such as concrete or vegetation; both with a reflectance of about 0.25. Higher reflectance

[1] http://www.energystar.gov/productfinder/product/certified-roof-products/

ground cover will reduce ambient temperatures in an urban environment; however, the direct effect upon nearby buildings is to reflect more ground-incident solar energy back toward the buildings. This increases solar heat gain, which is beneficial in the winter but not in the summer.

The commercial (CG-1) and residential (RG-1) ground cover measures both examine the effect of Portland cement (or vegetation) as a ground cover instead of asphalt. For the purposes of cost estimation, a ground cover area with a width of four feet surrounding the West, South, and East perimeters of each building was considered. The incremental cost of Portland cement over asphalt ground cover was used in the analysis.

Tree Shading Measures

Trees are another HIR strategy; they reduce the amount of solar energy that reaches buildings and the ground and can cool the air through evapotranspiration. This study examines the direct effect of strategically placed trees that shade buildings. The effect and the cost of the shade trees depend on many factors, including the tree size, placement, and amount of sunlight penetration (including any seasonal differences). Based on a similar study[2], the tree shade measures considered mature box-shaped trees that are 15 feet wide with foliage that extends from 5 feet above ground to 15 feet above ground. The trees extend to within 5 feet of the building and are planted along the West, South, and East building facades (see Figure 1). The solar transmittance is modeled as 0.1 for April 1 through October 31 and as 0.9 the rest of the year (to mimic deciduous tree foliage). The commercial building tree shade measures CS-1, CS-2, and CS-3 consider 25%, 50%, and 75% tree coverage along the three facades, respectively. Residential tree shade measures RS-1, RS-2, and RS-3 are similarly defined for residential building types. Tree cost can be highly variable depending on the size, location, and type of tree. The literature show cost estimates ranging from approximately $1/tree to $1000/tree. A cost of $100/tree was used in this study, although the measure cost is something that can be adjusted in the provided spreadsheets.

[2] LBNL-49638: "Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City)", S. Konopacki and H. Akbari, Heat Island Group - Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory - University of California, February 2002.

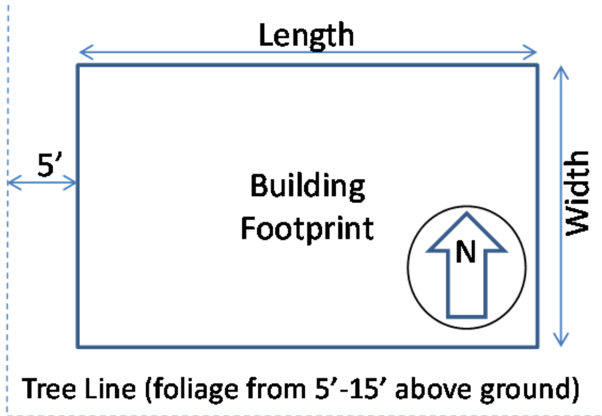


Figure 1. Tree Shading Diagram (Plan View)

Results

Comprehensive results are provided in Appendices A & B for the commercial and residential building HIR measures studied. Any number of combinations can be examined using the results database spreadsheets provided. To summarize the results further, Tables 9-14 indicate the range of energy impacts observed for each measure. In each case a range is seen due to the different building characteristics based on vintage. For example, older buildings with lower roof insulation levels exhibit different savings for a high albedo roof than a new building with more roof insulation.

A detailed look at the roof measure data show, as expected, that high albedo roofs save summer cooling energy but also increase the required winter heating energy. For the building types with multi-zone reheat systems (hospital, large office, medium office, and primary school), some net heating energy savings can be seen. This is because the high albedo roof reduces the difference in cooling requirements between the zones with roof exposure and those without. The result is that the zones without roof exposure require less reheat during the cooling season. Tables 9 & 12 show net energy cost savings for all of the commercial and residential roof measures, although the magnitude of the savings is not compelling enough to justify the investment in most cases. Measure CR-3 (white EPDM instead of black EPDM) does have reasonable payback for buildings with relatively low roof insulation, however additional roof insulation would generally be recommended at the time of roof replacement anyway.

The high albedo ground cover measures cause increased solar gains to nearby buildings, as expected. This does save some heating energy, but it also increases cooling energy. The net result is increased energy cost for the buildings; the one exception being older mid rise apartments, which show a small net energy cost savings.

Table 9. Commercial Building Roof Measures

	Energy Cost Savings ($/Roof kSF)			Simple Payback (Years)		
Measure	CR-1	CR-2	CR-3	CR-1	CR-2	CR-3
Hospital	1.2 to 30	2.8 to 58	3.1 to 61	71 to >100	31 to >100	2.0 to 40
Large Office	2.3 to 13	6.3 to 26	7.6 to 25	>100	70 to >100	5.0 to 17
Medium Office	2.2 to 11	5.6 to 27	6.6 to 32	>100	69 to >100	3.9 to 19
Mid Rise Apartment	2.1 to 4.3	5.0 to 10	5.4 to 11	>100	>100	11 to 23
Primary School	3.7 to 20	9.7 to 44	12 to 55	>100	43 to >100	2.3 to 11
Stand-Alone Retail	2.4 to 14	8.1 to 42	9.8 to 44	>100	42 to >100	2.9 to 13

Table 10. Commercial Building Ground Cover Measure

	Energy Cost Savings ($/Conditioned kSF)	Simple Payback (Years)
Measure	CG-1	CG-1
Hospital	-40 to -6.8	Note 1
Large Office	-4.8 to -1.5	
Medium Office	-16 to -5.8	
Mid Rise Apartment	-1.0 to 1.8	
Primary School	-27 to -15	
Stand-Alone Retail	-5.4 to -1.9	

Notes

1. Direct energy impacts to the buildings are a net energy cost for all but older apartments, which have a small savings but a long (35+ year) payback.

Table 11. Commercial Building Tree Shade Measures

	Energy Cost Savings ($/Tree)			Simple Payback (Years)		
Measure	CS-1	CS-2	CS-3	CS-1	CS-2	CS-3
Hospital	14 to 35	14 to 35	12 to 31	2.8 to 7.1	2.9 to 7.4	3.2 to 8.7
Large Office	17 to 30	7.2 to 13	6.5 to 11	4.7 to 6.1	7.7 to 15	11 to 16
Medium Office	28 to 64	27 to 60	26 to 57	1.6 to 3.5	1.7 to 3.7	1.8 to 3.9
Mid Rise Apartment	5.7 to 9.0	4.9 to 7.8	4.2 to 7.1	11 to 18	13 to 21	14 to 24
Primary School	18 to 25	20 to 30	20 to 31	4.7 to 5.6	3.5 to 5.0	3.3 to 5.0
Stand-Alone Retail	4.5 to 7.4	4.3 to 7.1	4.0 to 6.6	15 to 26	15 to 27	16 to 29

Table 12. Residential Building Roof Measures

	Energy Cost Savings ($/Roof kSF)			Simple Payback (Years)		
Measure	RR-1	RR-2	RR-3	RR-1	RR-2	RR-3
Single Family w/ Furnace	1.9 to 16	1.2 to 10	2.0 to 20	35 to >100	56 to >100	25 to >100
Single Family w/ Heat Pump	1.4 to 12	0.8 to 7.5	1.6 to 16	65 to >100	>100	41 to >100
Multi Family w/ Furnace	1.7 to 14	1.1 to 8.3	2.2 to 17	41 to >100	66 to >100	29 to >100
Multi Family w/ Heat Pump	1.7 to 5.7	1.1 to 3.7	2.3 to 7.6	96 to >100	>100	66 to >100

Table 13. Residential Building Ground Cover Measure

	Energy Cost Savings ($/Conditioned kSF)	Simple Payback (Years)
Measure	RG-1	RG-1
Single Family w/ Furnace	-25 to -4.3	Note 1
Single Family w/ Heat Pump	-15 to -2.0	
Multi Family w/ Furnace	-19 to -5.1	
Multi Family w/ Heat Pump	-7.5 to -3.9	

Notes

1. Direct energy impacts to the buildings are a net energy cost, which explains the negative simple paybacks.

Table 14. Residential Building Tree Shade Measures

	Energy Cost Savings ($/Tree)			Simple Payback (Years)		
Measure	RS-1	RS-2	RS-3	RS-1	RS-2	RS-3
Single Family w/ Furnace	8.5 to 17	7.7 to 16	7.0 to 15	5.9 to 12	6.4 to 14	6.9 to 14
Single Family w/ Heat Pump	8.6 to 14	7.9 to 14	7.1 to 14	7.3 to 12	7.0 to 13	7.4 to 14
Multi Family w/ Furnace	21 to 29	21 to 30	19 to 29	3.4 to 4.7	3.3 to 4.8	3.5 to 5.2
Multi Family w/ Heat Pump	19 to 28	20 to 28	18 to 25	3.6 to 5.2	3.6 to 5.1	4.0 to 5.8

The tree shade measures generally show the most promise for significant energy savings at reasonable payback. This is true for both the commercial and residential buildings studied. The range of savings occurs mainly because of different window solar heat gain coefficients (SHGCs) that are modeled for different vintages. As expected, more savings occurs from shading an older window with a higher SHGC than occurs from shading a new window with a low SHGC. For any given building type, Tables 11 and 14 show very similar numbers across the measures (CS-1 through CS-3 and RS-1 through RS-3). This is because the savings results are expressed on a per tree basis. The savings are roughly linear then for additional shade trees in this model. Simple payback scales roughly linearly as well because the savings per tree is roughly linear and the cost per tree is linear.

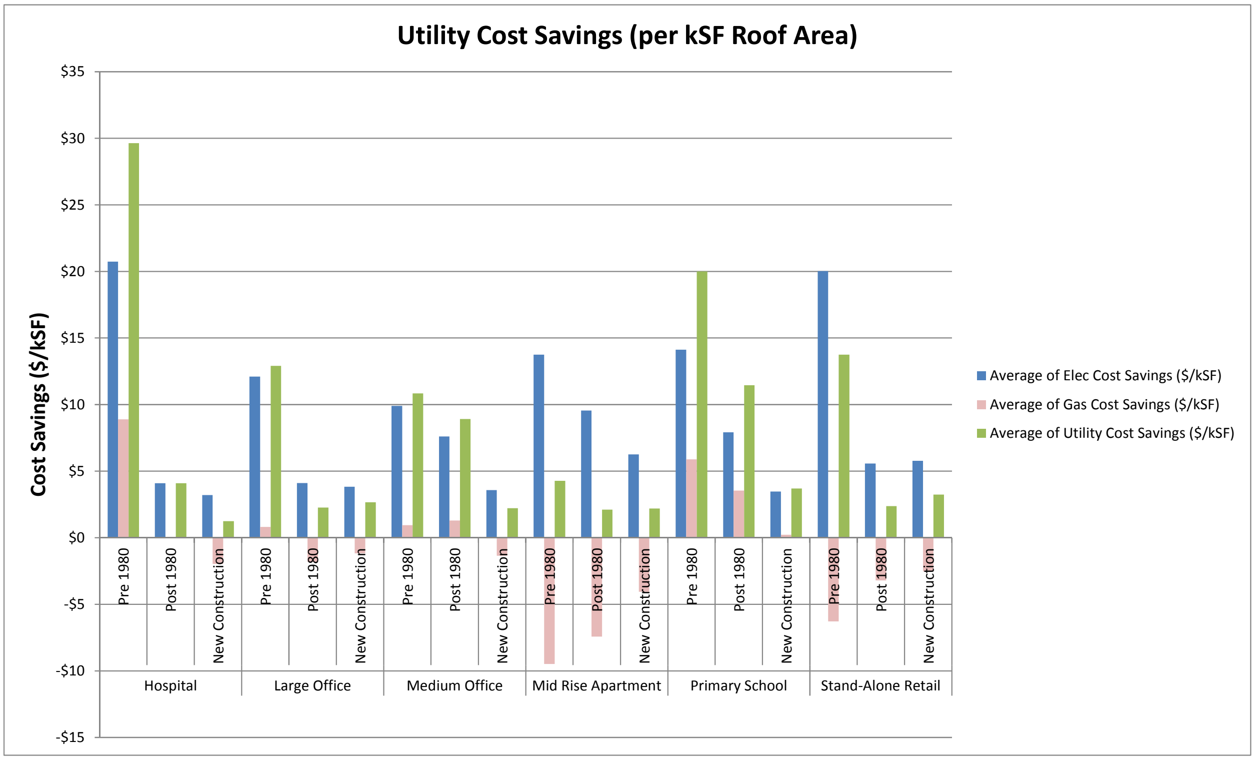
Of course, for any given building the tree placement will significantly affect the results. In this study trees were placed within a reasonable distance of the building (canopy within 5 feet) and along the best building exposures (West, South, and East). This methodology averages out the effect of a shade tree planted somewhere on that tree line (see Figure 1). More or less benefit could be realized depending on the exact tree placement. This means that careful regard for tree placement with respect to building glazing will show even better savings per tree and better payback than average.

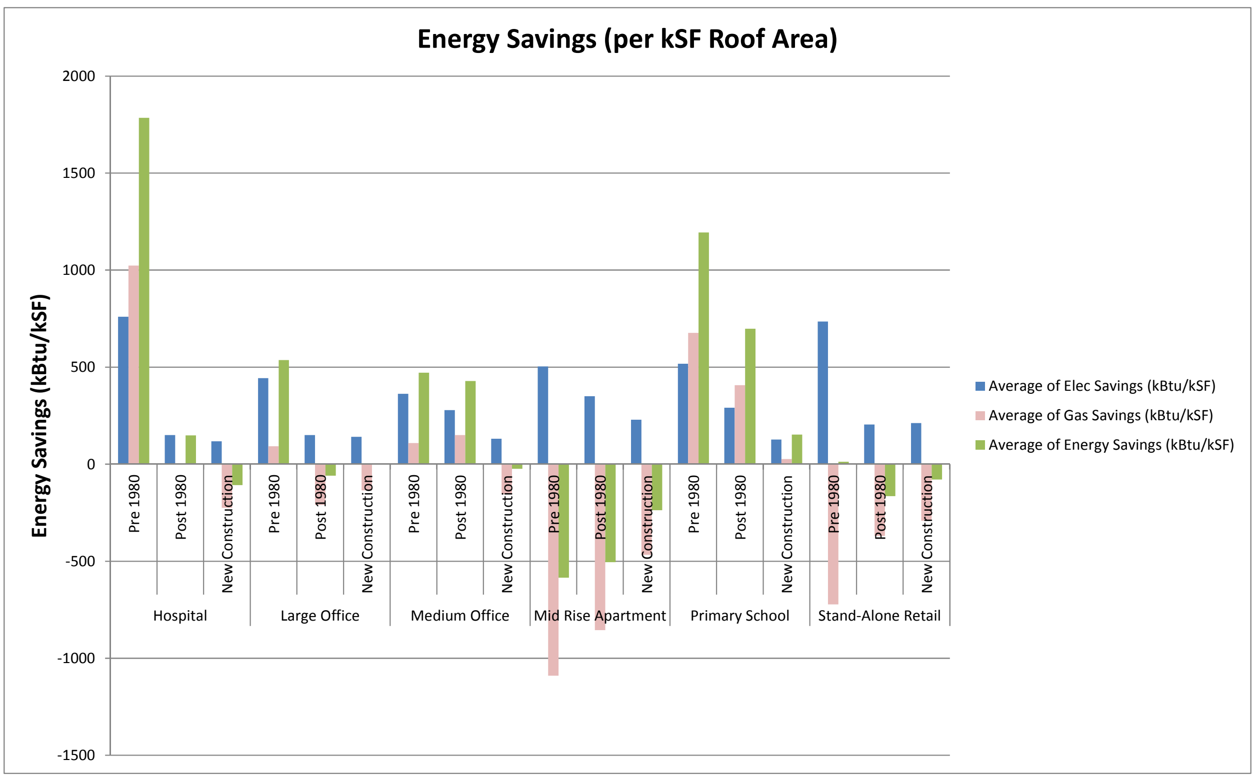
Conclusions

The purpose of this study was to determine the direct energy impacts to buildings from implementation of heat island reduction measures in the Kansas City region. The parametric energy model approach provided a wealth of data to examine the energy impacts on various building types and with various building characteristics common to the region. Implementation cost estimates were also developed. The high albedo roof measure savings show significant dependence on the roof insulation level, as expected. Overall, the net energy cost savings of high albedo roofs could not reasonably support the additional cost. High albedo ground cover results in a net energy cost increase when only direct building impacts are considered. Tree shading measures show significant promise for both the commercial and residential buildings studied. Careful consideration of tree placement relative to the building can further improve the savings per tree and the payback beyond the average results obtained in this study.

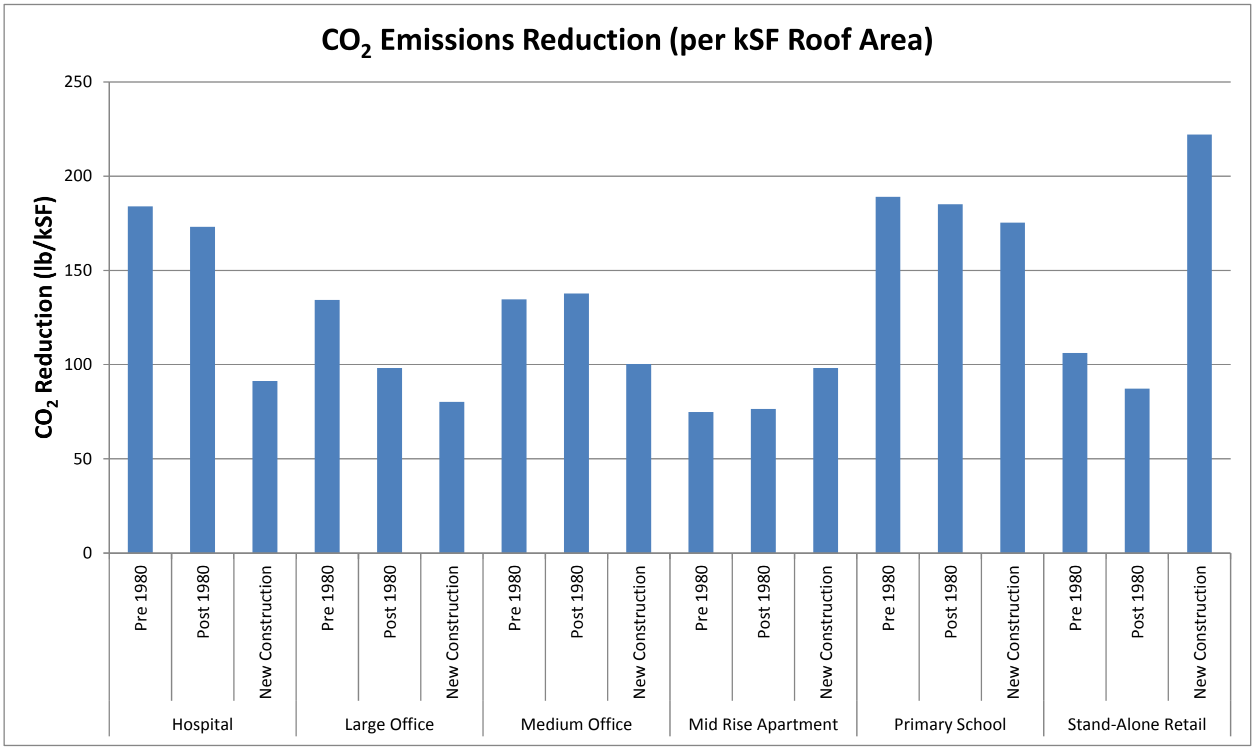
Appendix A: Commercial Measure Results

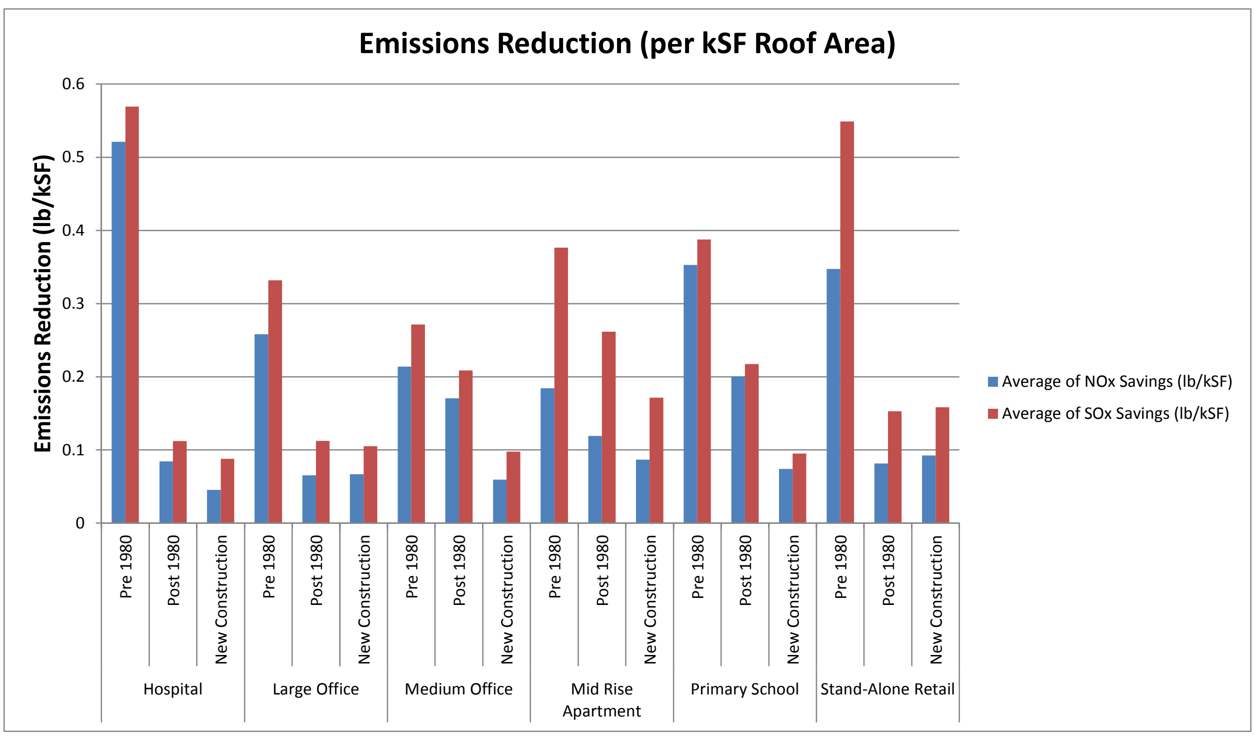
Measure CR-1


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$35
$30
$25
$20
$15
$10
$5
$0
-$5
-$10
-$15
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

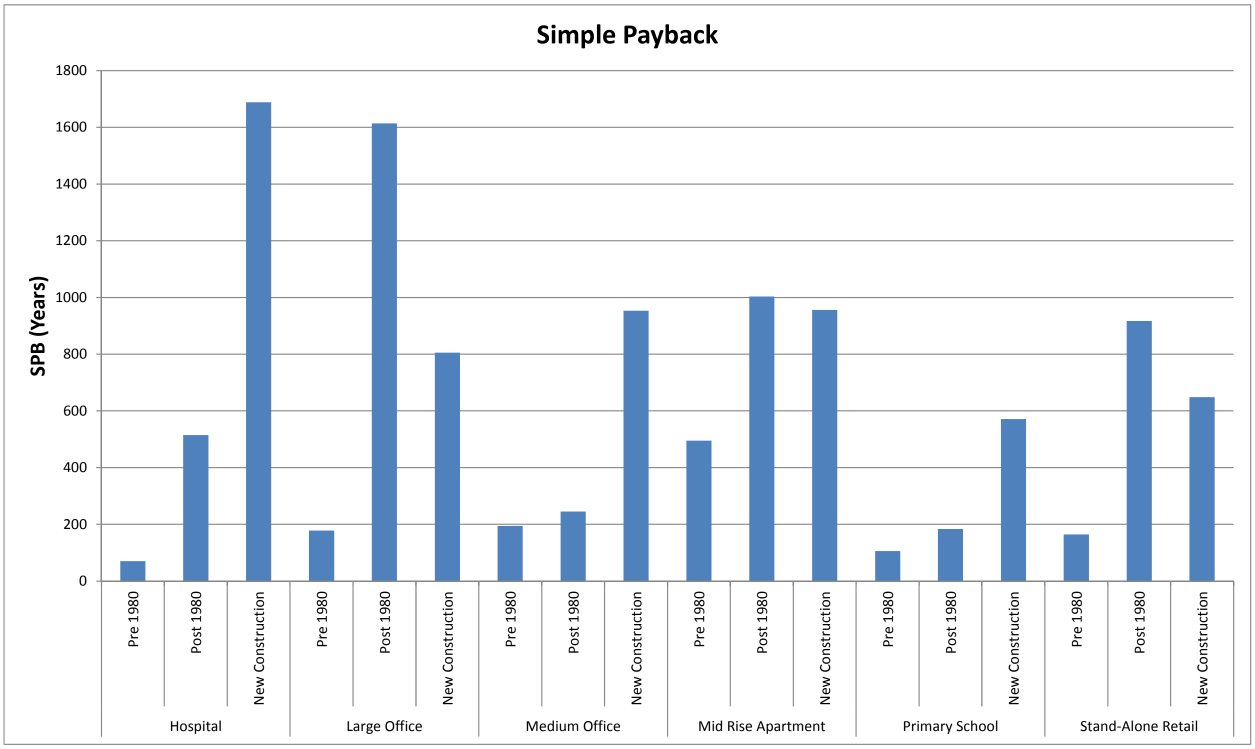

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
2000
1500
1000
500
0
-500
-1000
-1500
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

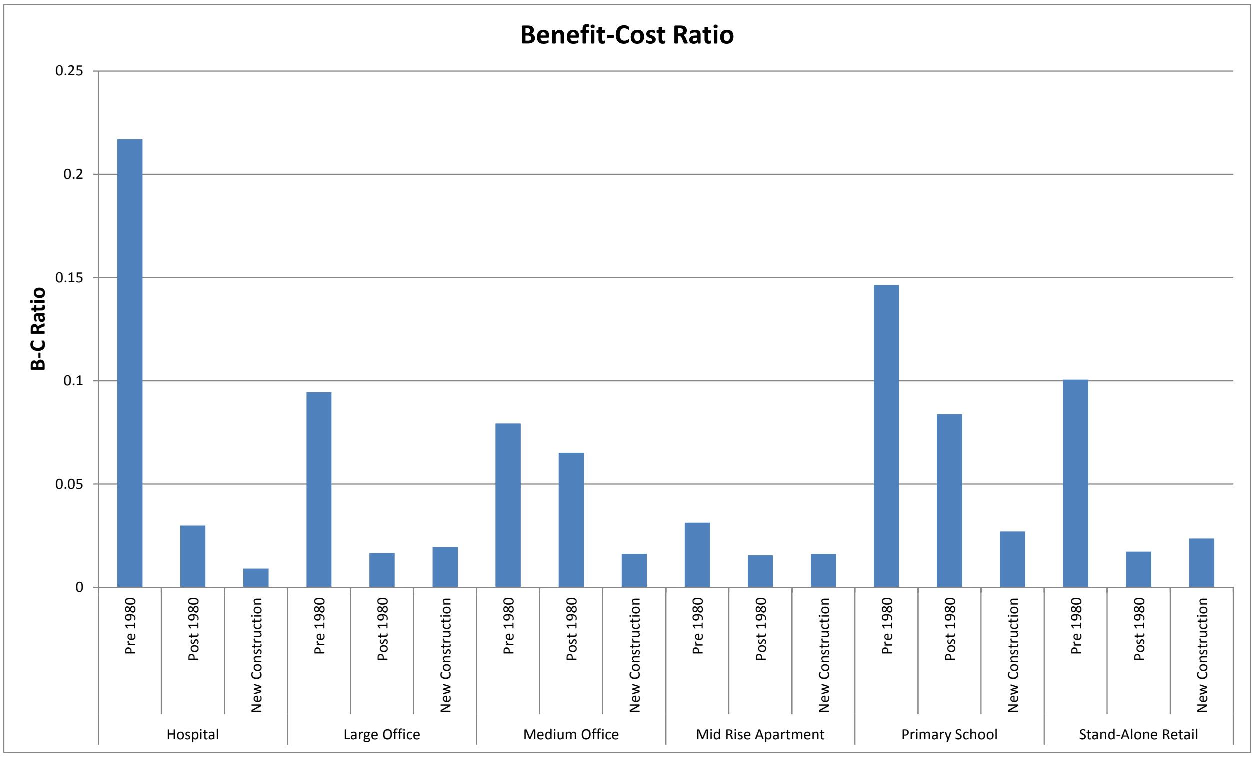
Measure CR-1


CO_2 Emissions Reduction (per kSF Roof Area)
CO_2 Reduction (lb/kSF)
0
50
100
150
200
250
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

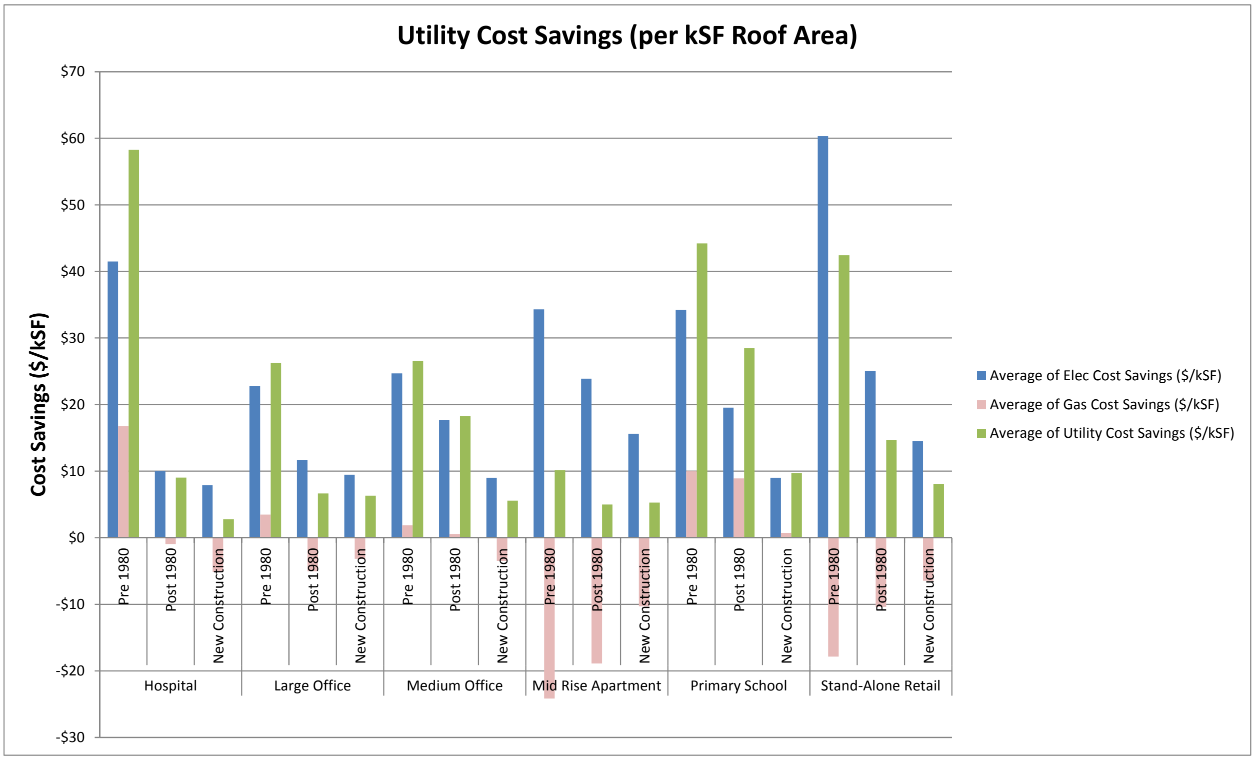

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0
0.1
0.2
0.3
0.4
0.5
0.6
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

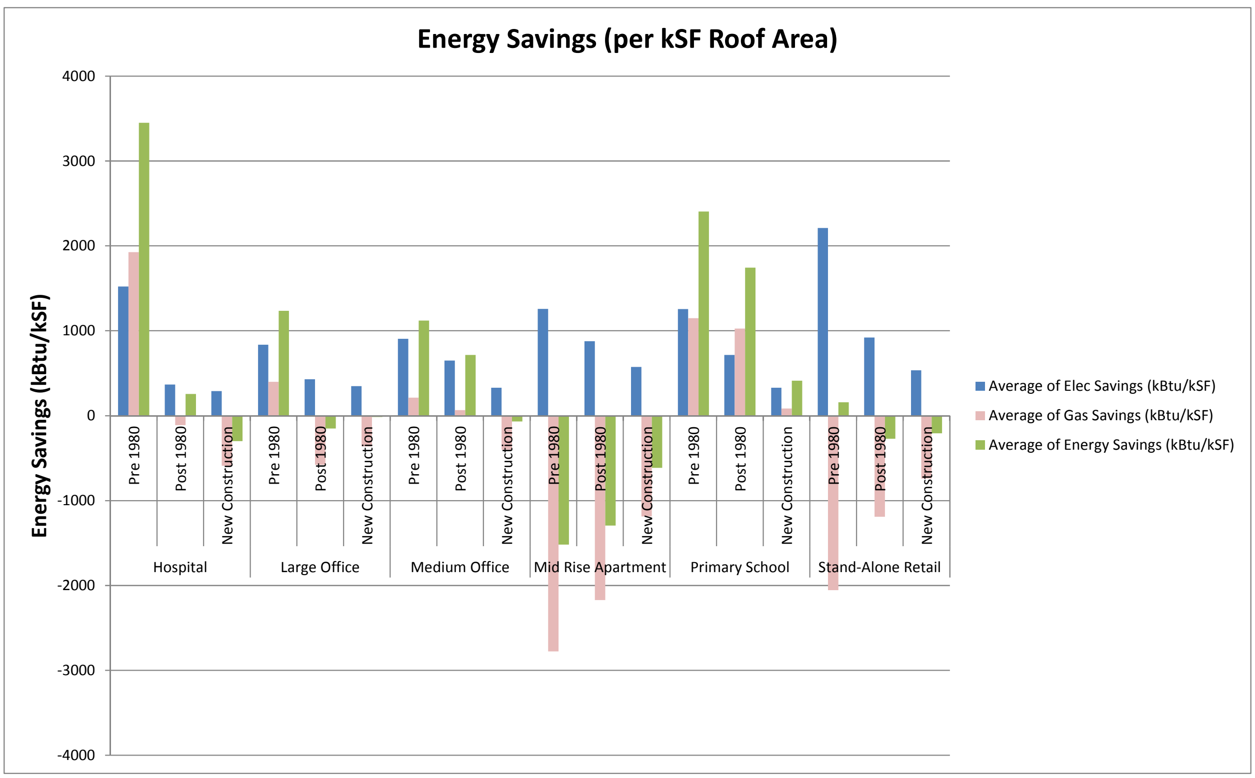
Measure CR-1


Simple Payback
SPB (Years)
1800
1600
1400
1200
1000
800
600
400
200
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

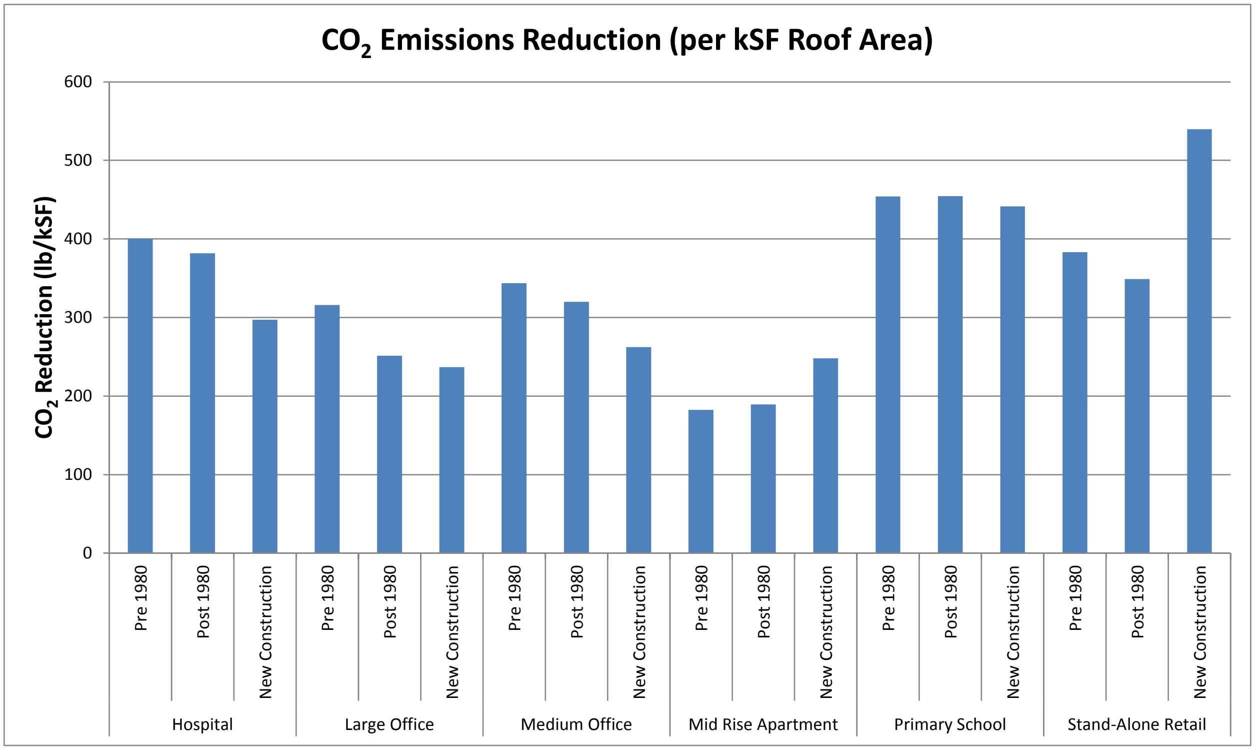

Benefit-Cost Ratio
B-C Ratio
0.25
0.2
0.15
0.1
0.05
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

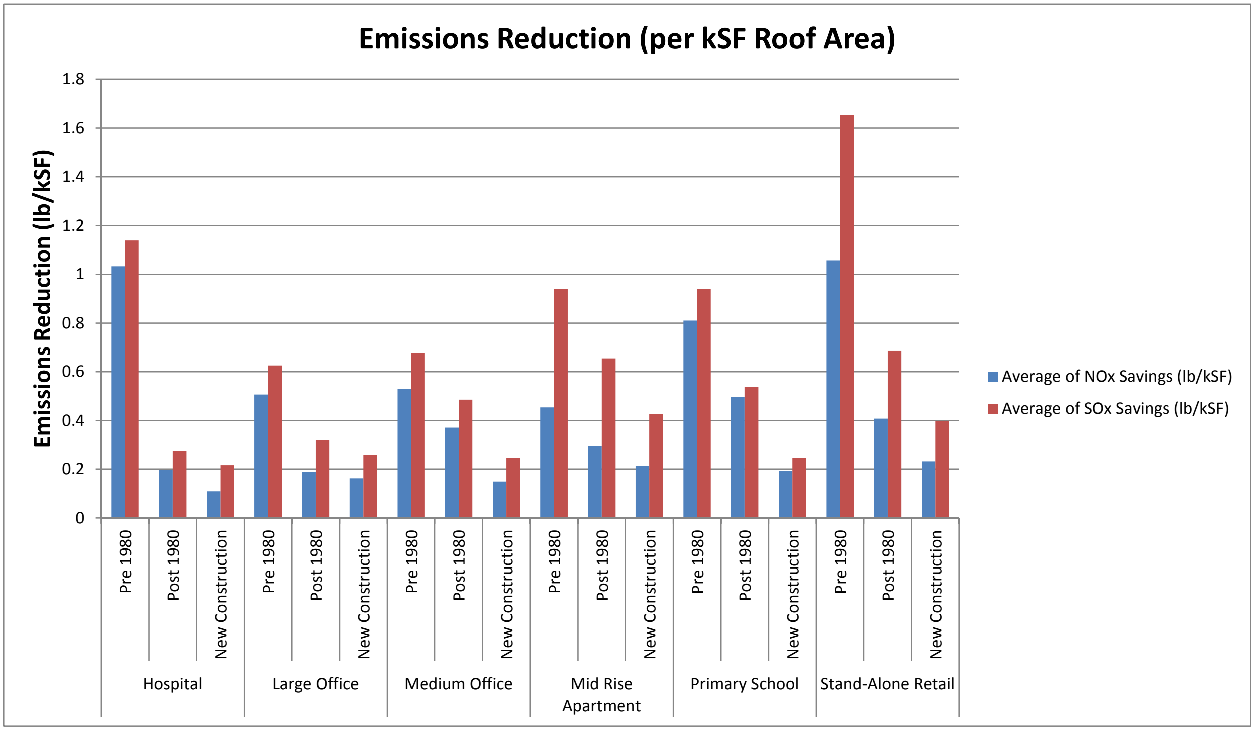
Measure CR-2


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$70
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
-$30
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

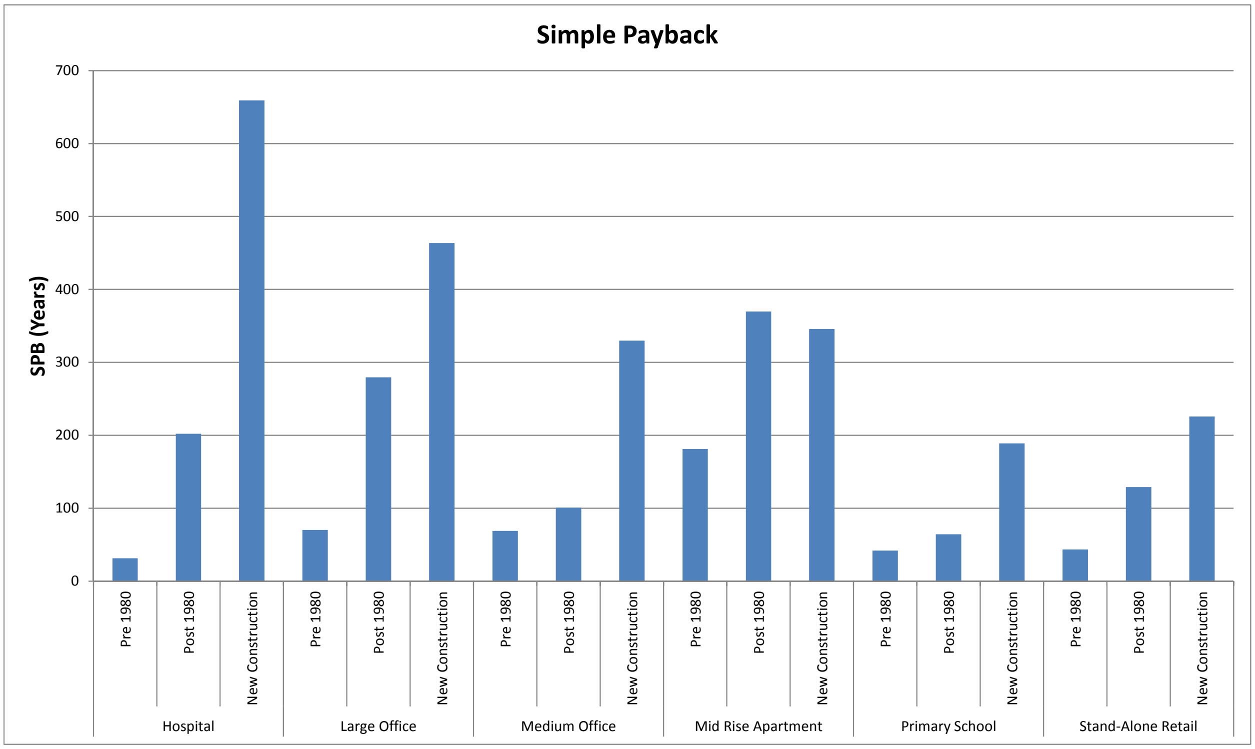

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

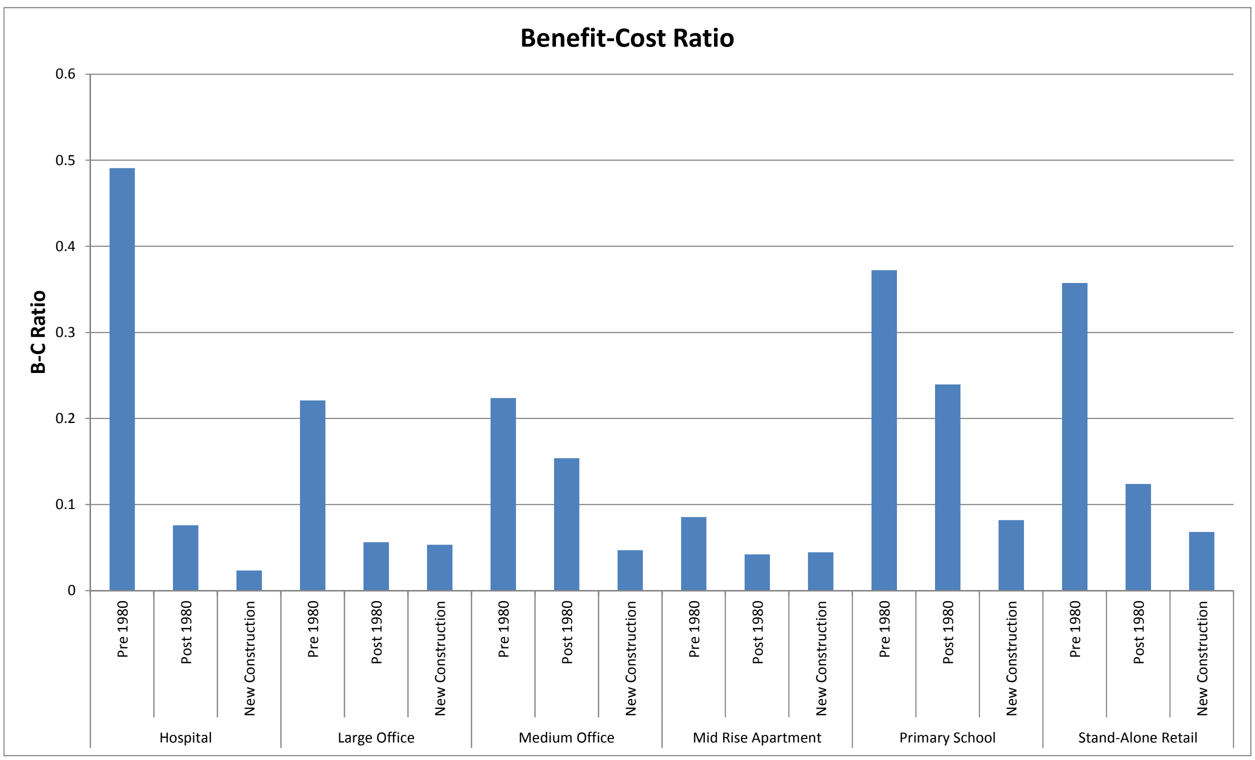
Measure CR-2


CO_2 Emissions Reduction (per kSF Roof Area)
CO_2 Reduction (lb/kSF)
0
100
200
300
400
500
600
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

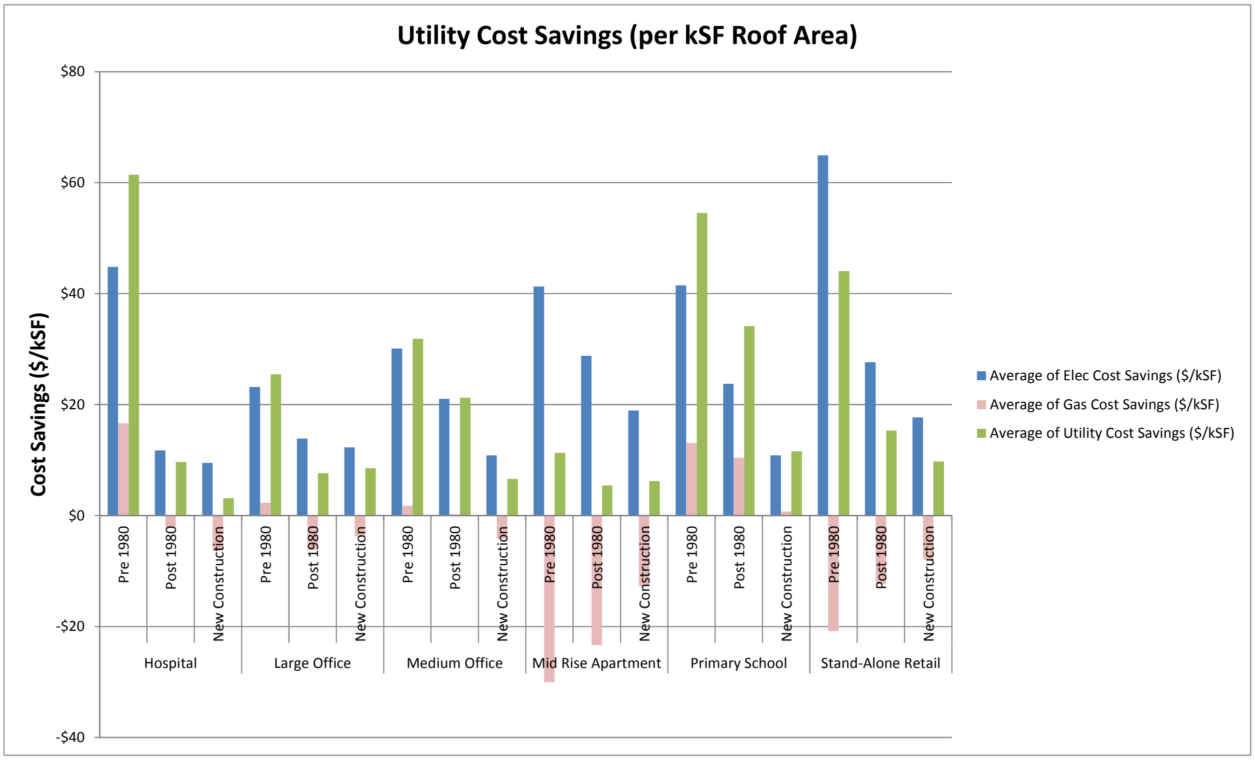

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

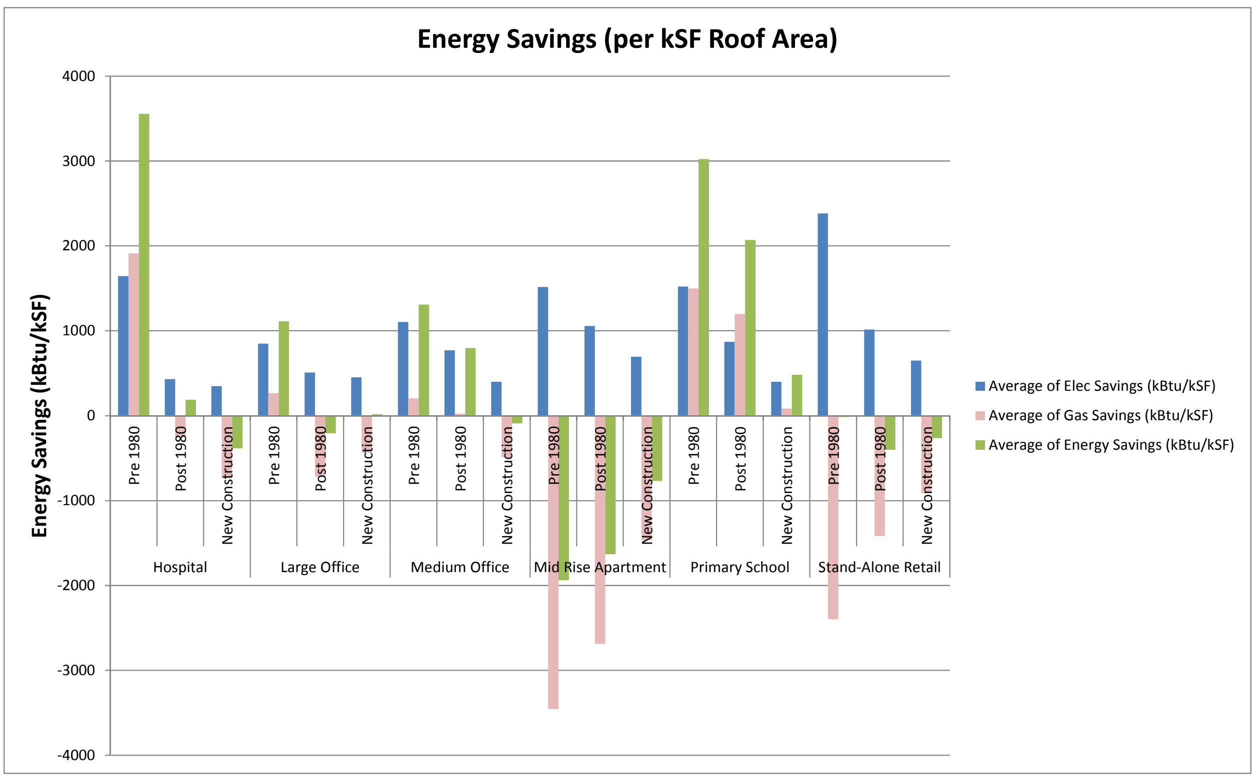
Measure CR-2


Simple Payback
SPB (Years)
700
600
500
400
300
200
100
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

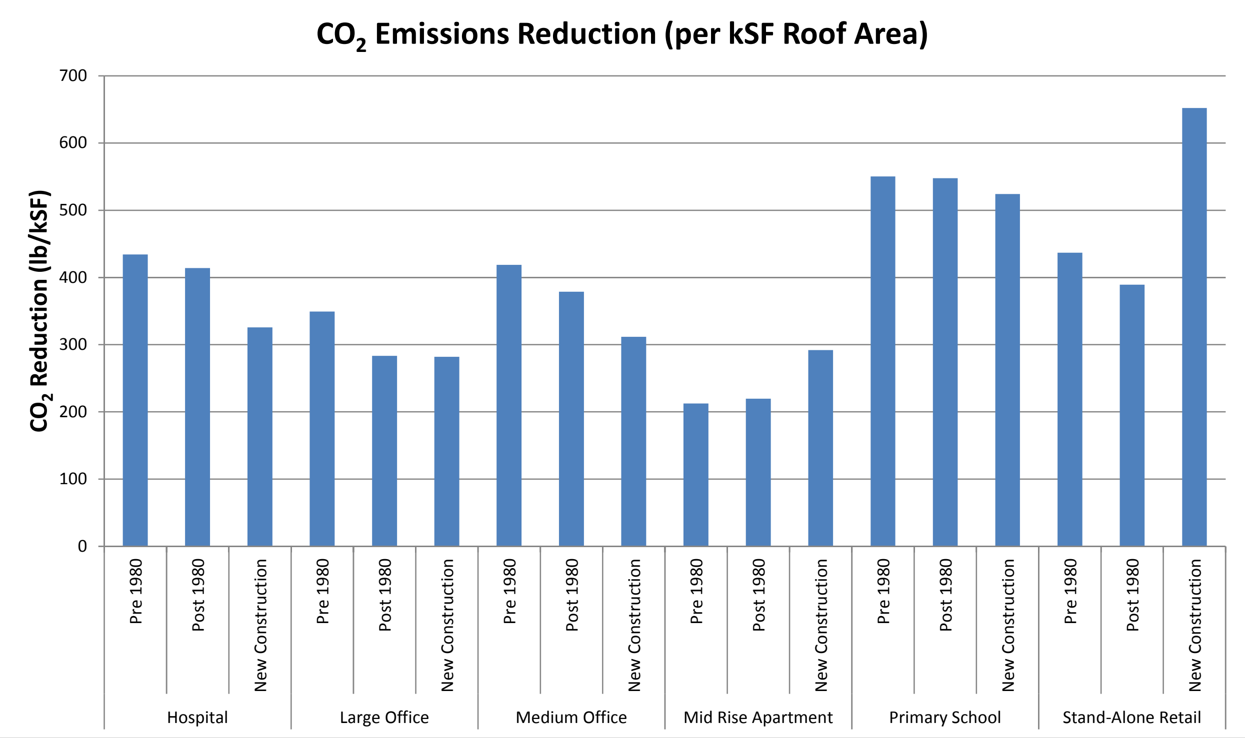

Benefit-Cost Ratio
B-C Ratio
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

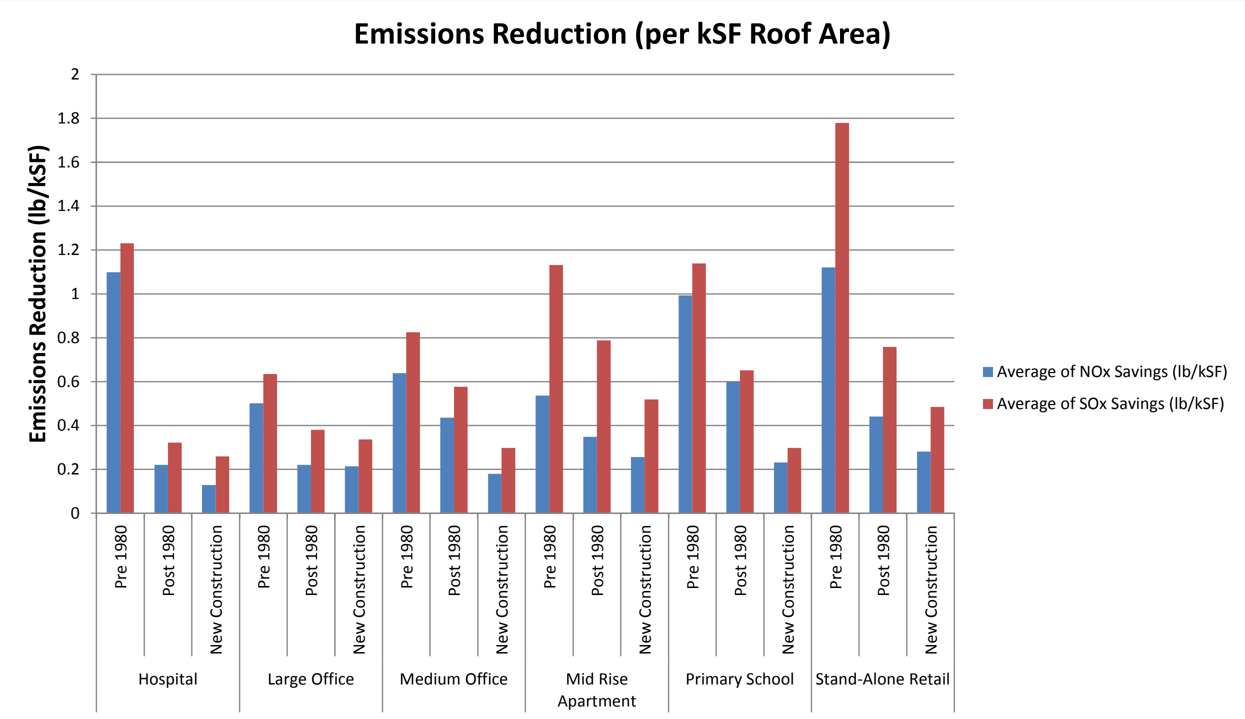
Measure CR-3


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$80
$60
$40
$20
$0
-$20
-$40
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

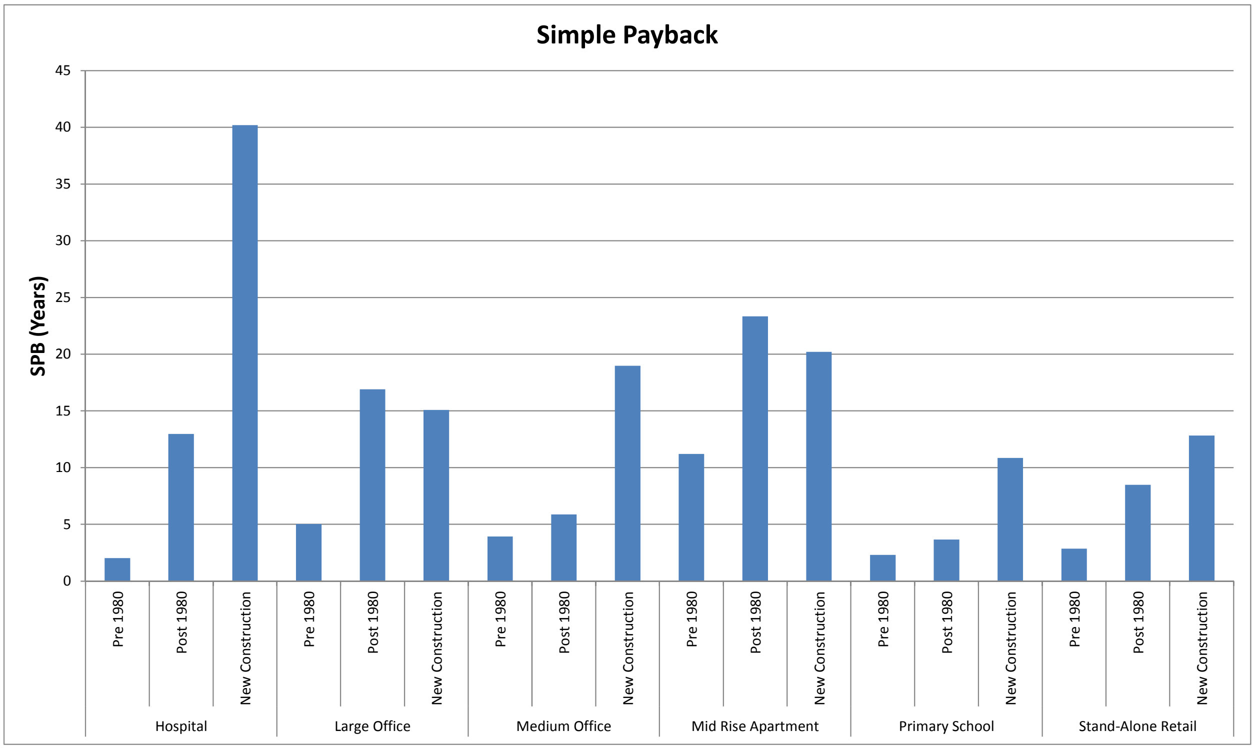

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

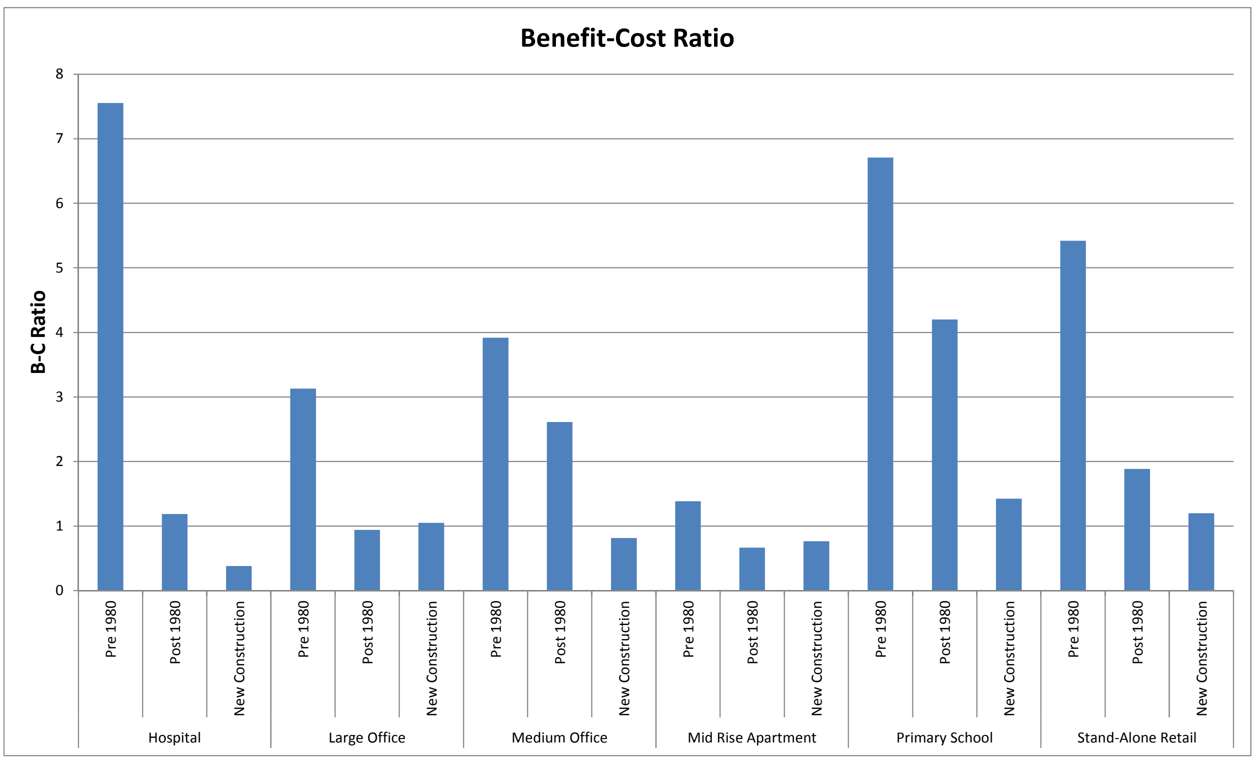
Measure CR-3


CO_2 Emissions Reduction (per kSF Roof Area)
CO_2 Reduction (lb/kSF)
0
100
200
300
400
500
600
700
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

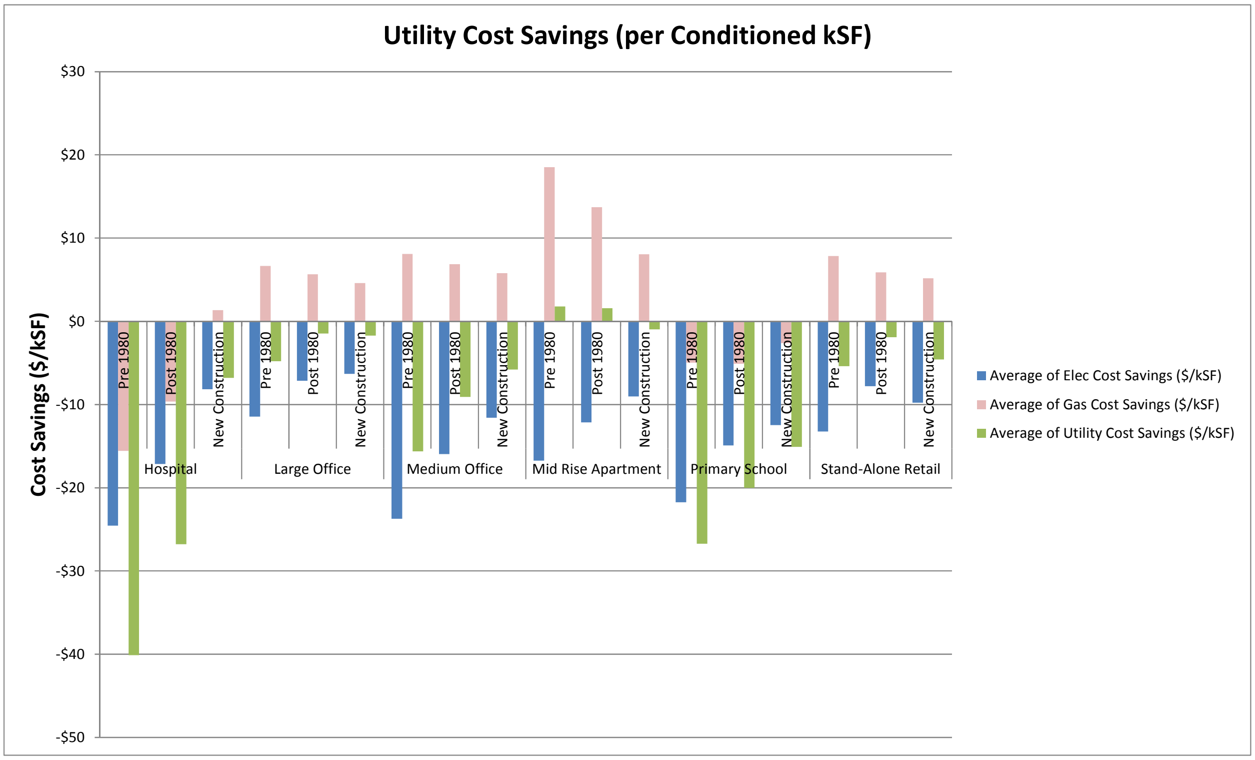

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

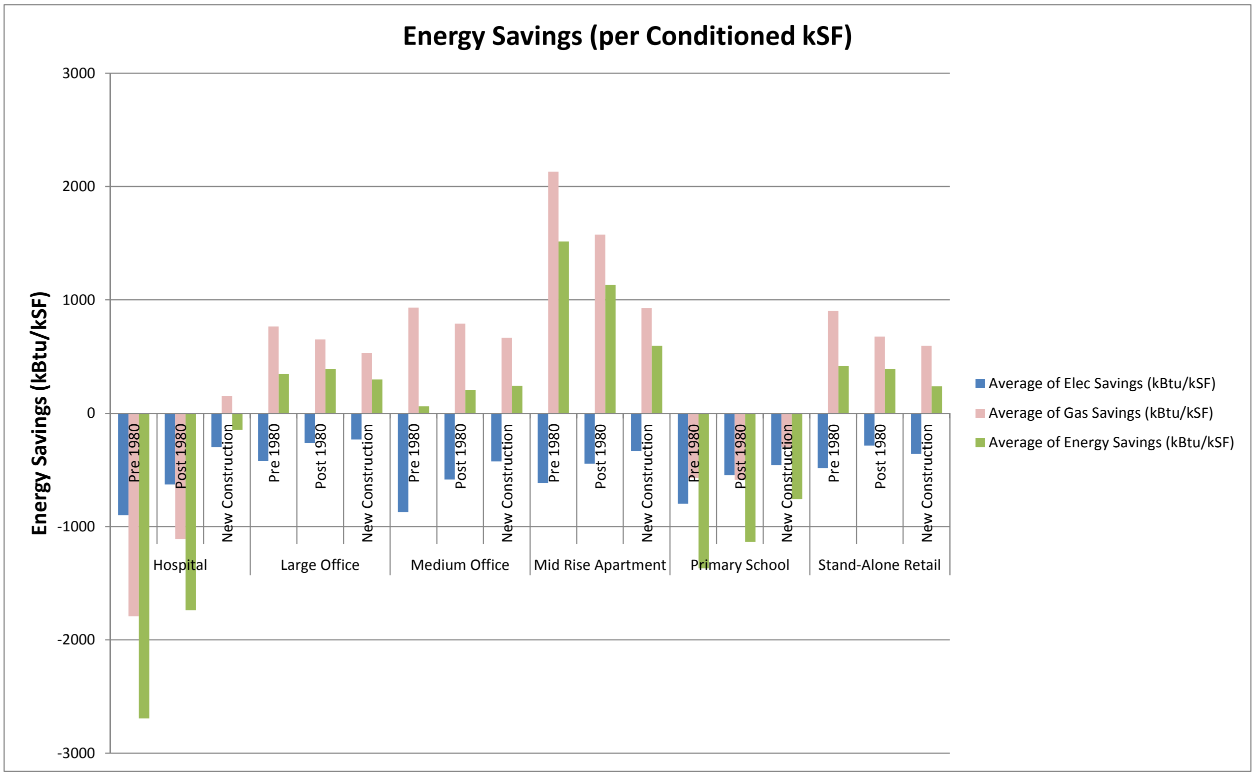
Measure CR-3


Simple Payback
SPB (Years)
0
5
10
15
20
25
30
35
40
45
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

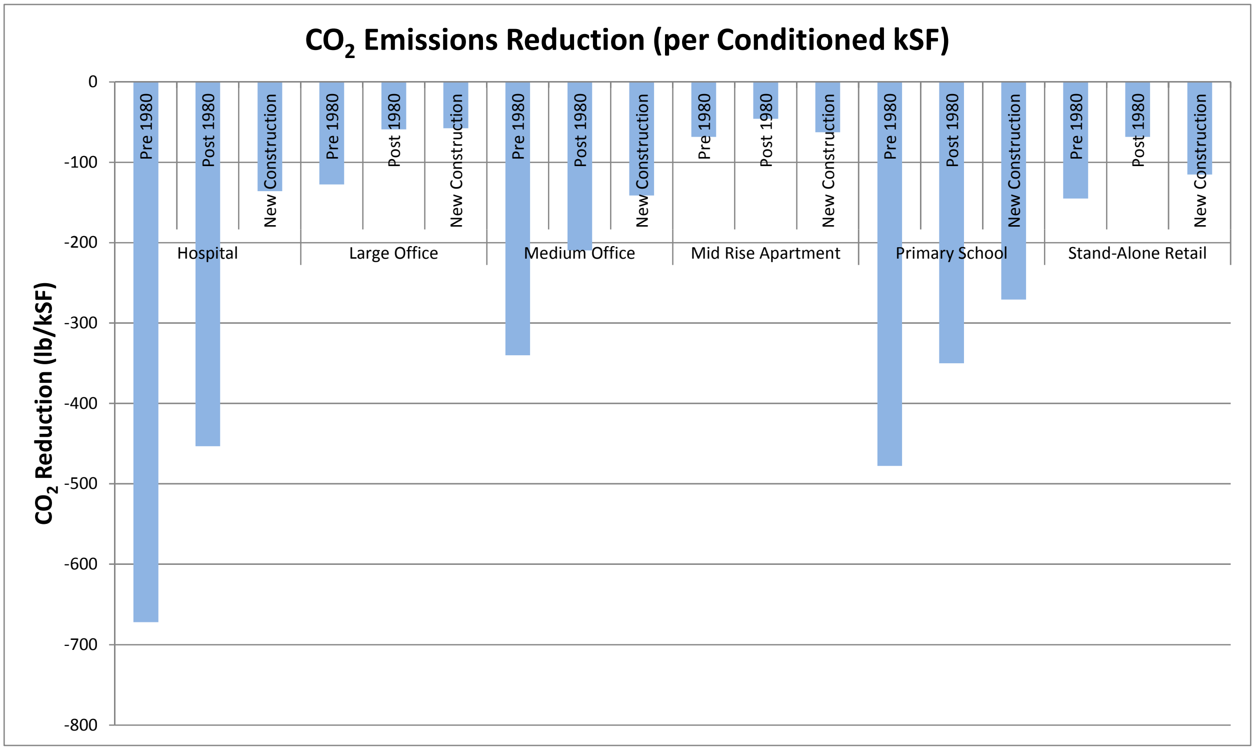

Benefit-Cost Ratio
B-C Ratio
0
1
2
3
4
5
6
7
8
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

Measure CG-1

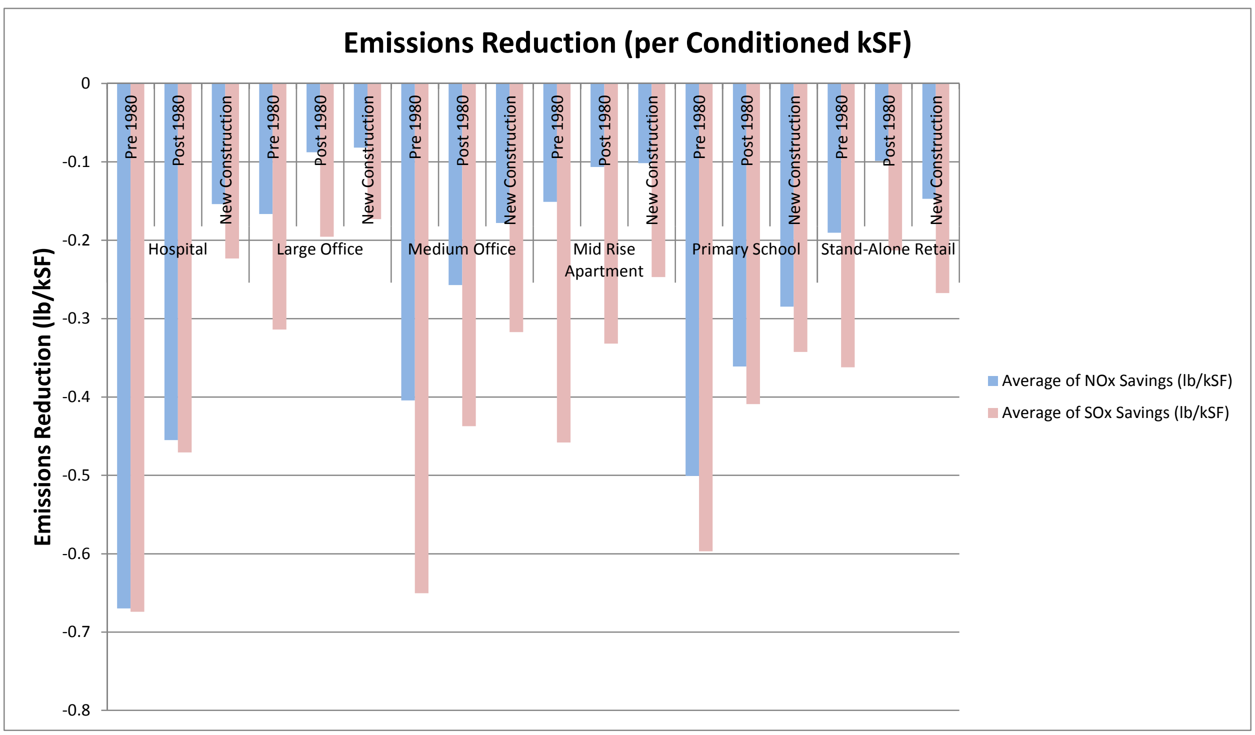

Utility Cost Savings (per Conditioned kSF)
Cost Savings ($/kSF)
$30
$20
$10
$0
-$10
-$20
-$30
-$40
-$50
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)


Energy Savings (per Conditioned kSF)
Energy Savings (kBtu/kSF)
3000
2000
1000
0
-1000
-2000
-3000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

Measure CG-1

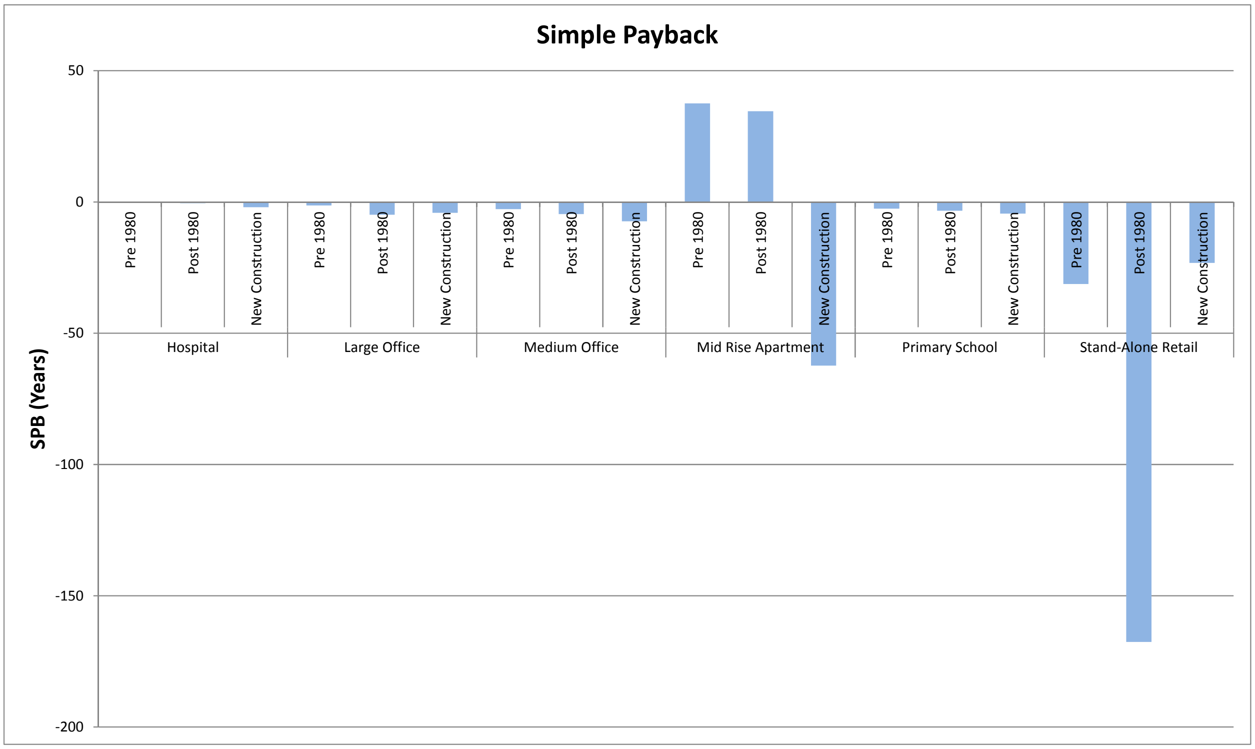


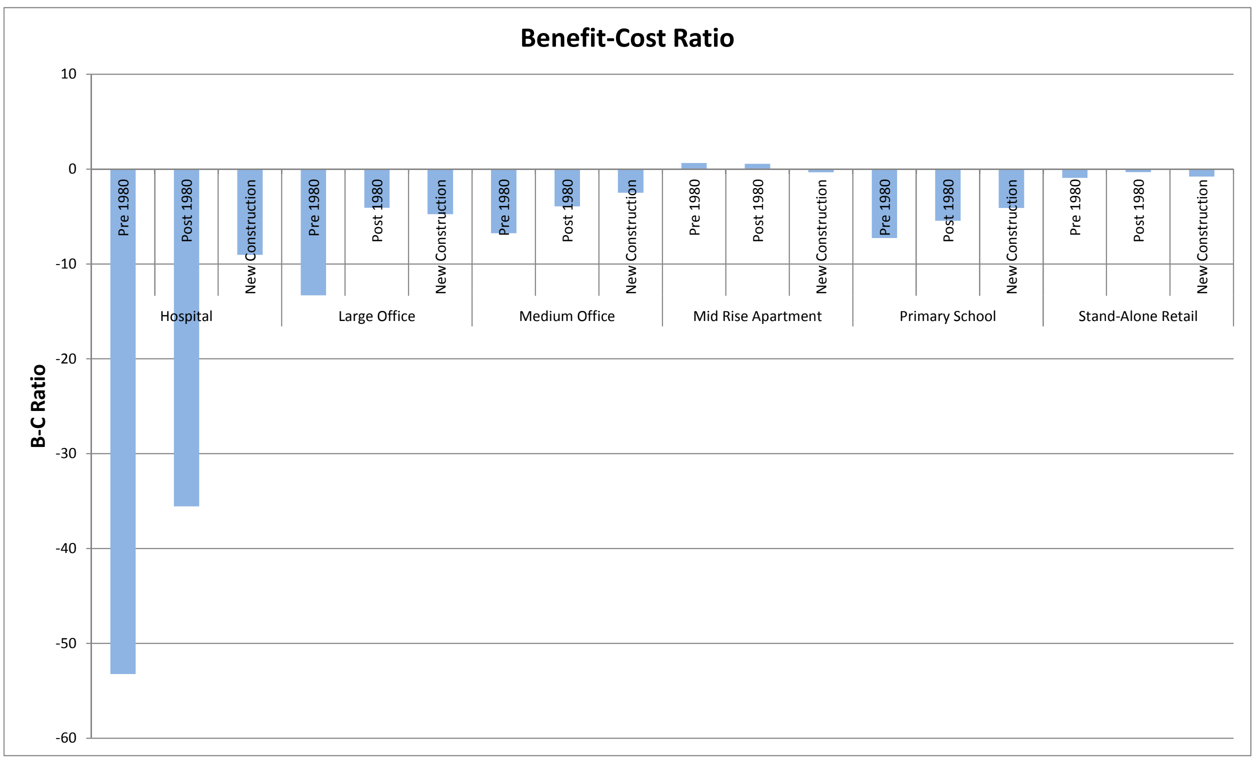
CO2 Emissions Reduction (per Conditioned kSF)
CO2 Reduction (lb/kSF)
0
-100
-200
-300
-400
-500
-600
-700
-800
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail



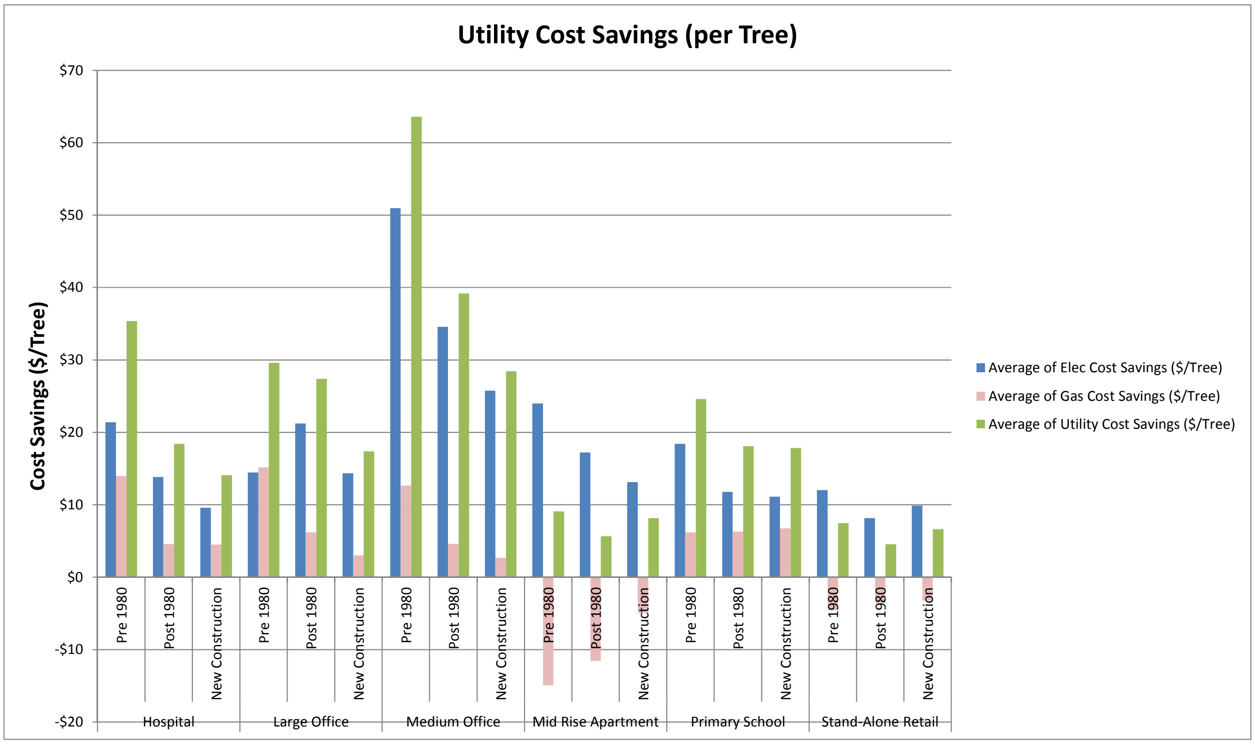
Emissions Reduction (per Conditioned kSF)
Emissions Reduction (lb/kSF)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

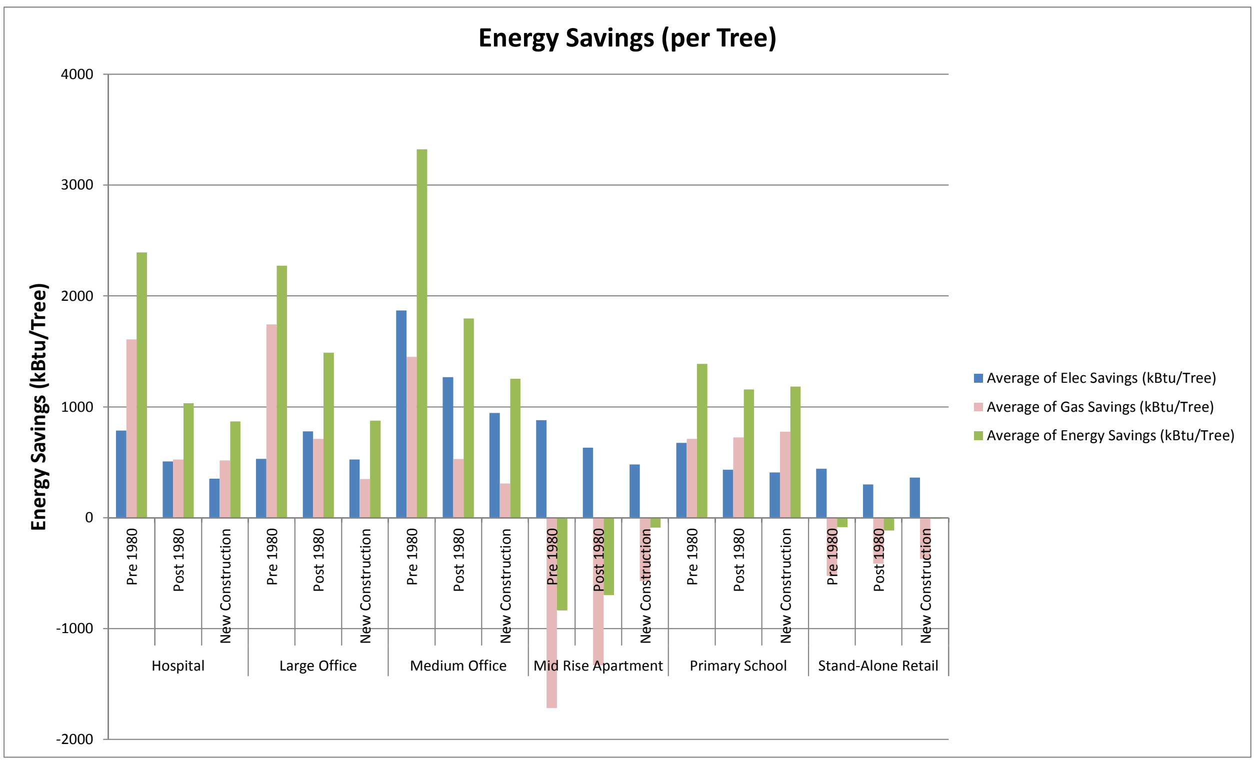
Measure CG-1


Simple Payback
SPB (Years)
50
0
-50
-100
-150
-200
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

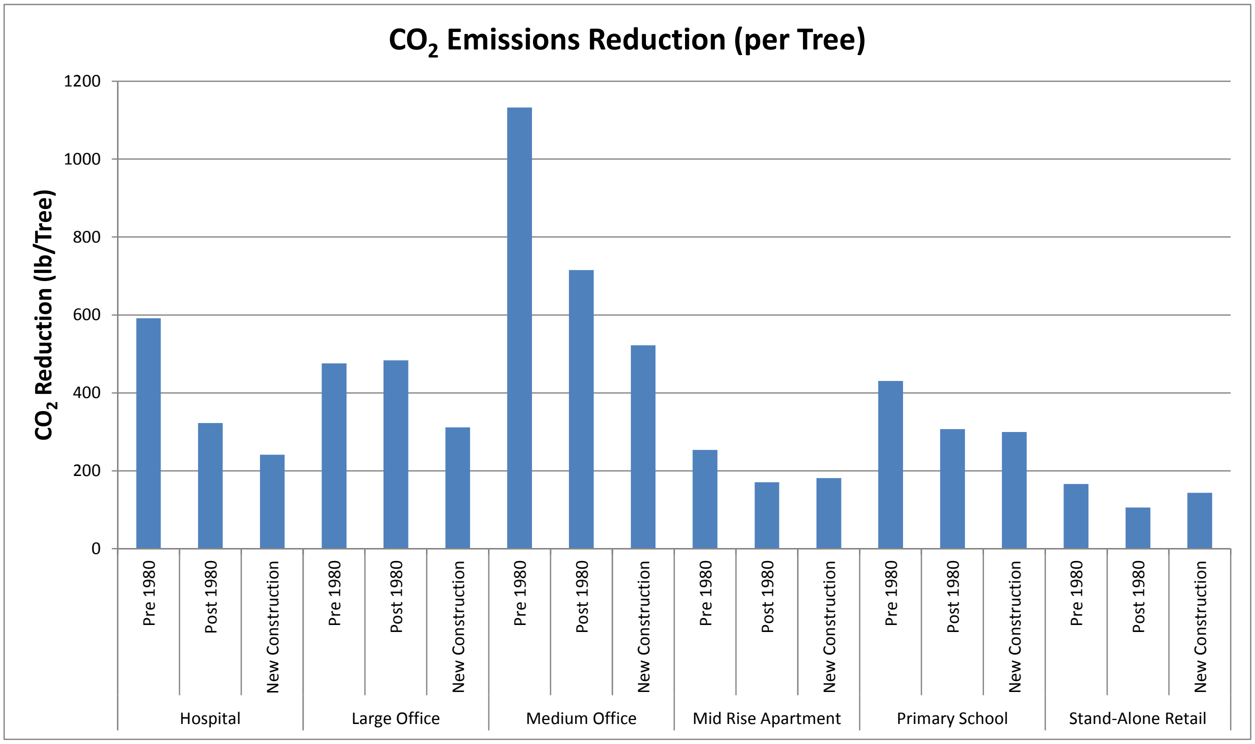

Benefit-Cost Ratio
B-C Ratio
10
0
-10
-20
-30
-40
-50
-60
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

Measure CS-1

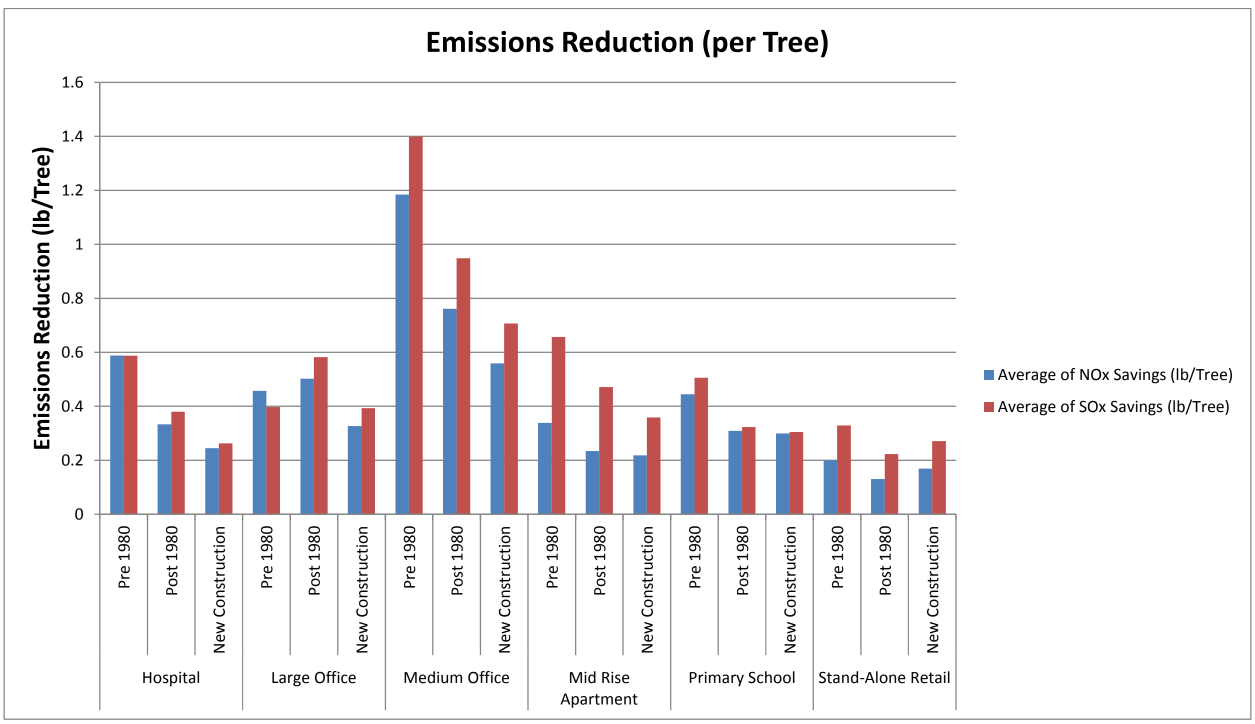

Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$70
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)


Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
4000
3000
2000
1000
0
-1000
-2000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

Measure CS-1

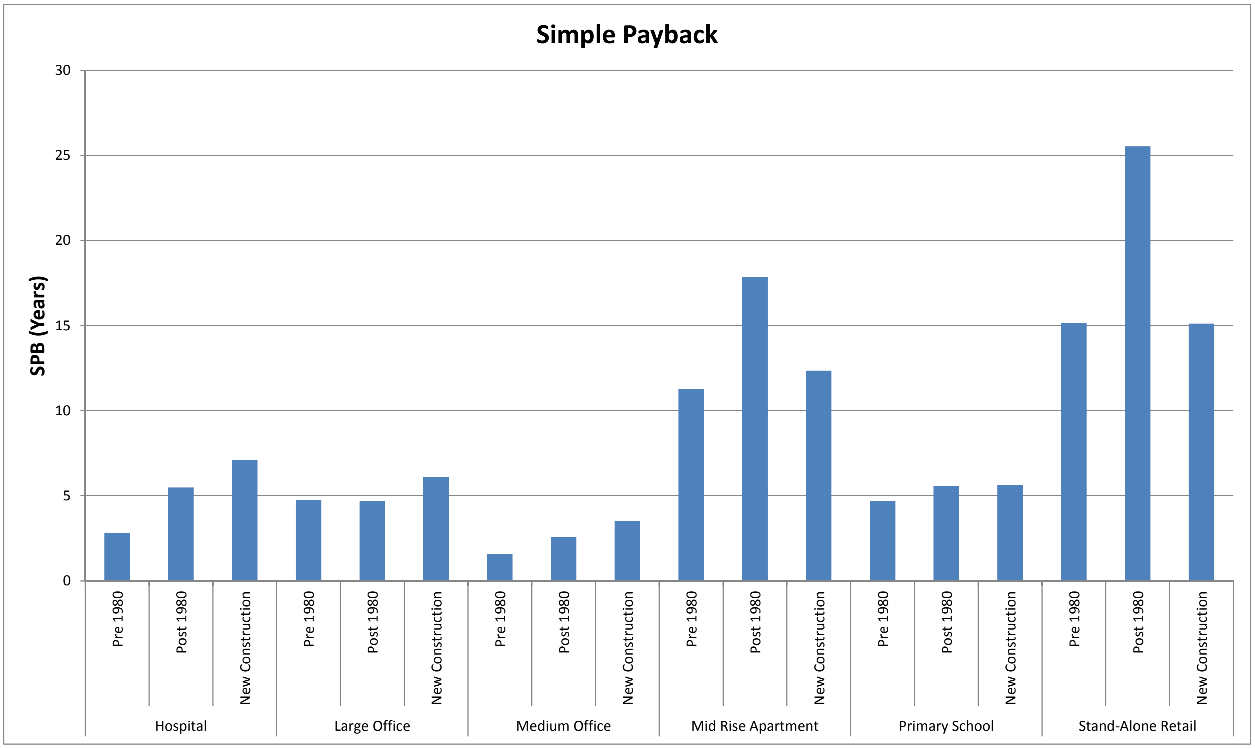


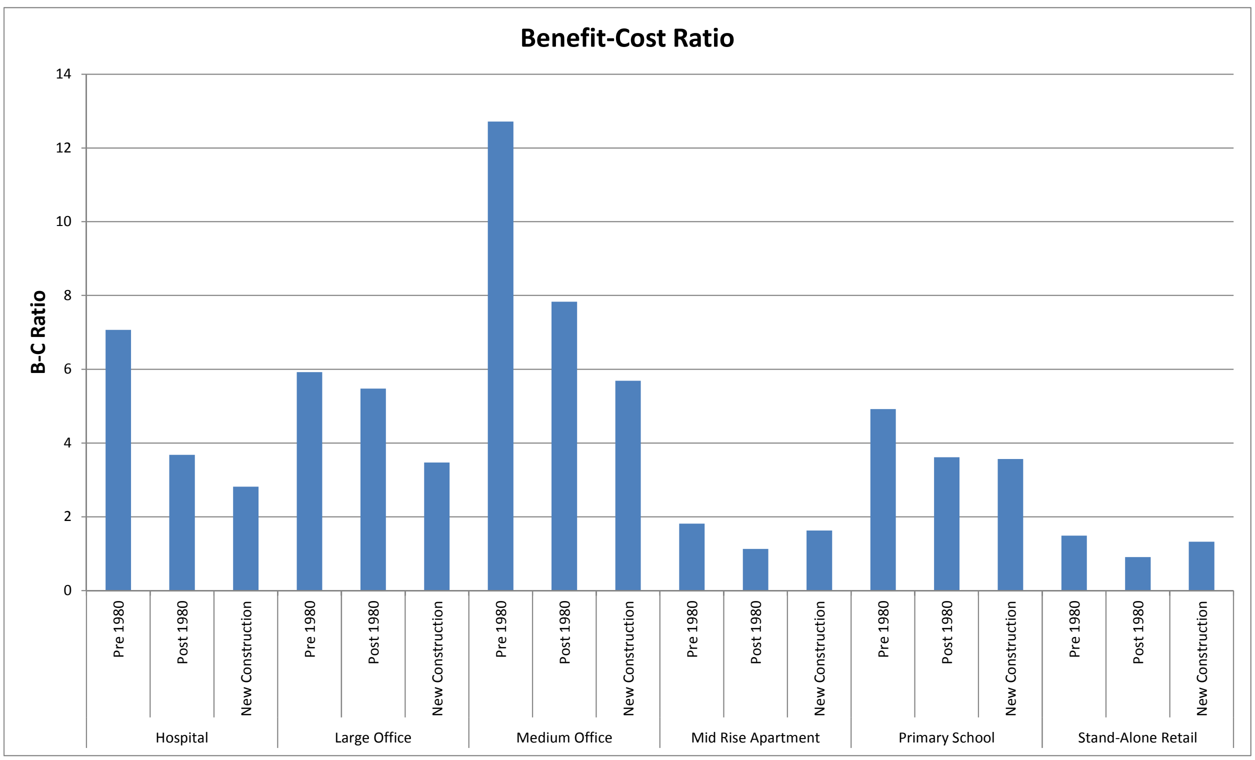
CO2 Emissions Reduction (per Tree)
CO2 Reduction (lb/Tree)
0
200
400
600
800
1000
1200
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail



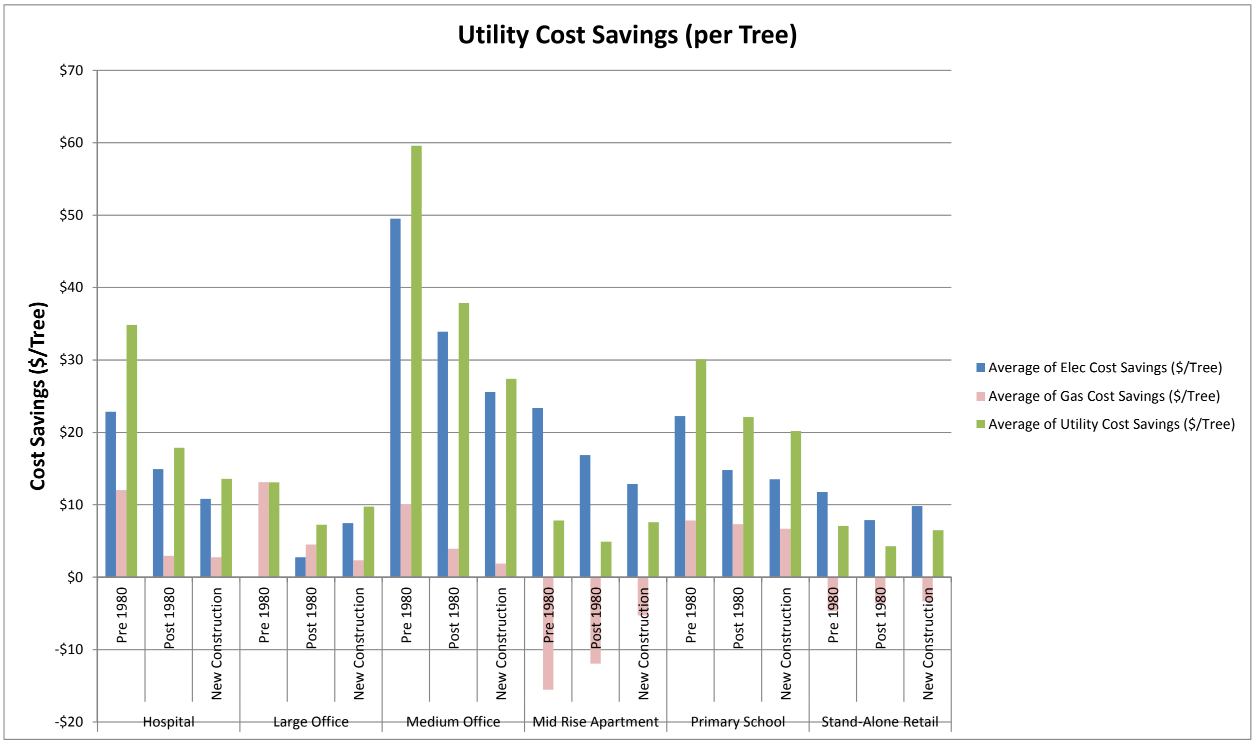
Emissions Reduction (per Tree)
Emissions Reduction (lb/Tree)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)

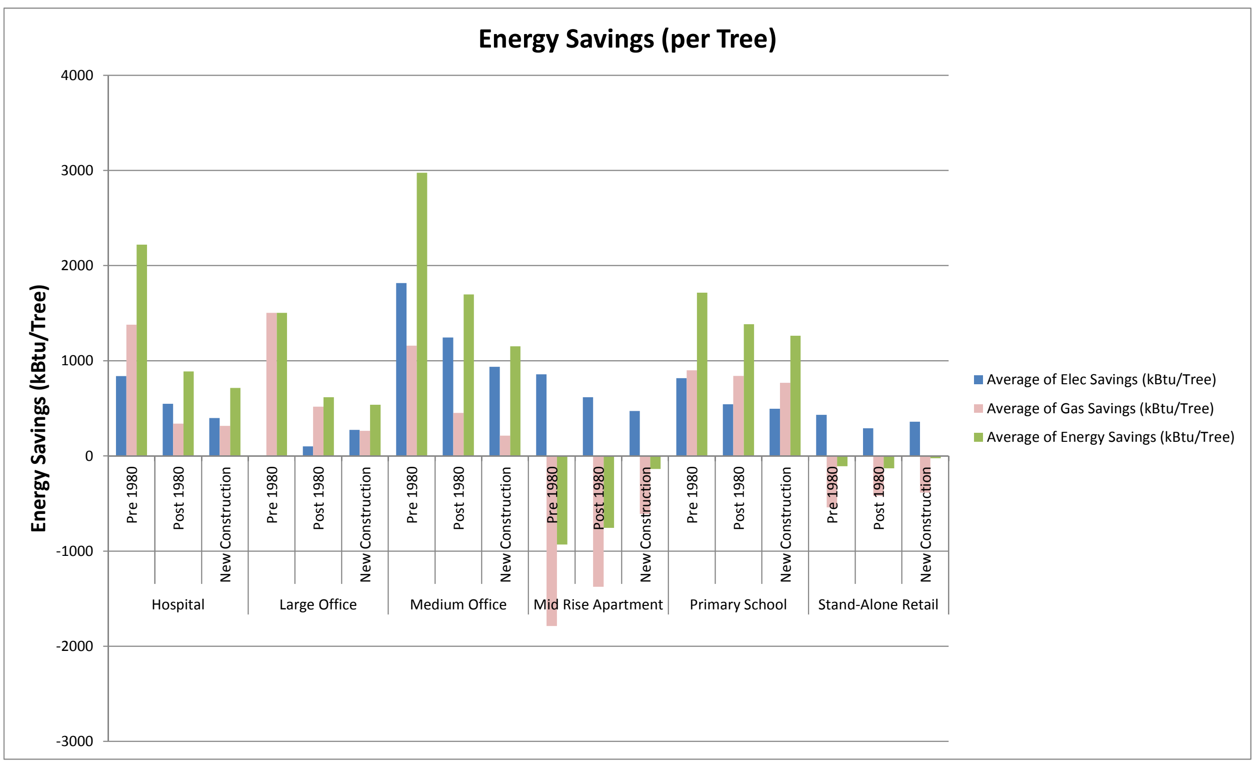
Measure CS-1


Simple Payback
SPB (Years)
0
5
10
15
20
25
30
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

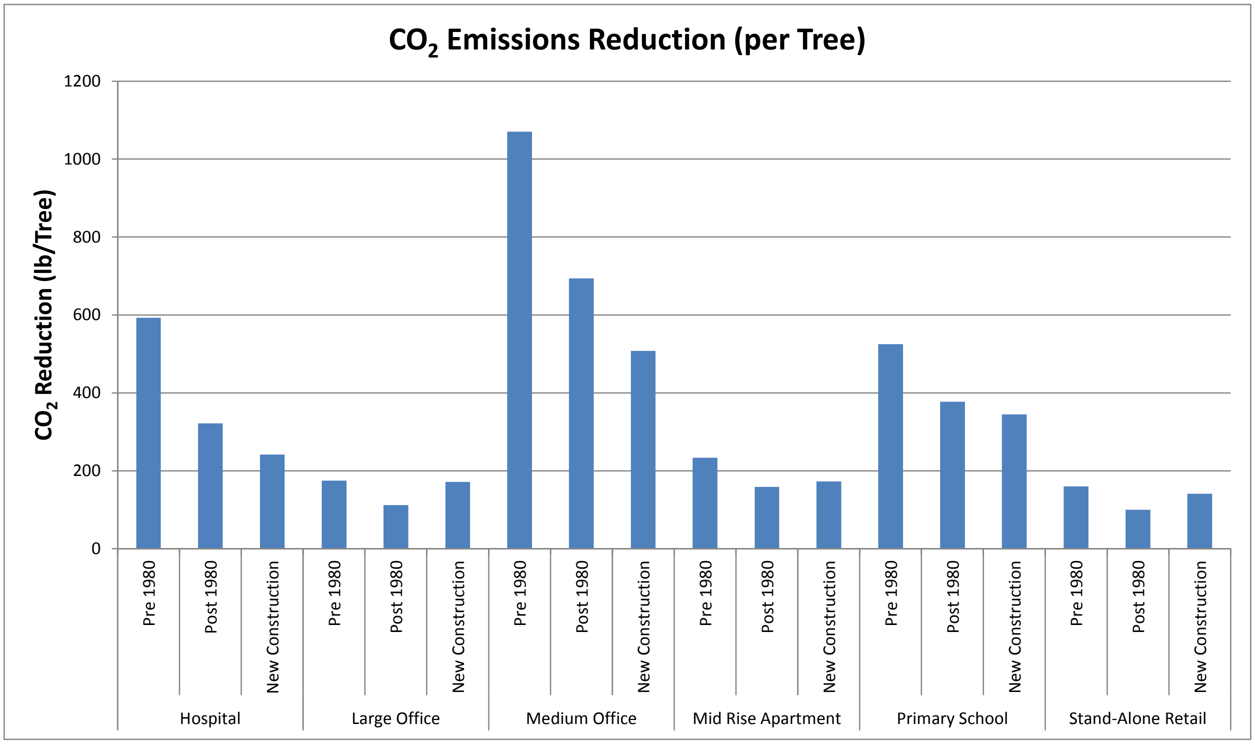

Benefit-Cost Ratio
B-C Ratio
0
2
4
6
8
10
12
14
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

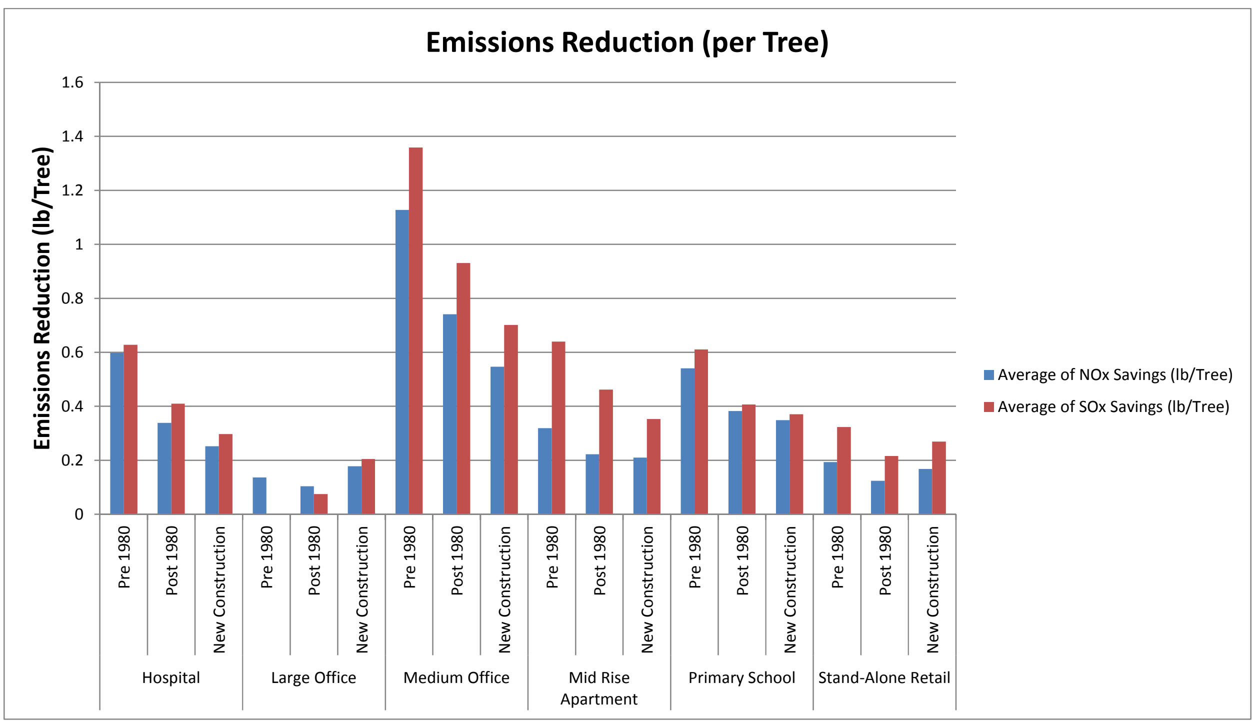
Measure CS-2


Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$70
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)

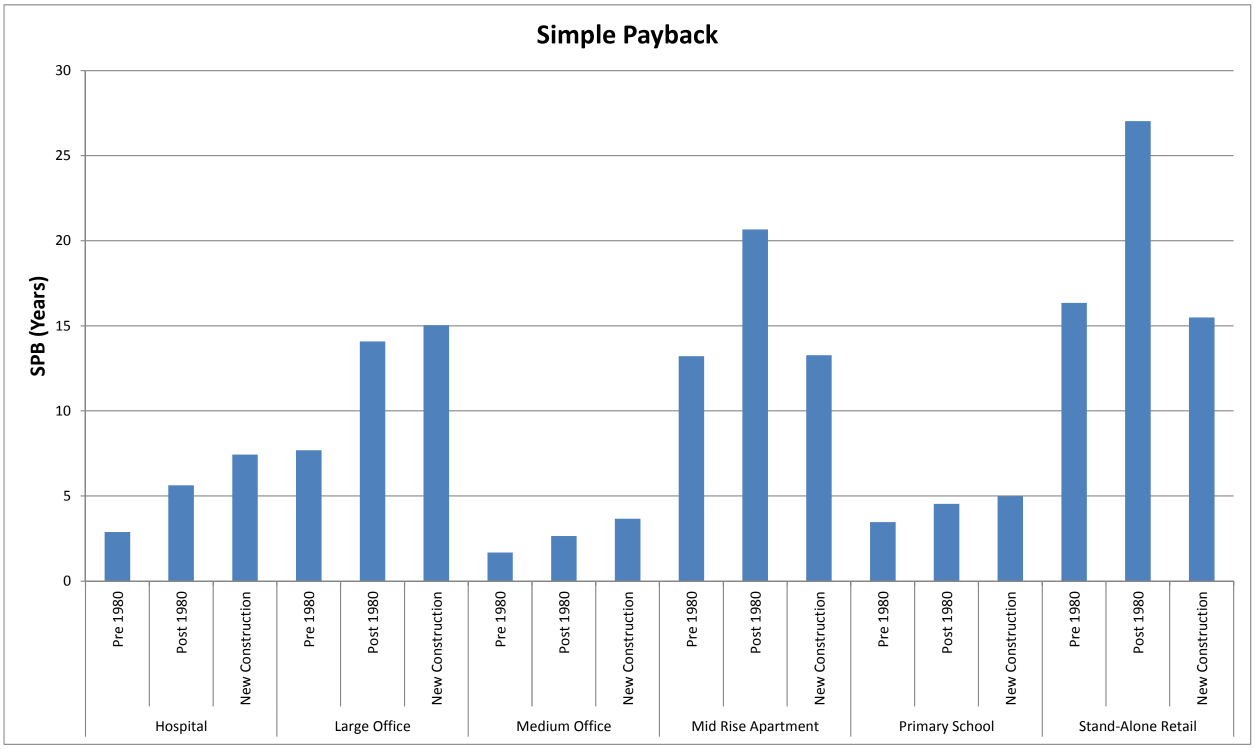

Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
4000
3000
2000
1000
0
-1000
-2000
-3000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

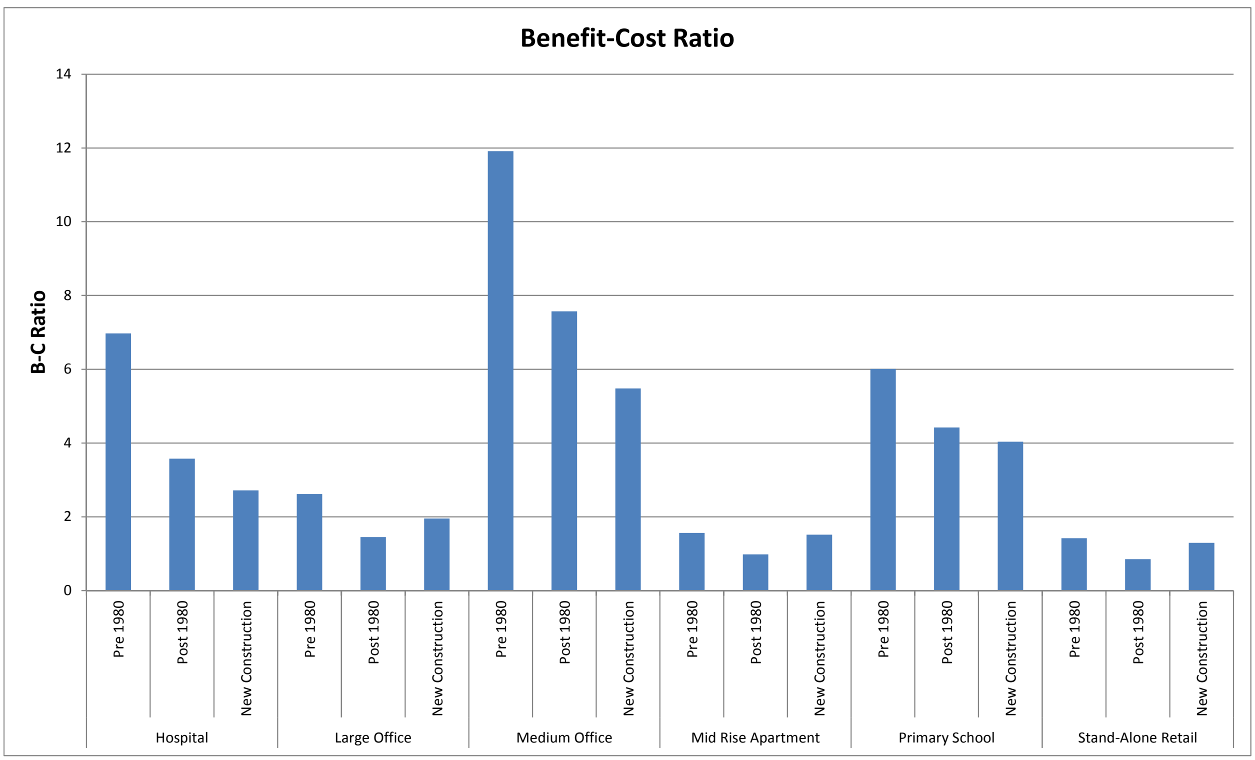
Measure CS-2


CO_2 Emissions Reduction (per Tree)
CO_2 Reduction (lb/Tree)
1200
1000
800
600
400
200
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

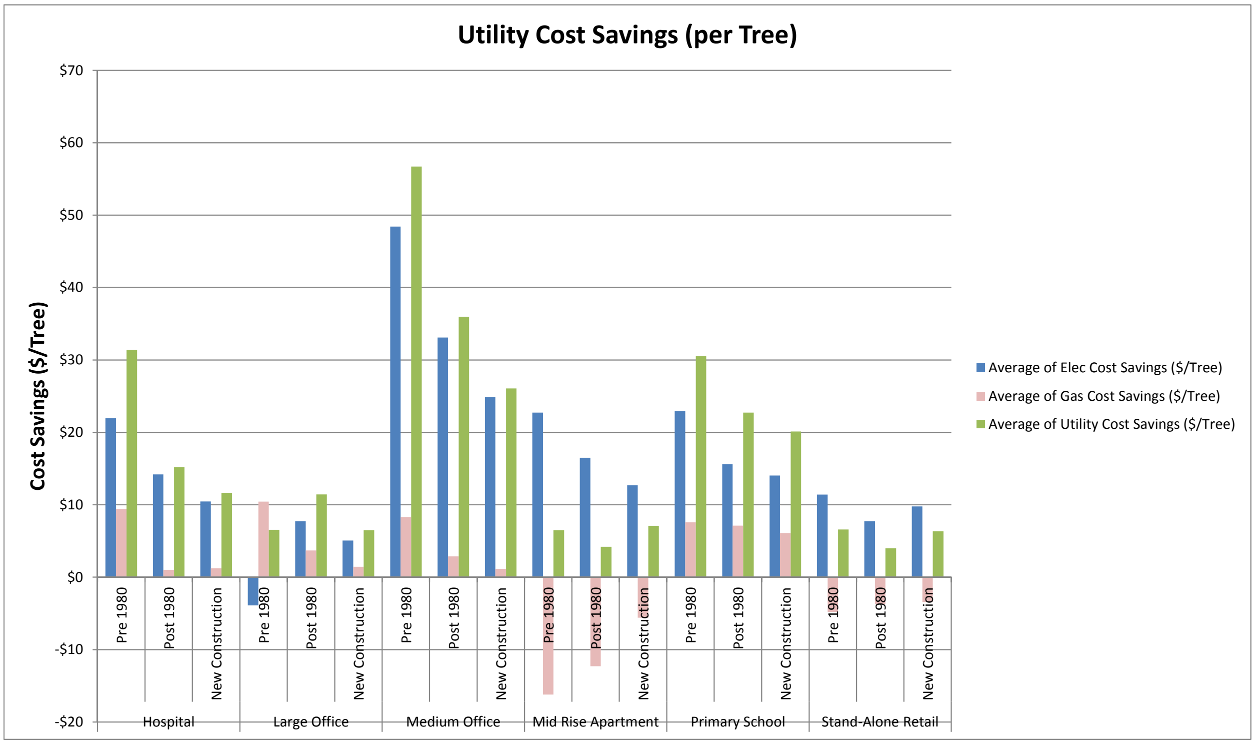

Emissions Reduction (per Tree)
Emissions Reduction (lb/Tree)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)

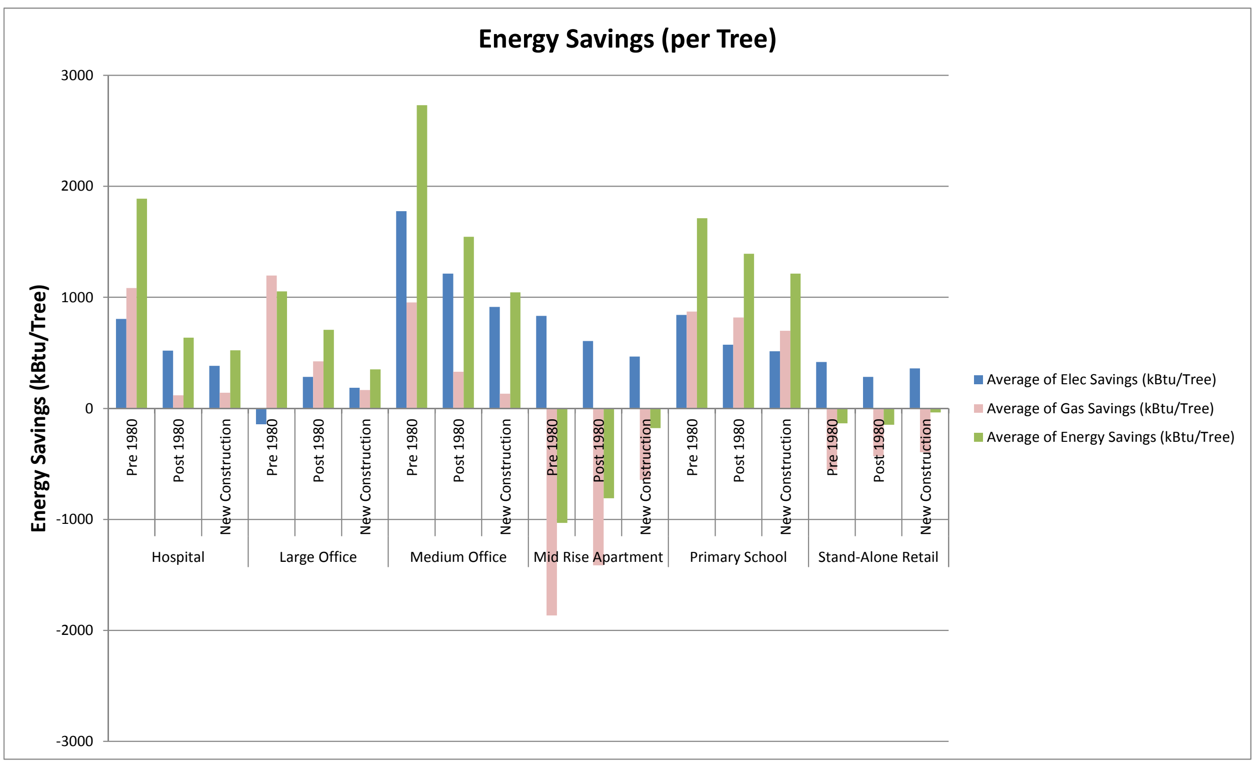
Measure CS-2


Simple Payback
SPB (Years)
0
5
10
15
20
25
30
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

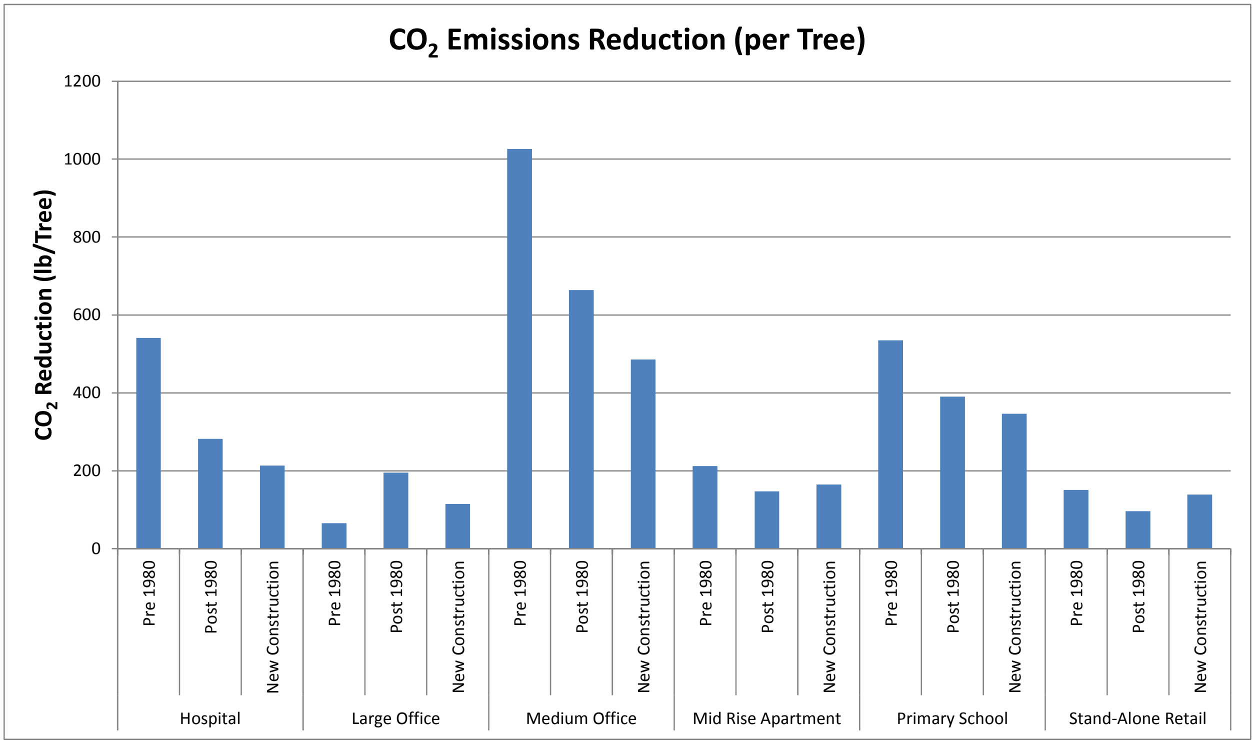

Benefit-Cost Ratio
B-C Ratio
0
2
4
6
8
10
12
14
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

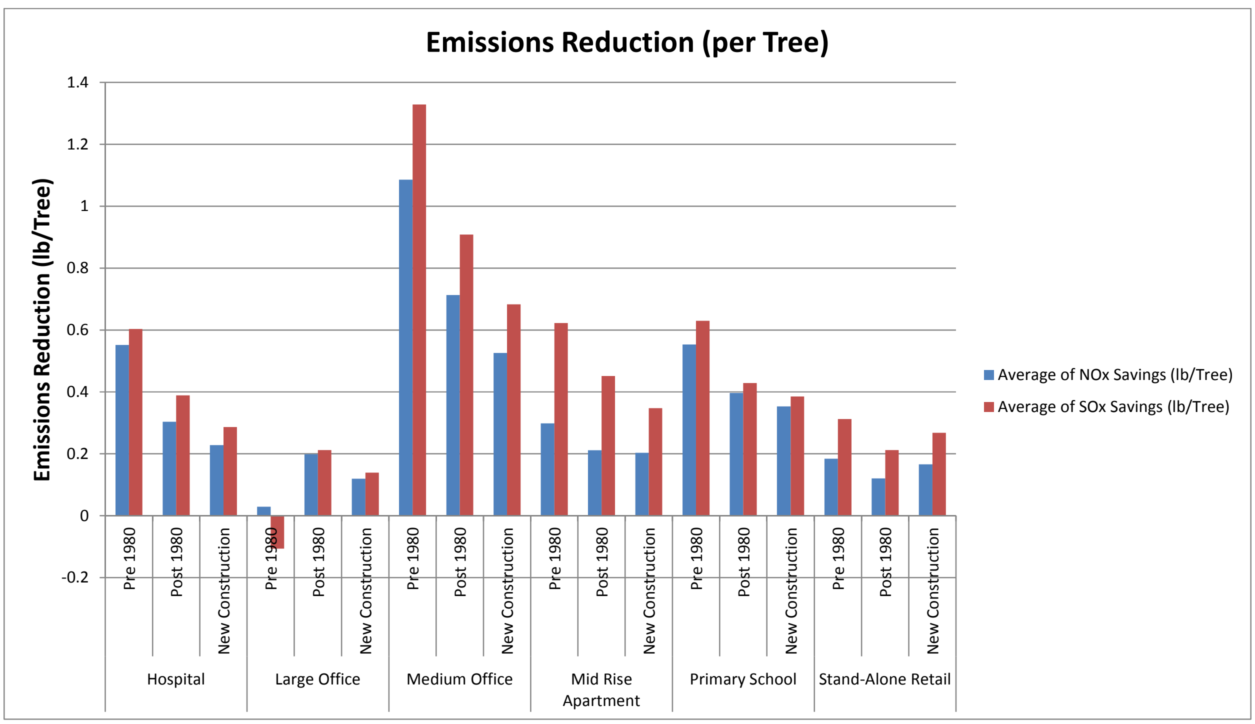
Measure CS-3


Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$70
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)

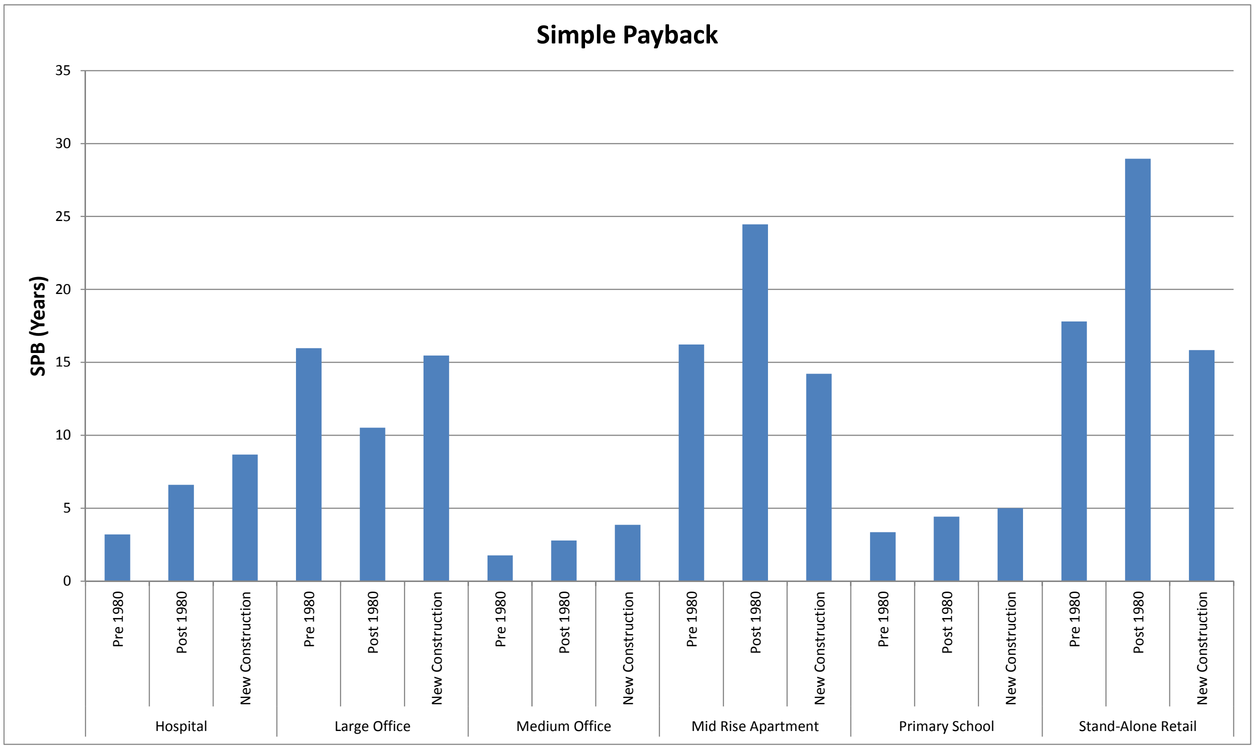

Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
3000
2000
1000
0
-1000
-2000
-3000
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

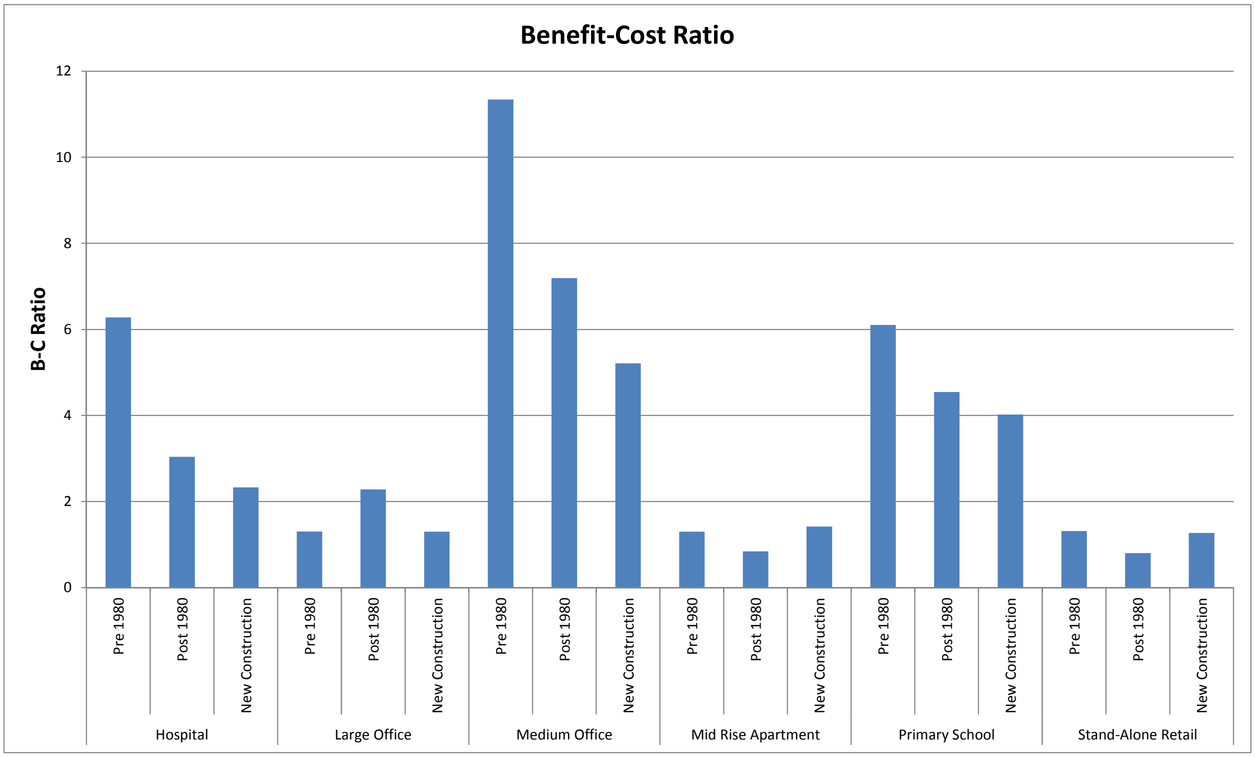
Measure CS-3


CO2 Emissions Reduction (per Tree)
CO2 Reduction (lb/Tree)
1200
1000
800
600
400
200
0
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail


Emissions Reduction (per Tree)
Emissions Reduction (lb/Tree)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)

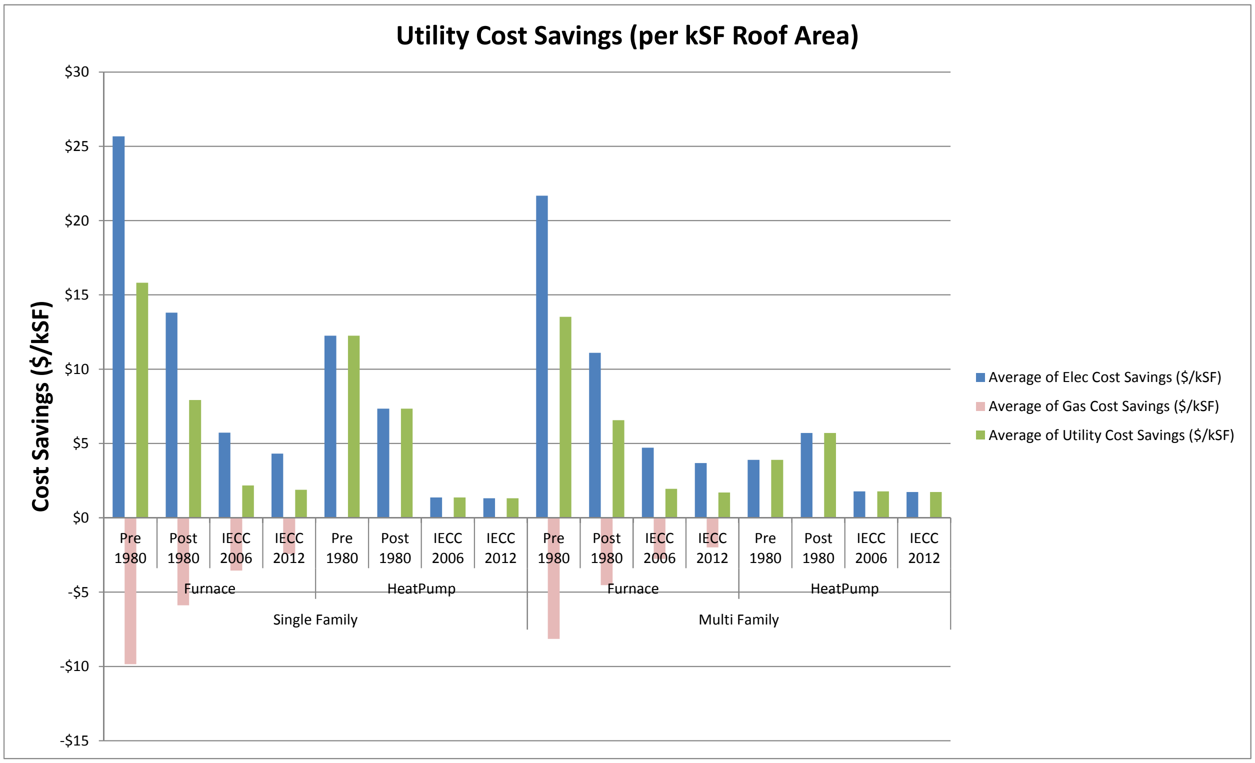
Measure CS-3

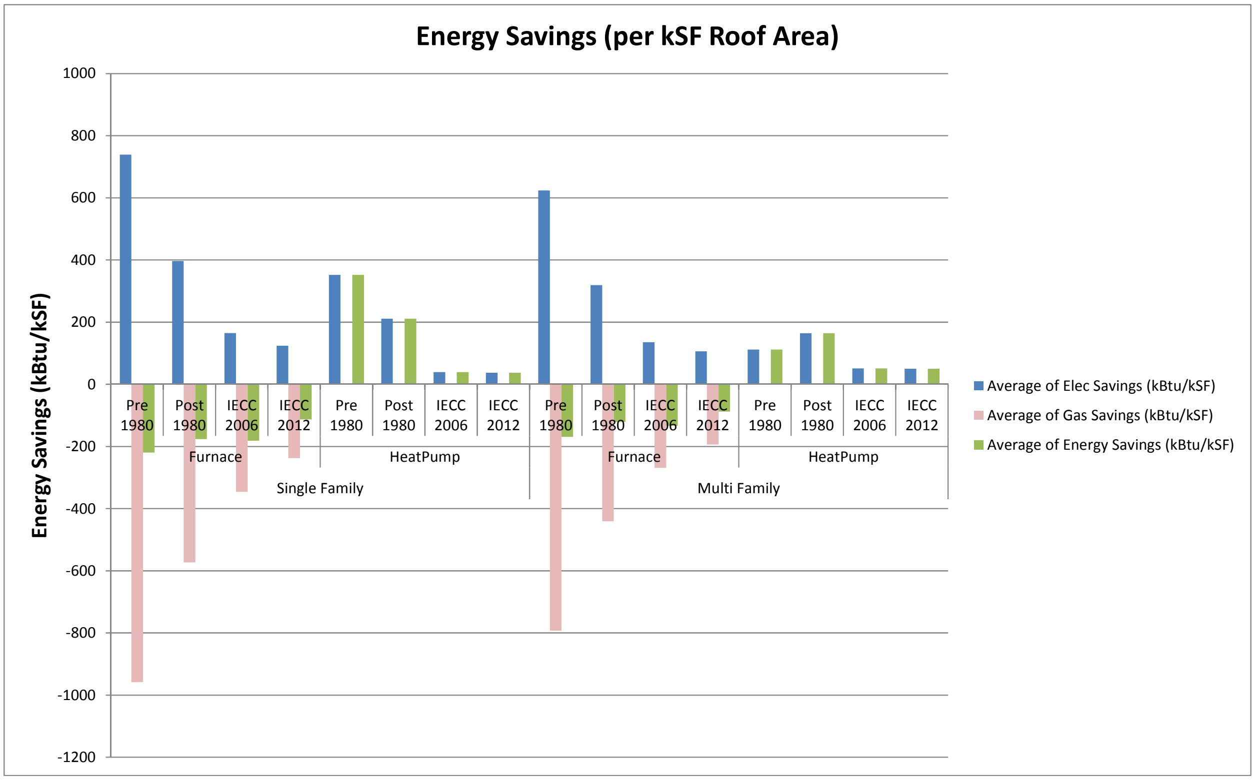

Simple Payback
SPB (Years)
0
5
10
15
20
25
30
35
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail


Benefit-Cost Ratio
B-C Ratio
0
2
4
6
8
10
12
Pre 1980
Post 1980
New Construction
Hospital
Large Office
Medium Office
Mid Rise Apartment
Primary School
Stand-Alone Retail

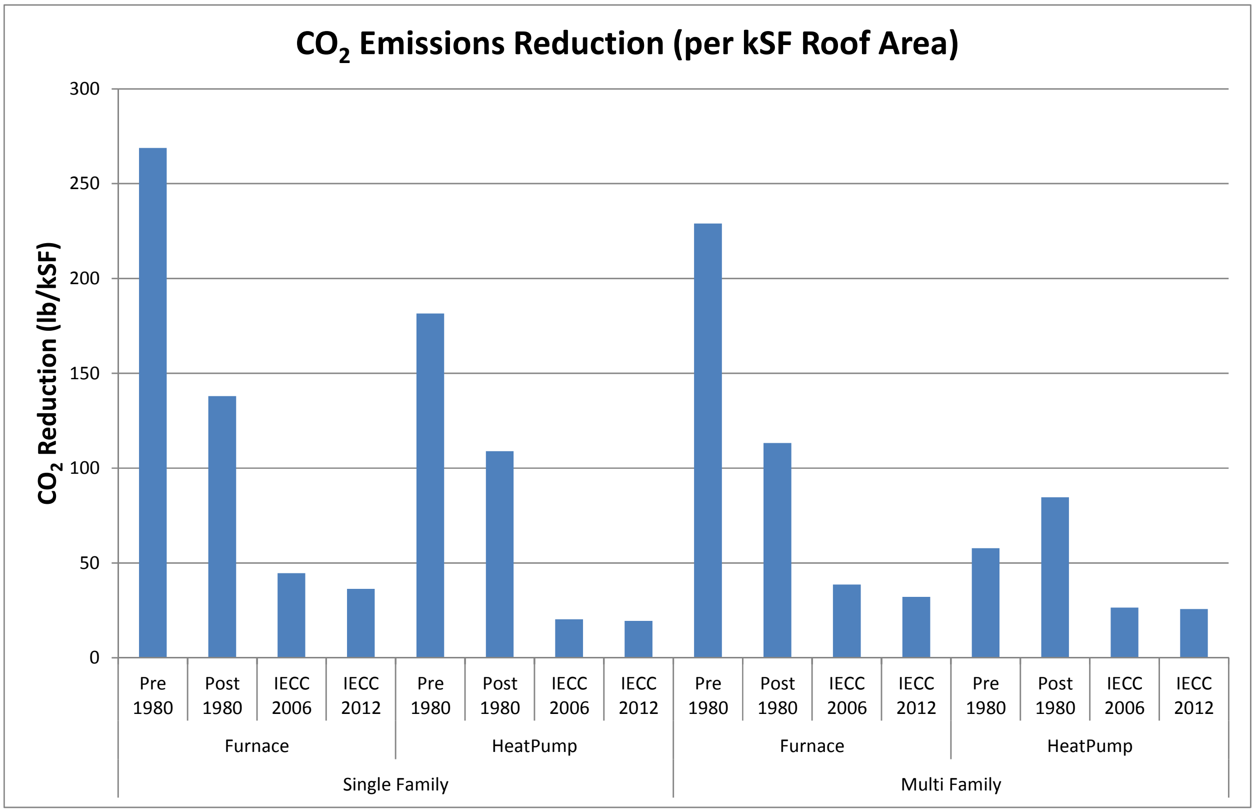
Appendix B: Residential Measure Results

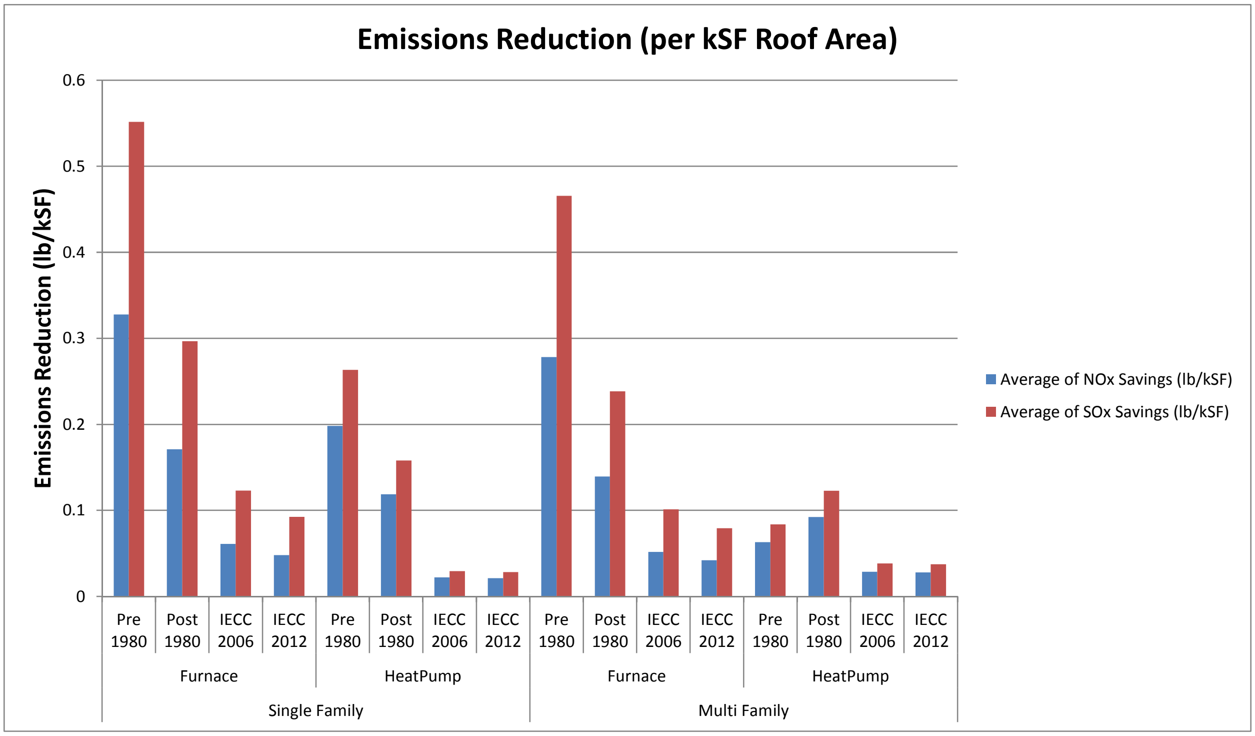
Measure RR-1


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$30
$25
$20
$15
$10
$5
$0
-$5
-$10
-$15
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

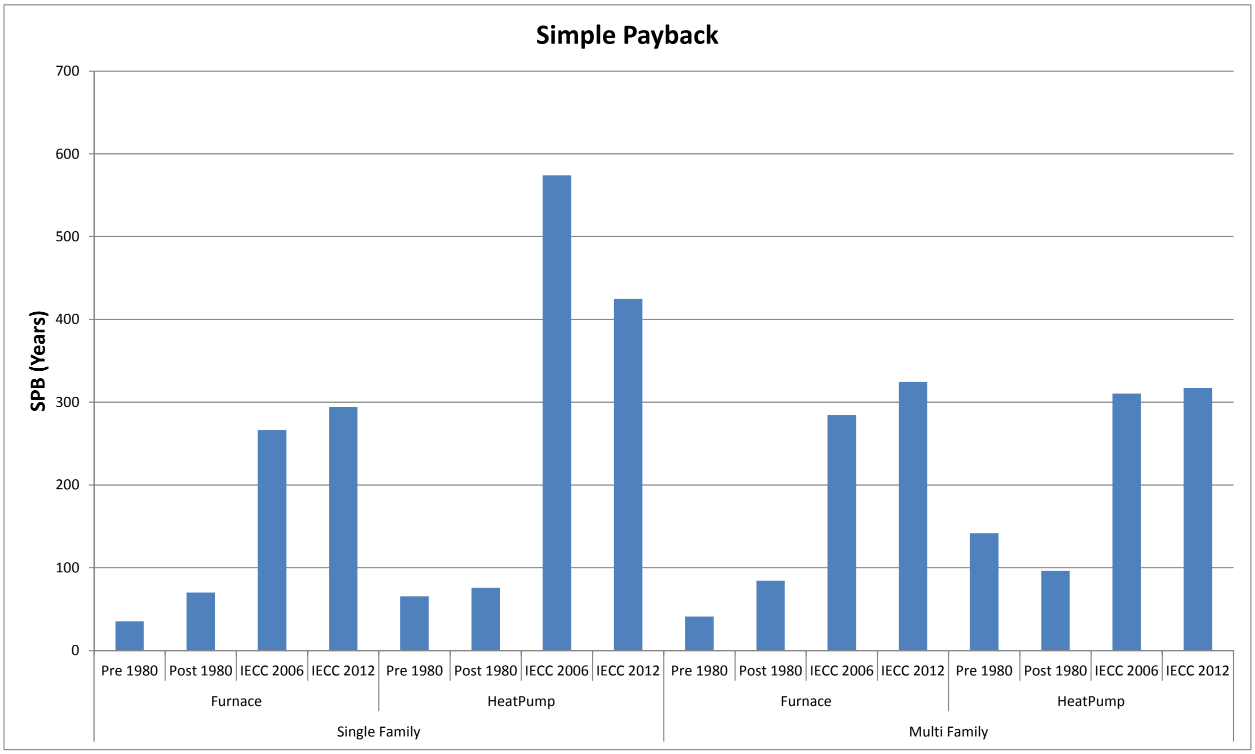

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

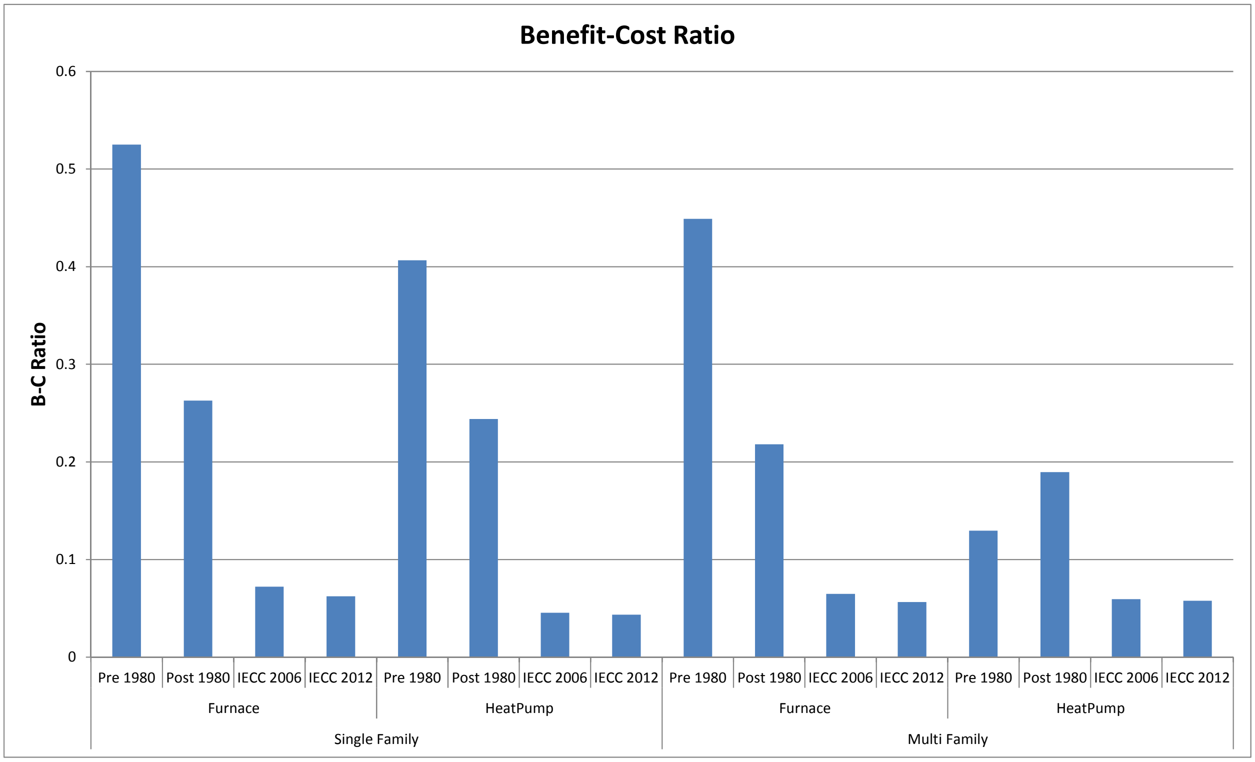
Measure RR-1


CO_2 Emissions Reduction (per kSF Roof Area)
CO_2 Reduction (lb/kSF)
300
250
200
150
100
50
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

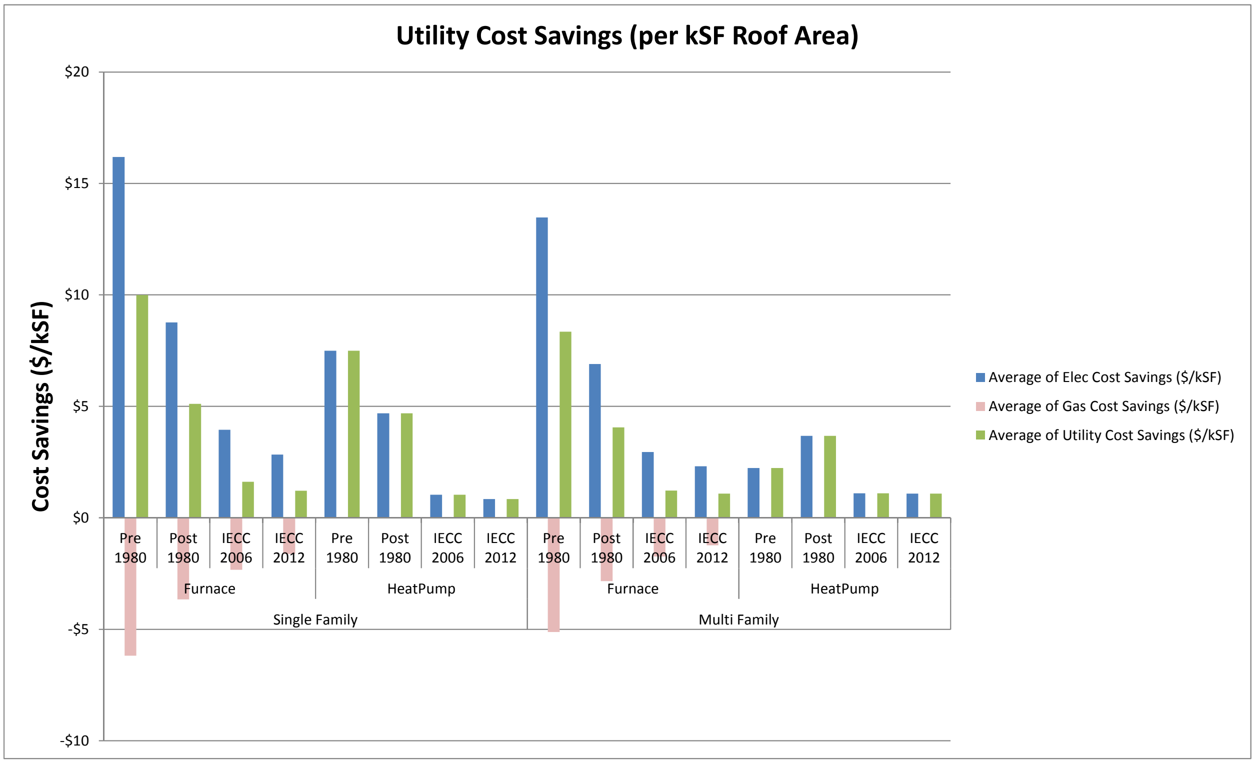

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

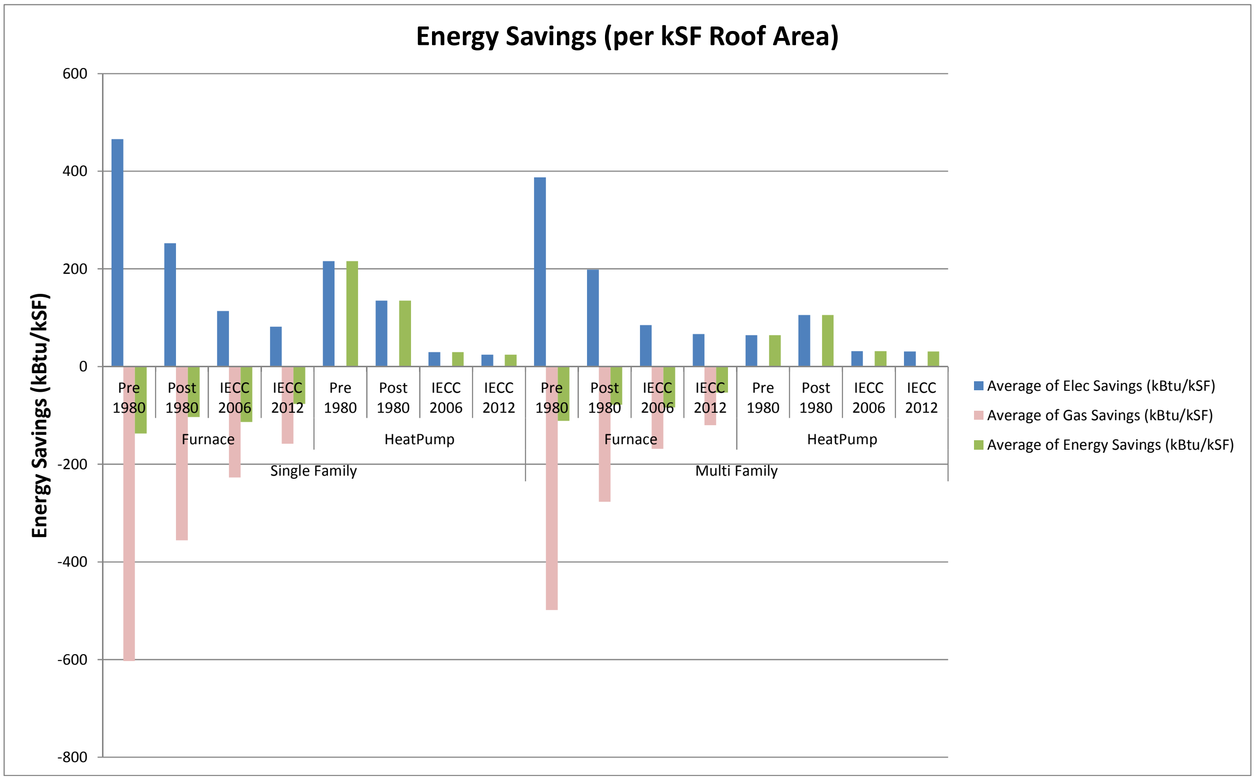
Measure RR-1


Simple Payback
SPB (Years)
700
600
500
400
300
200
100
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

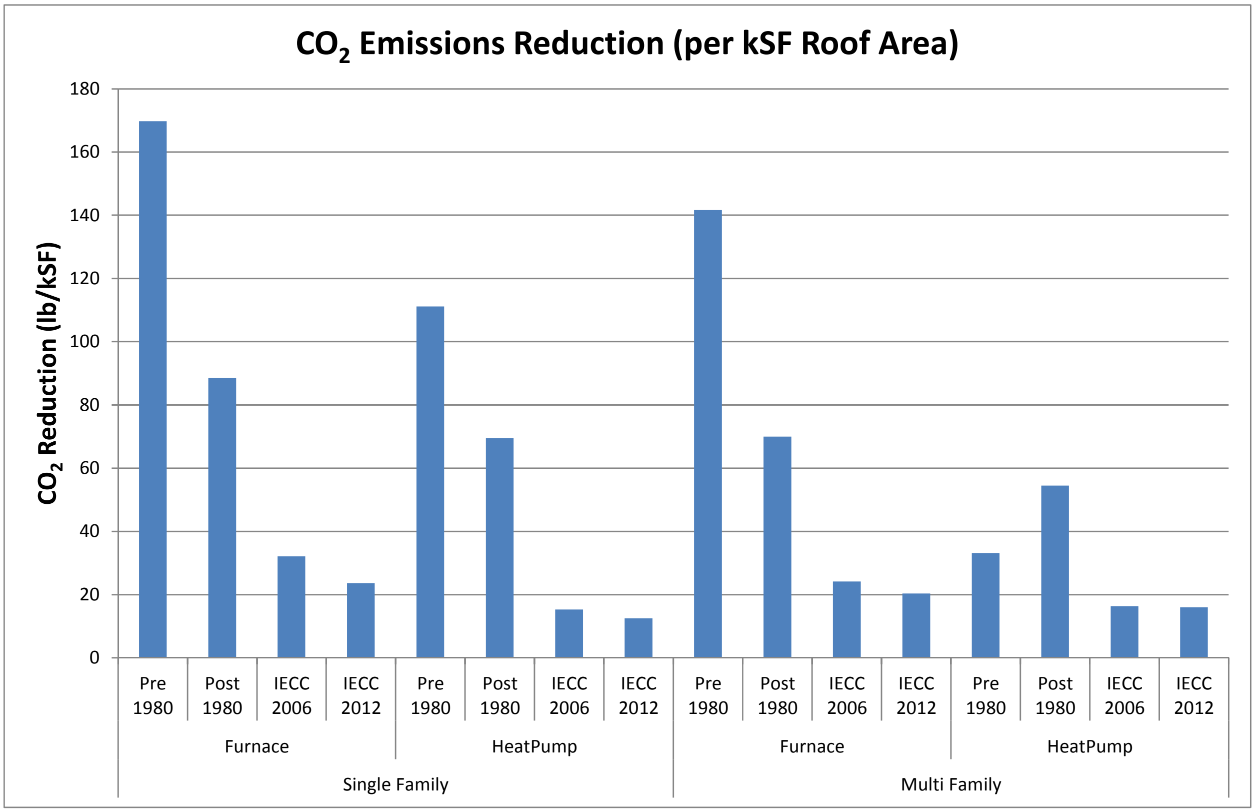

Benefit-Cost Ratio
B-C Ratio
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

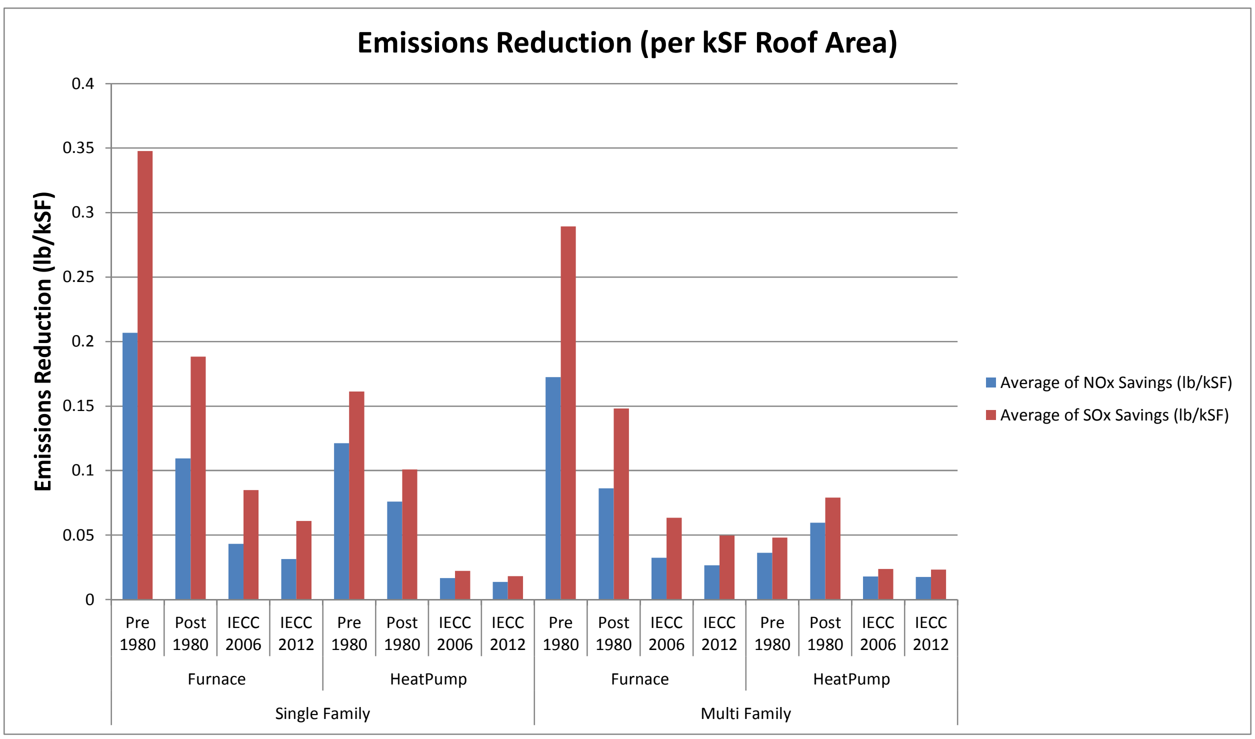
Measure RR-2


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$20
$15
$10
$5
$0
-$5
-$10
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

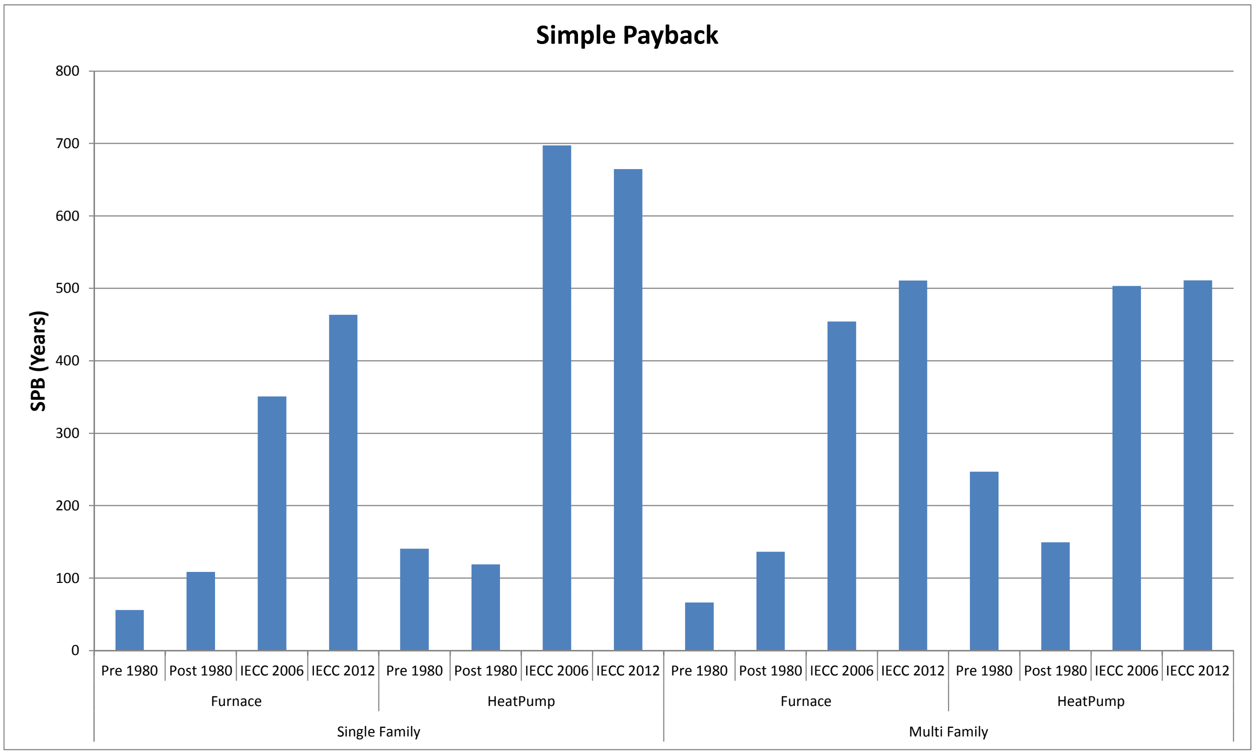

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
600
400
200
0
-200
-400
-600
-800
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

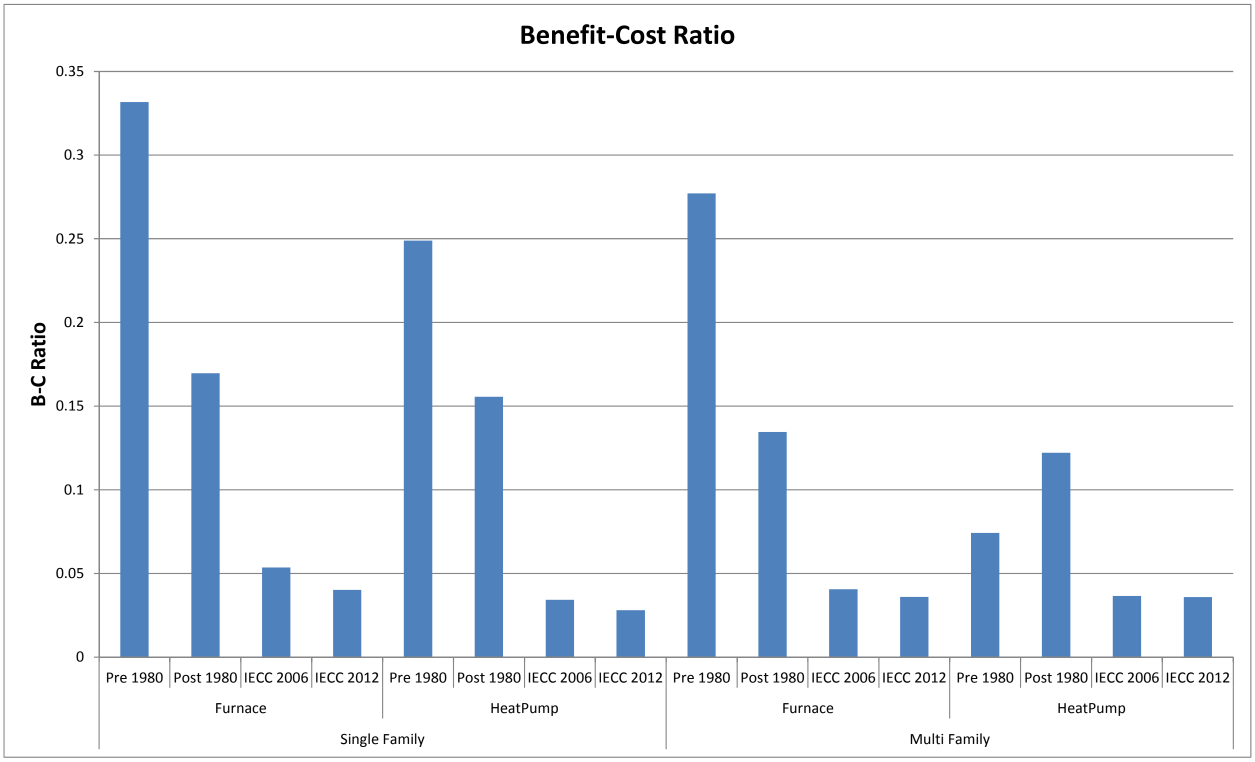
Measure RR-2


CO2 Emissions Reduction (per kSF Roof Area)
CO2 Reduction (lb/kSF)
180
160
140
120
100
80
60
40
20
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

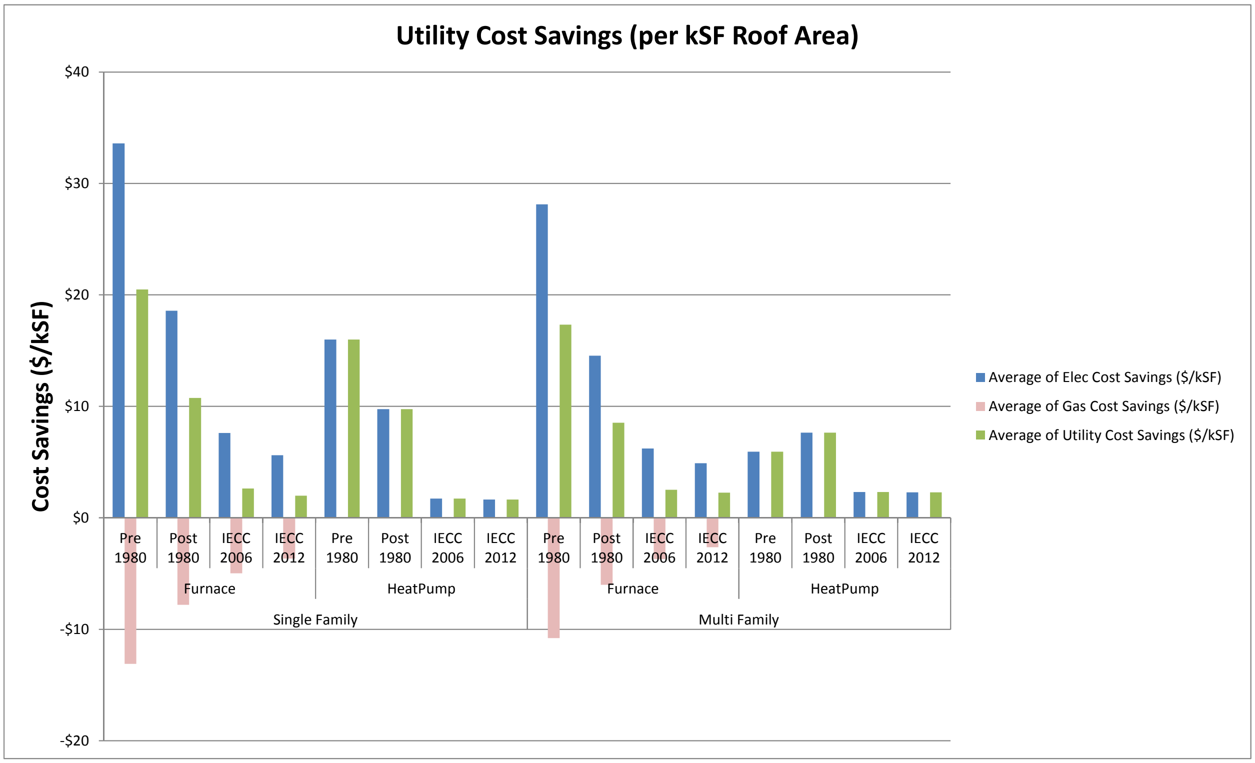

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

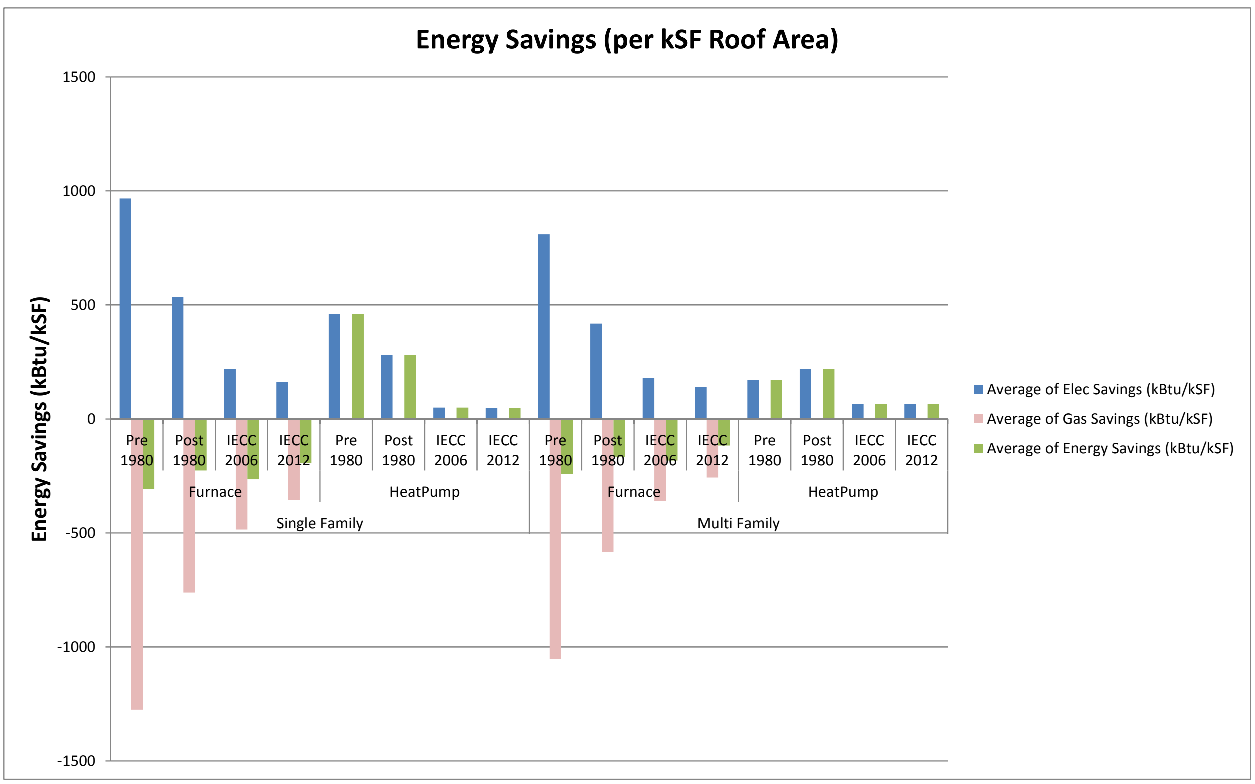
Measure RR-2


Simple Payback
SPB (Years)
800
700
600
500
400
300
200
100
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

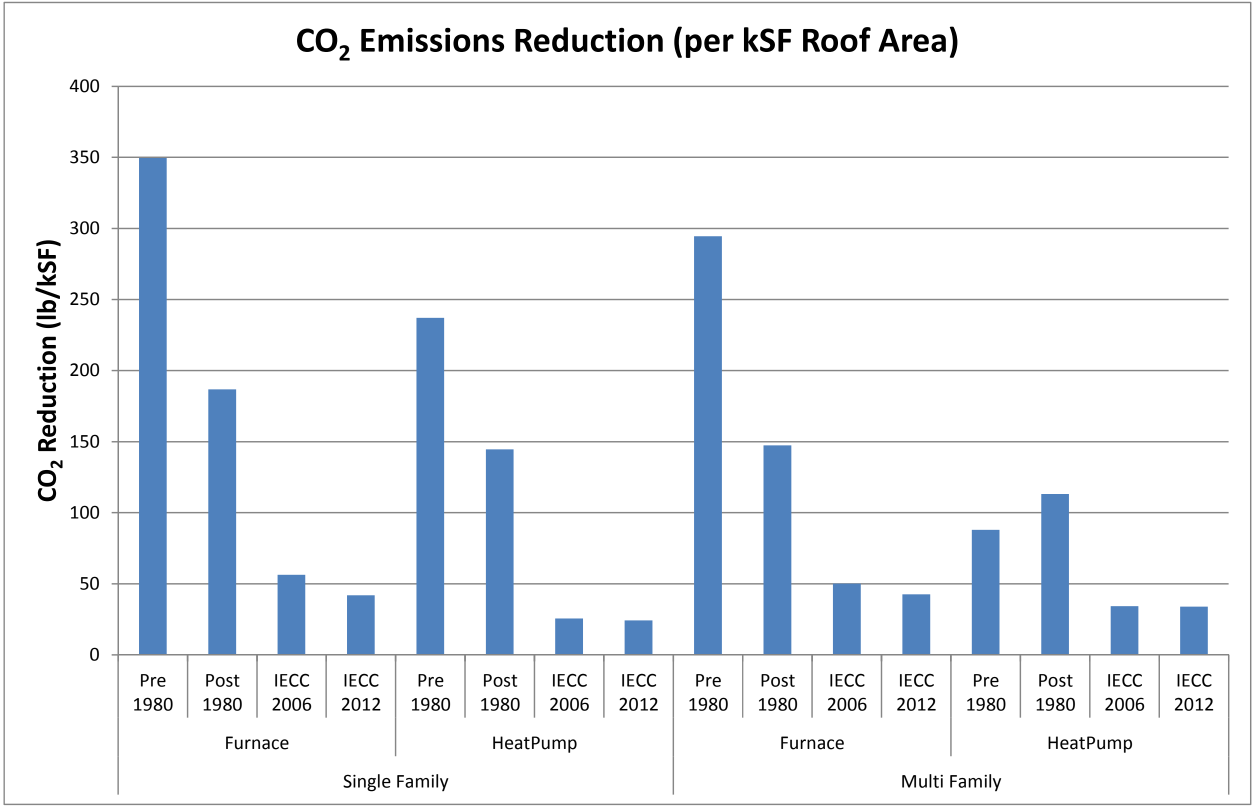

Benefit-Cost Ratio
B-C Ratio
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

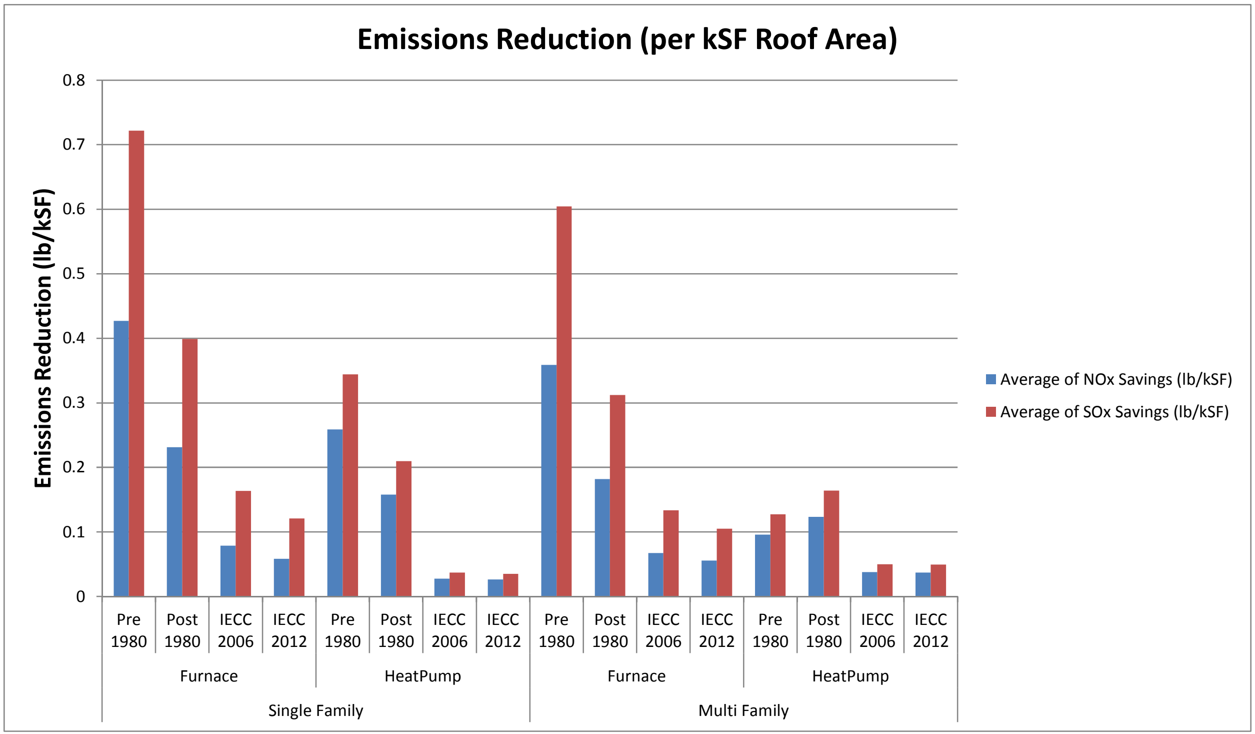
Measure RR-3


Utility Cost Savings (per kSF Roof Area)
Cost Savings ($/kSF)
$40
$30
$20
$10
$0
-$10
-$20
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

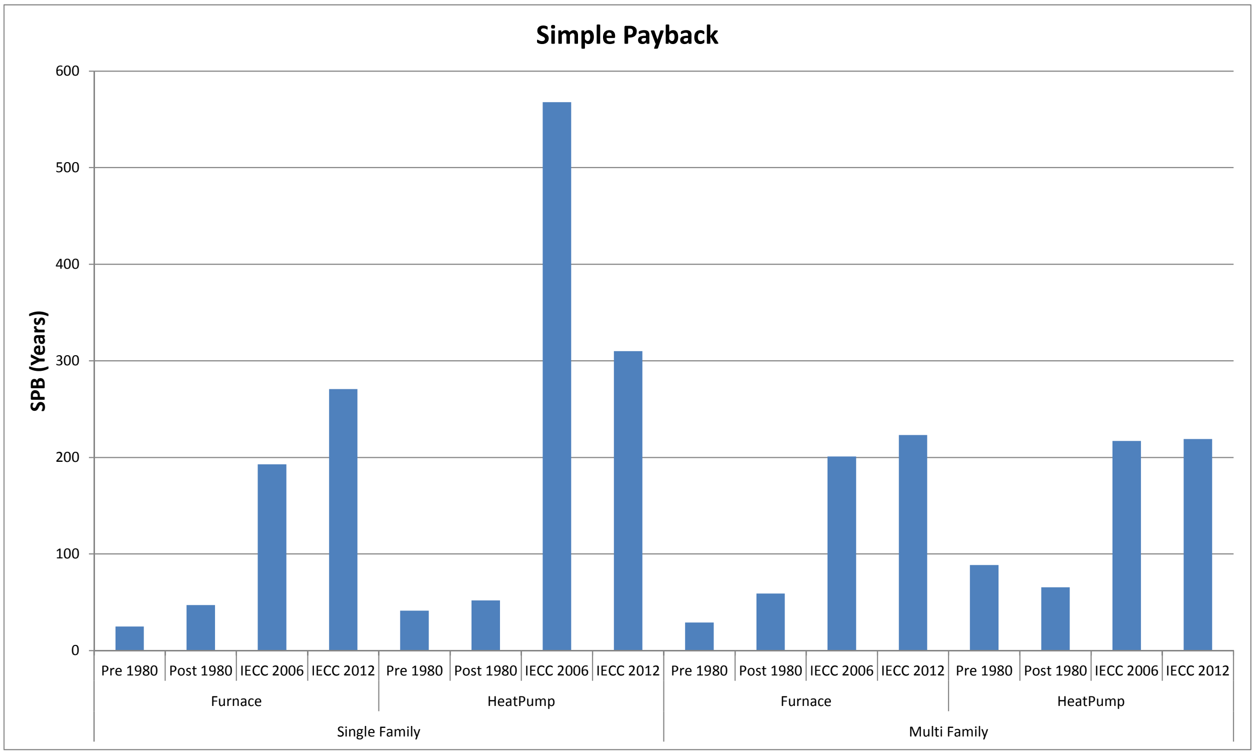

Energy Savings (per kSF Roof Area)
Energy Savings (kBtu/kSF)
1500
1000
500
0
-500
-1000
-1500
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

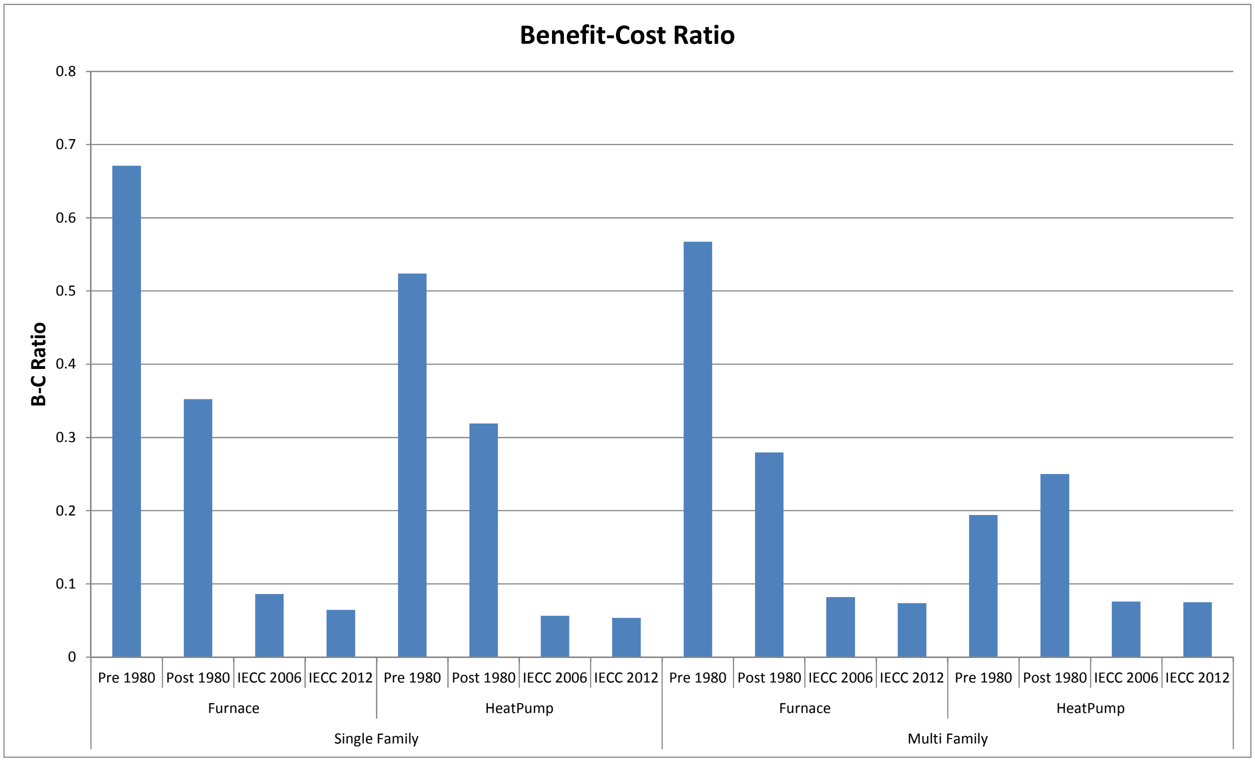
Measure RR-3


CO2 Emissions Reduction (per kSF Roof Area)
CO2 Reduction (lb/kSF)
400
350
300
250
200
150
100
50
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

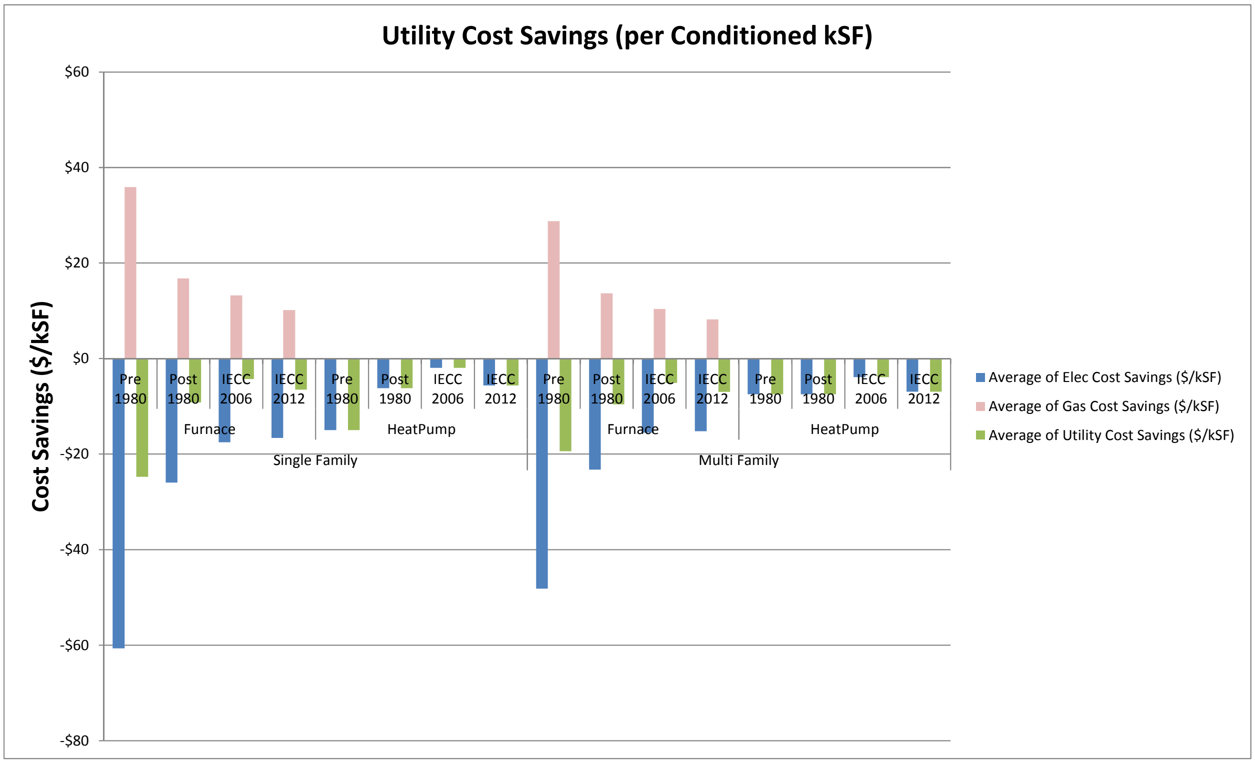

Emissions Reduction (per kSF Roof Area)
Emissions Reduction (lb/kSF)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

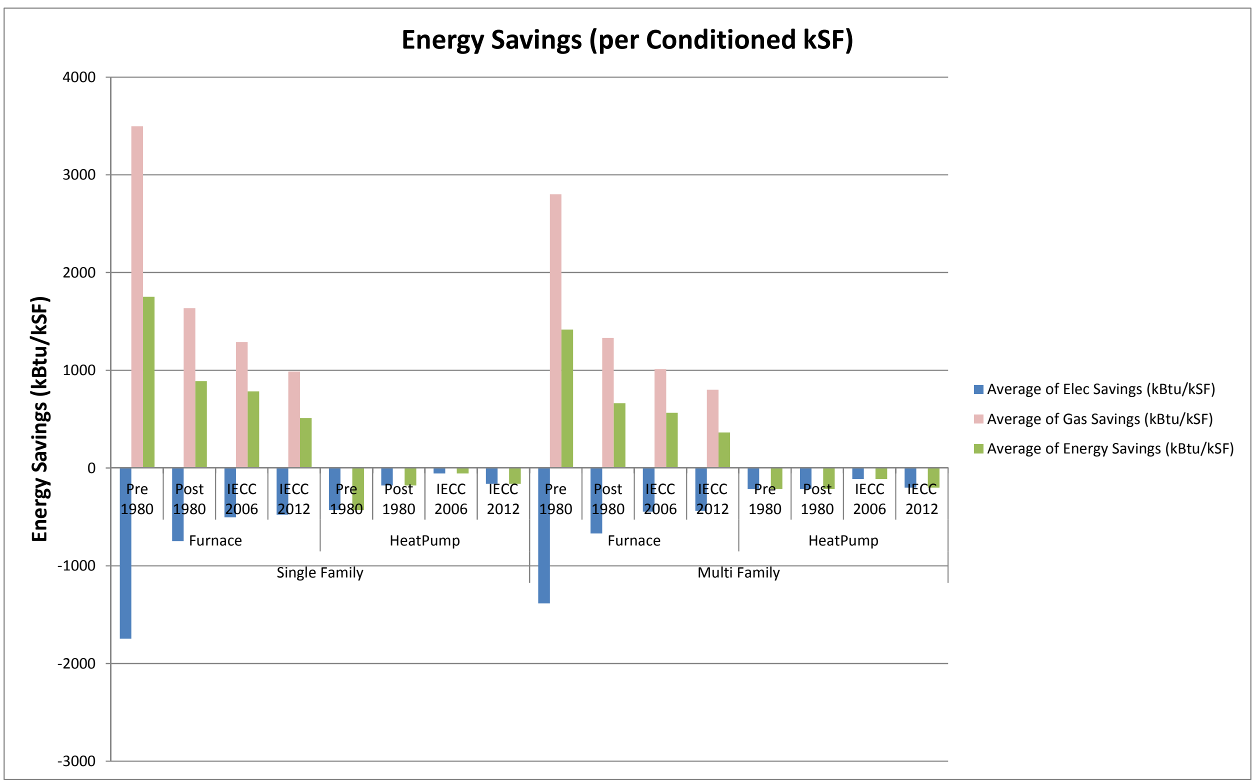
Measure RR-3


Simple Payback
SPB (Years)
600
500
400
300
200
100
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

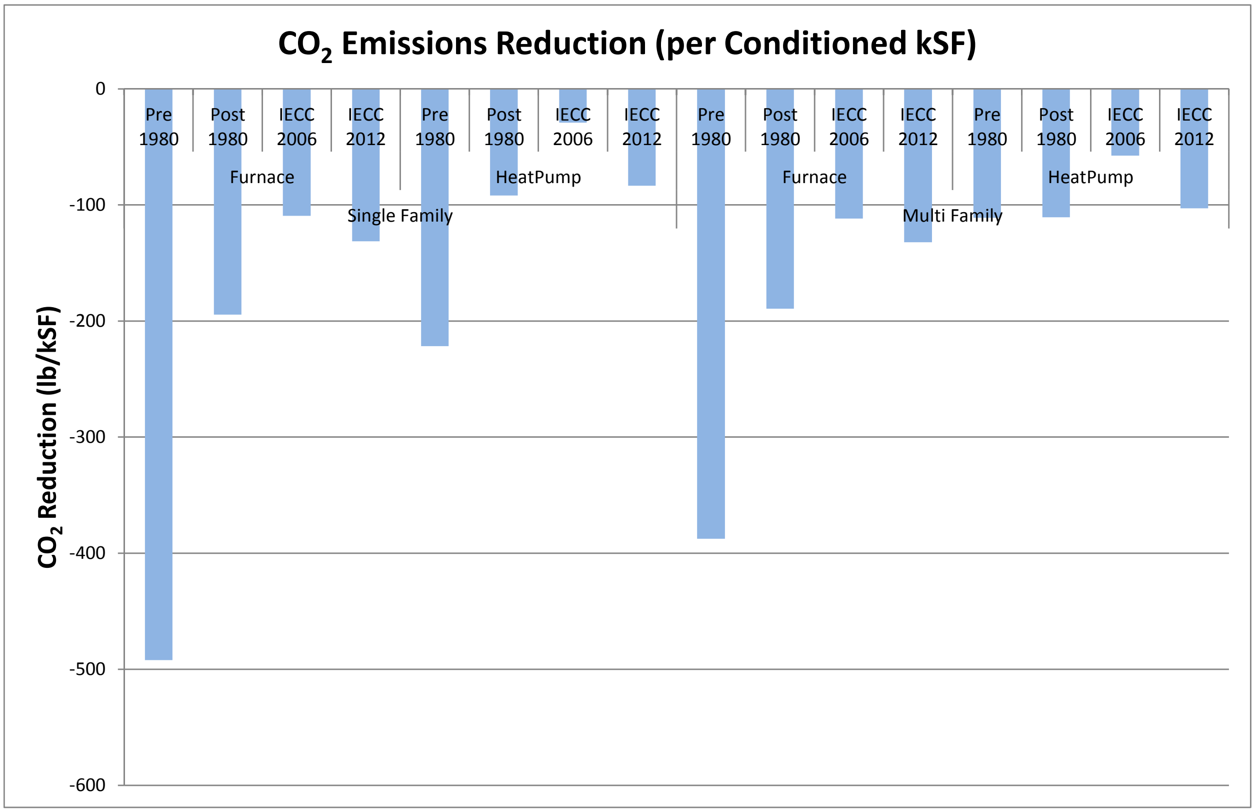

Benefit-Cost Ratio
B-C Ratio
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

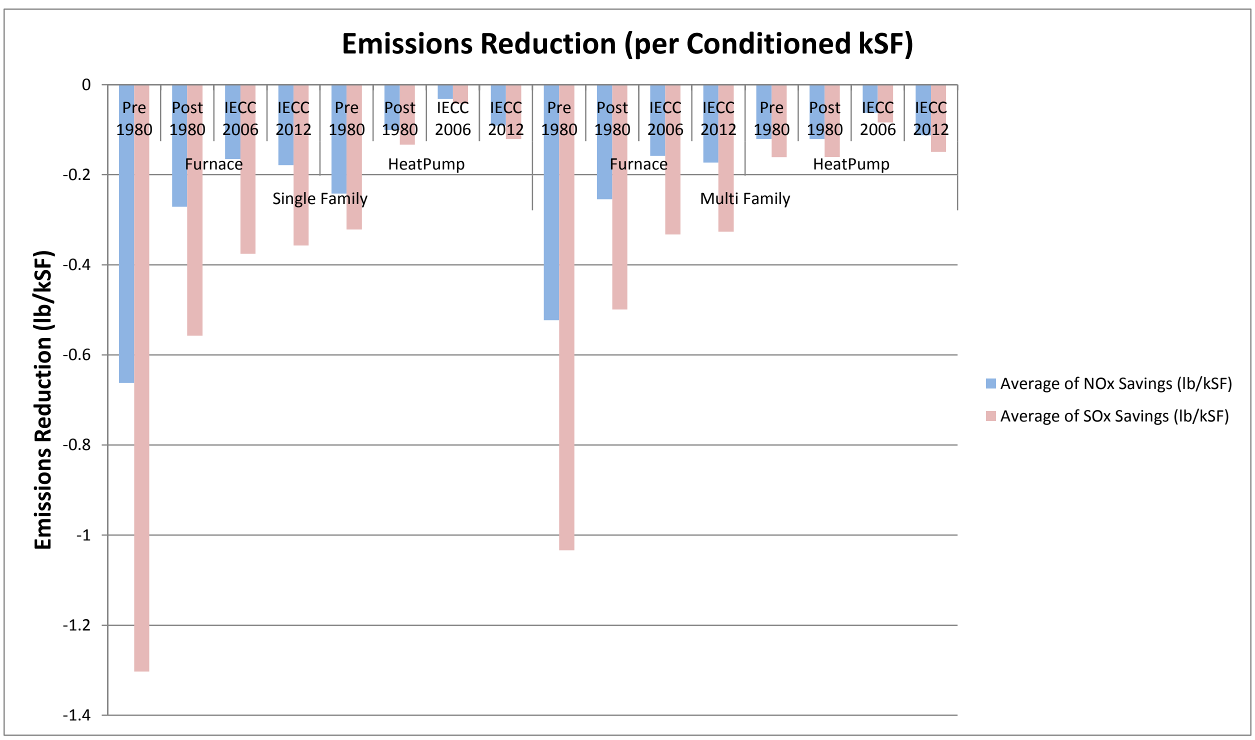
Measure RG-1


Utility Cost Savings (per Conditioned kSF)
Cost Savings ($/kSF)
$60
$40
$20
$0
-$20
-$40
-$60
-$80
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/kSF)
Average of Gas Cost Savings ($/kSF)
Average of Utility Cost Savings ($/kSF)

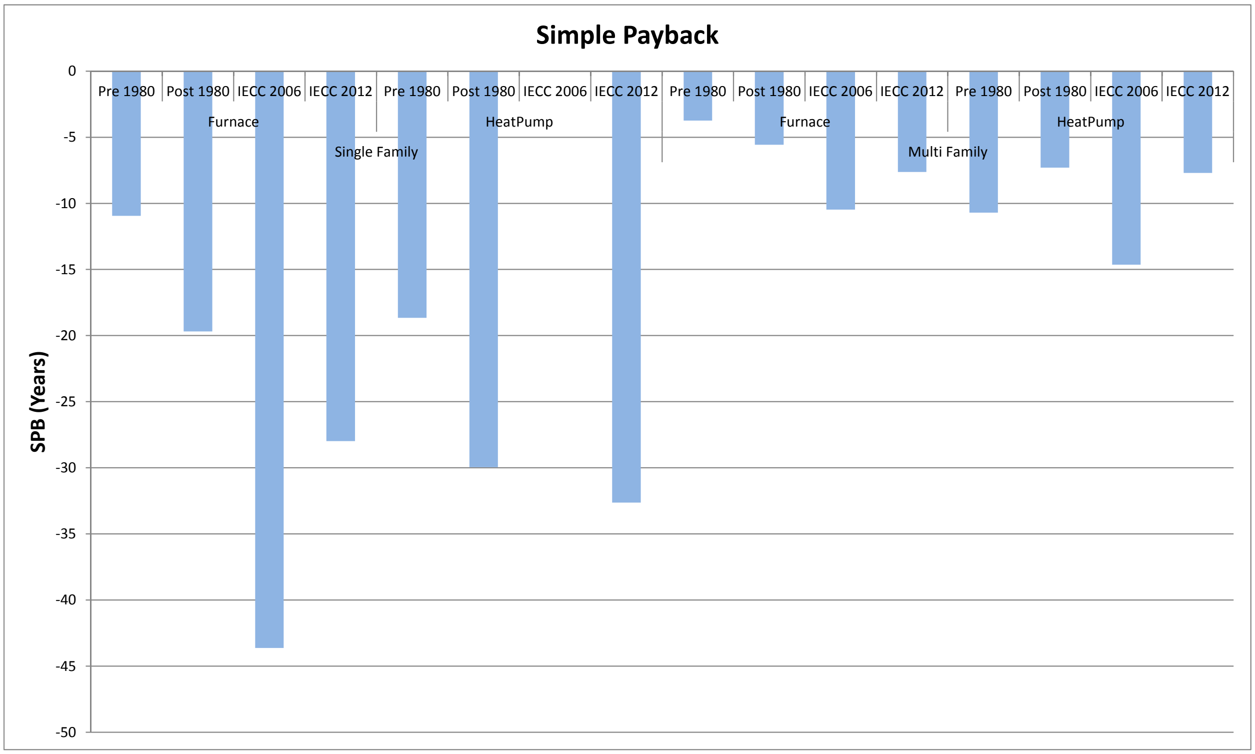

Energy Savings (per Conditioned kSF)
Energy Savings (kBtu/kSF)
4000
3000
2000
1000
0
-1000
-2000
-3000
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/kSF)
Average of Gas Savings (kBtu/kSF)
Average of Energy Savings (kBtu/kSF)

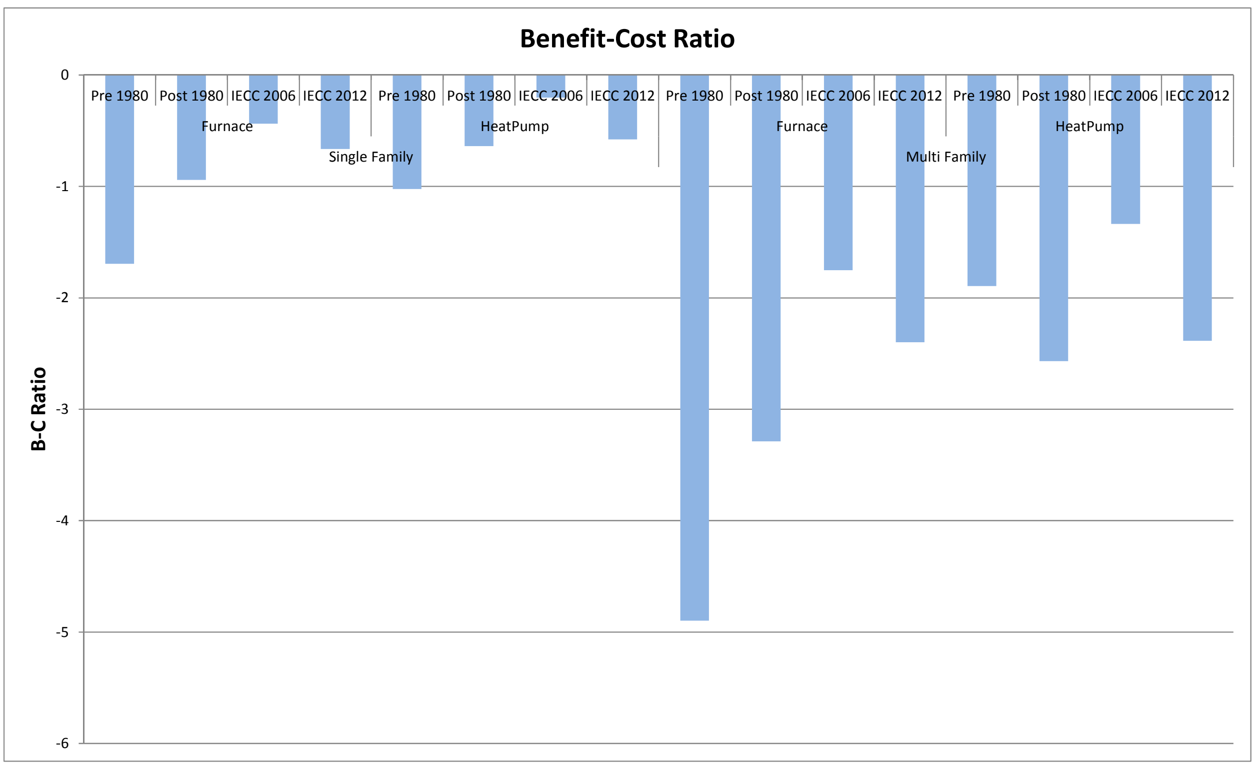
Measure RG-1


CO2 Emissions Reduction (per Conditioned kSF)
CO2 Reduction (lb/kSF)
0
-100
-200
-300
-400
-500
-600
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

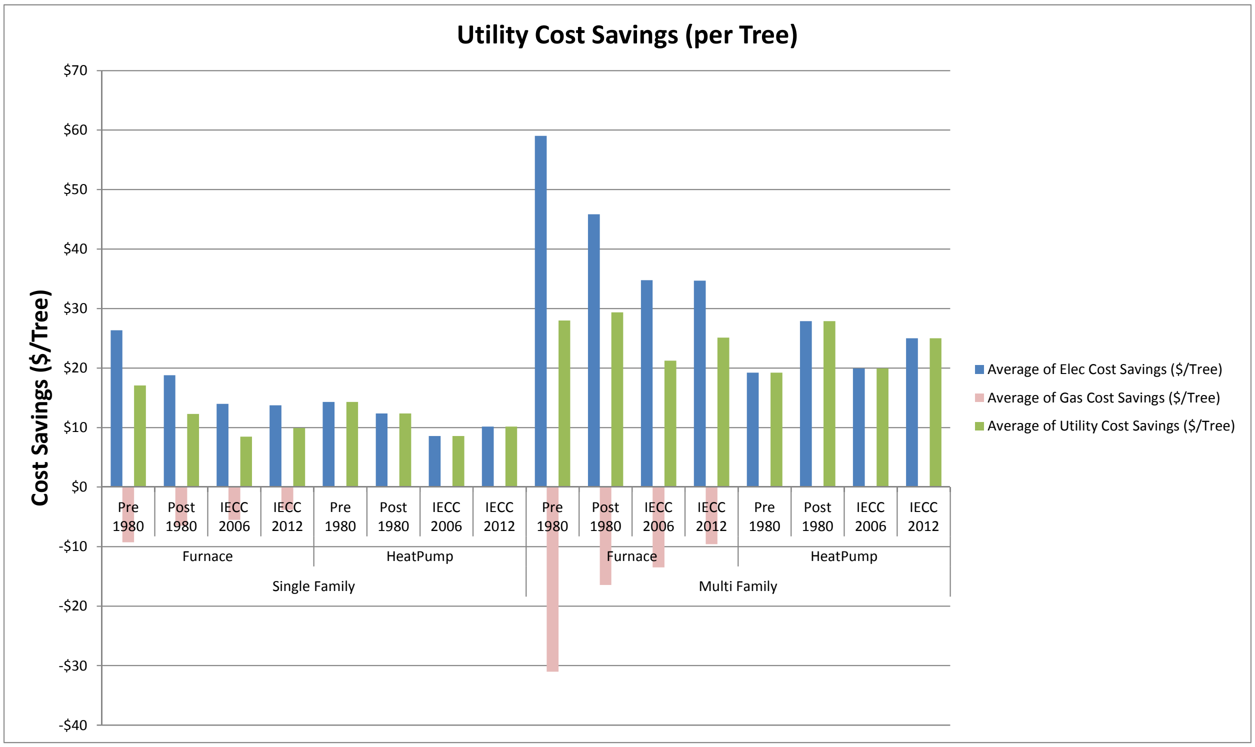

Emissions Reduction (per Conditioned kSF)
Emissions Reduction (lb/kSF)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/kSF)
Average of SOx Savings (lb/kSF)

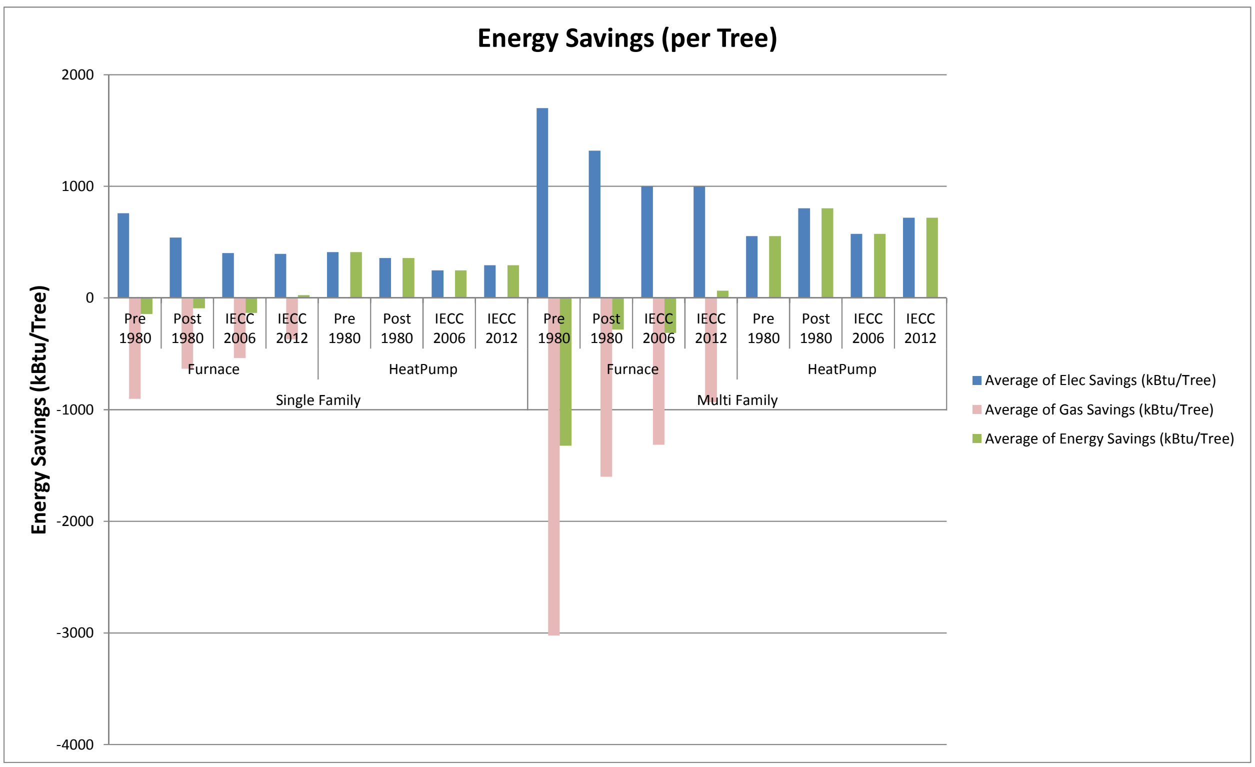
Measure RG-1


Simple Payback
SPB (Years)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

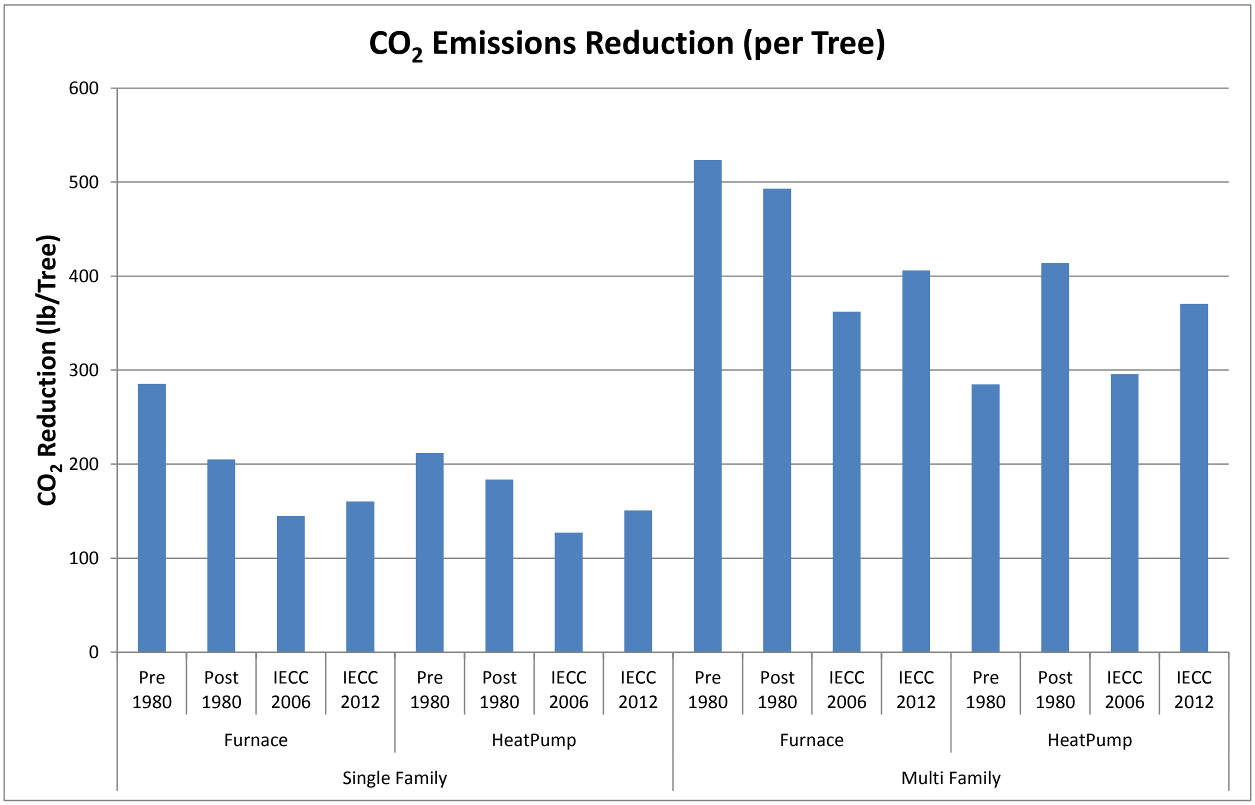

Benefit-Cost Ratio
B-C Ratio
0
-1
-2
-3
-4
-5
-6
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

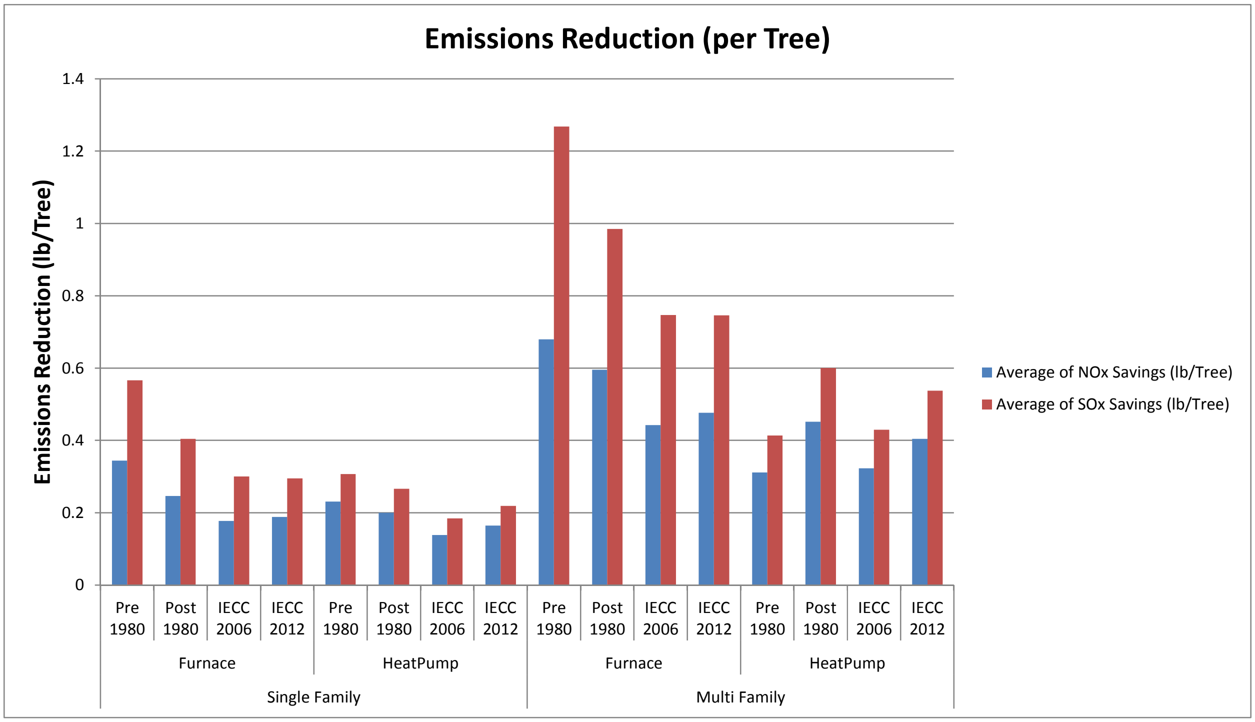
Measure RS-1


Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$70
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
-$30
-$40
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)

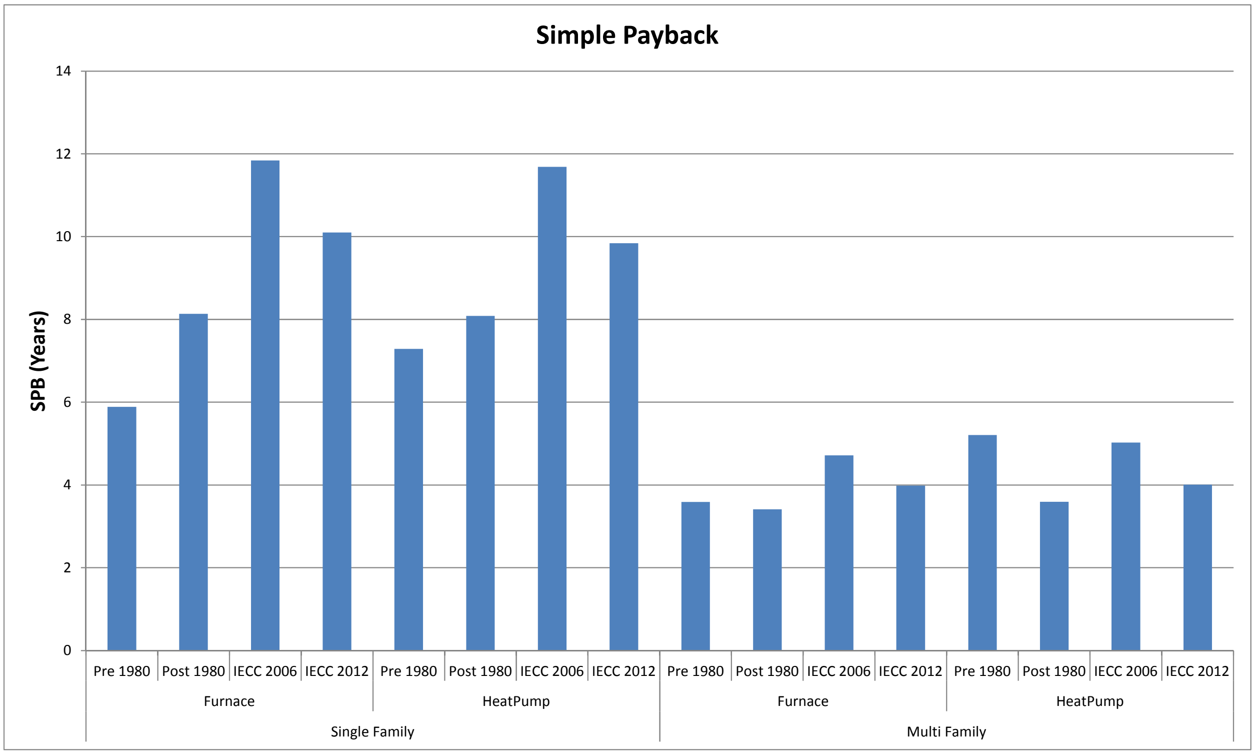

Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
2000
1000
0
-1000
-2000
-3000
-4000
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

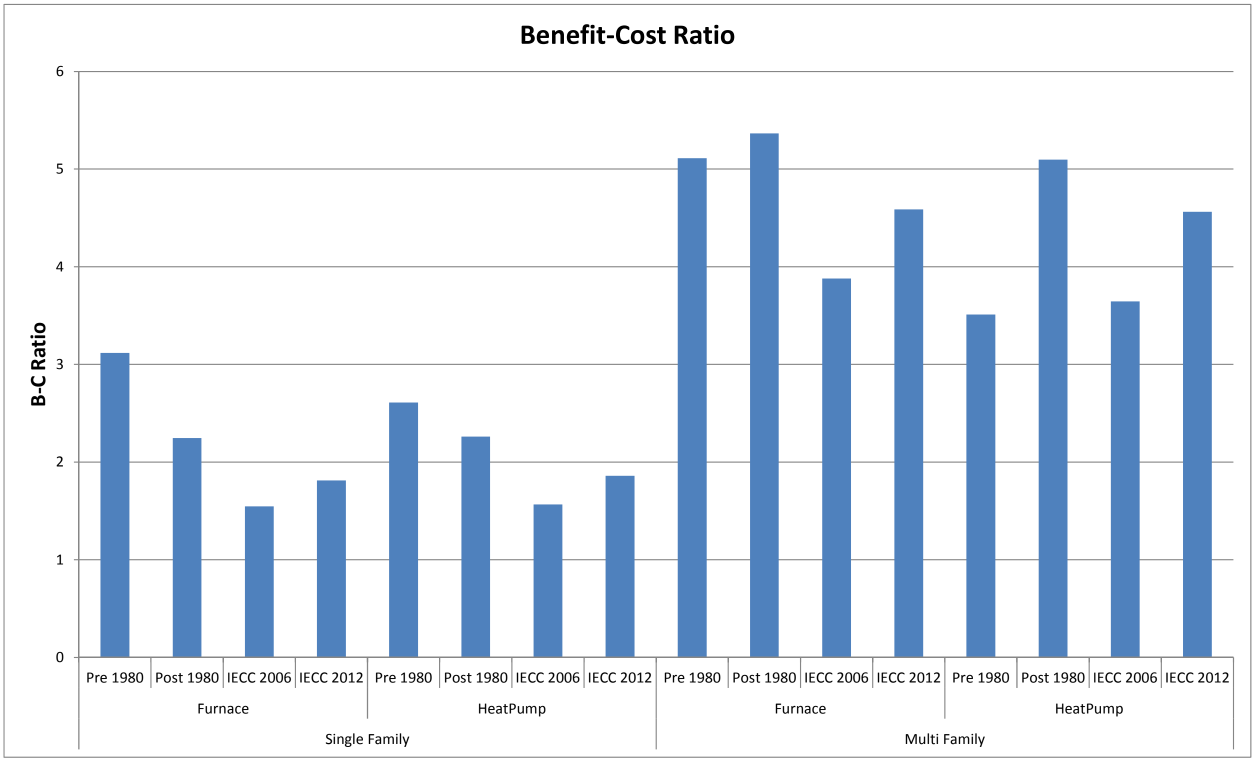
Measure RS-1


CO_2 Emissions Reduction (per Tree)
600
500
400
300
200
100
0
CO_2 Reduction (lb/Tree)
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

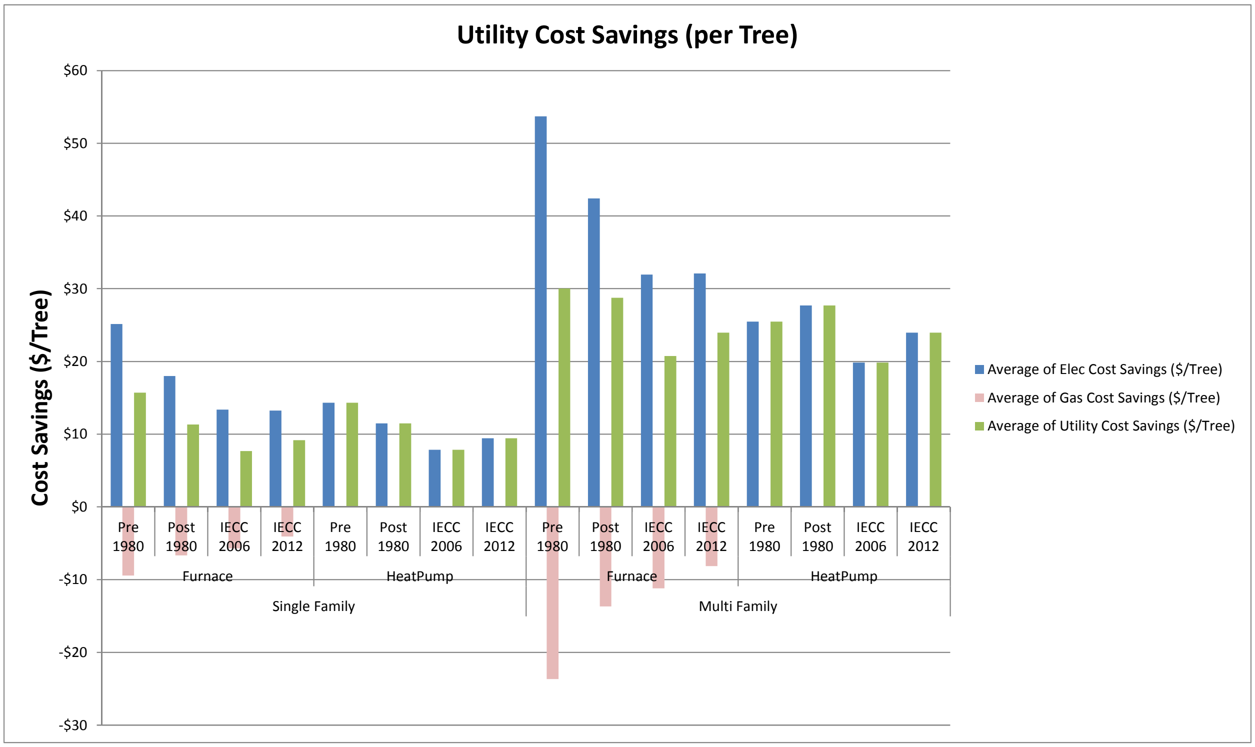

Emissions Reduction (per Tree)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Emissions Reduction (lb/Tree)
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

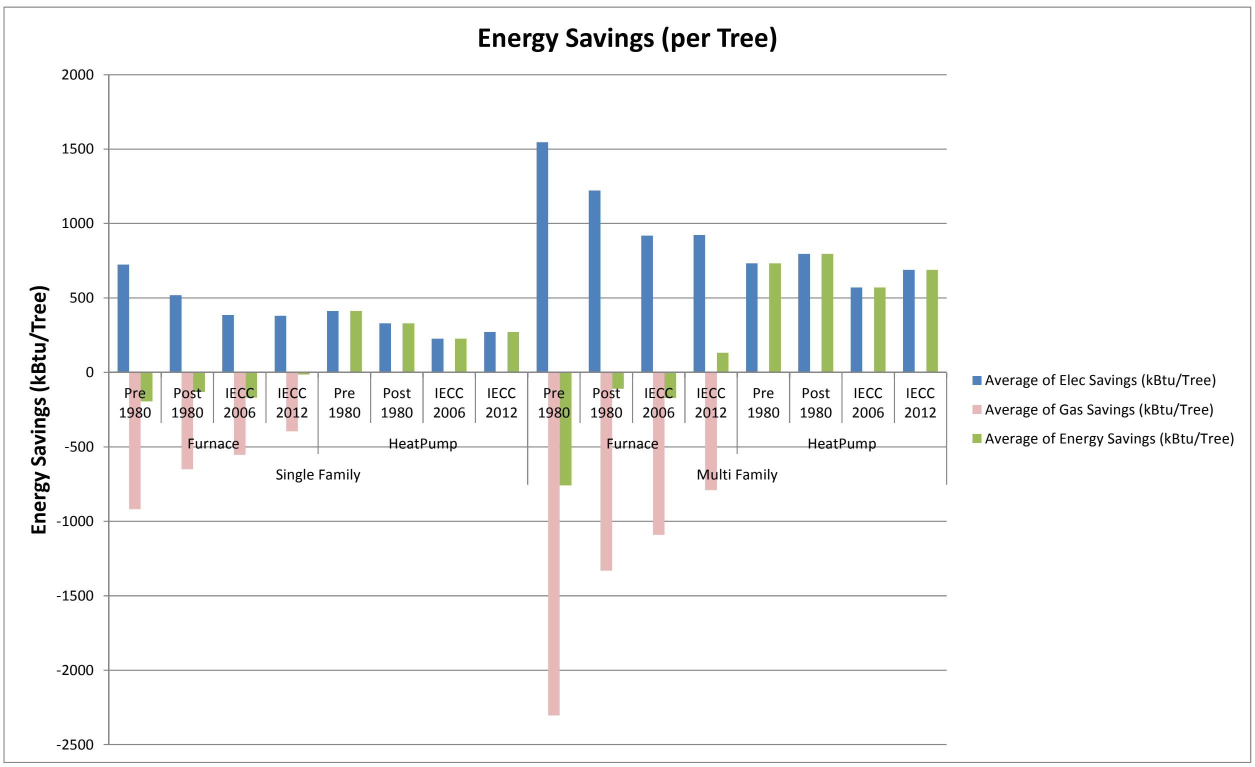
Measure RS-1


Simple Payback
SPB (Years)
14
12
10
8
6
4
2
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

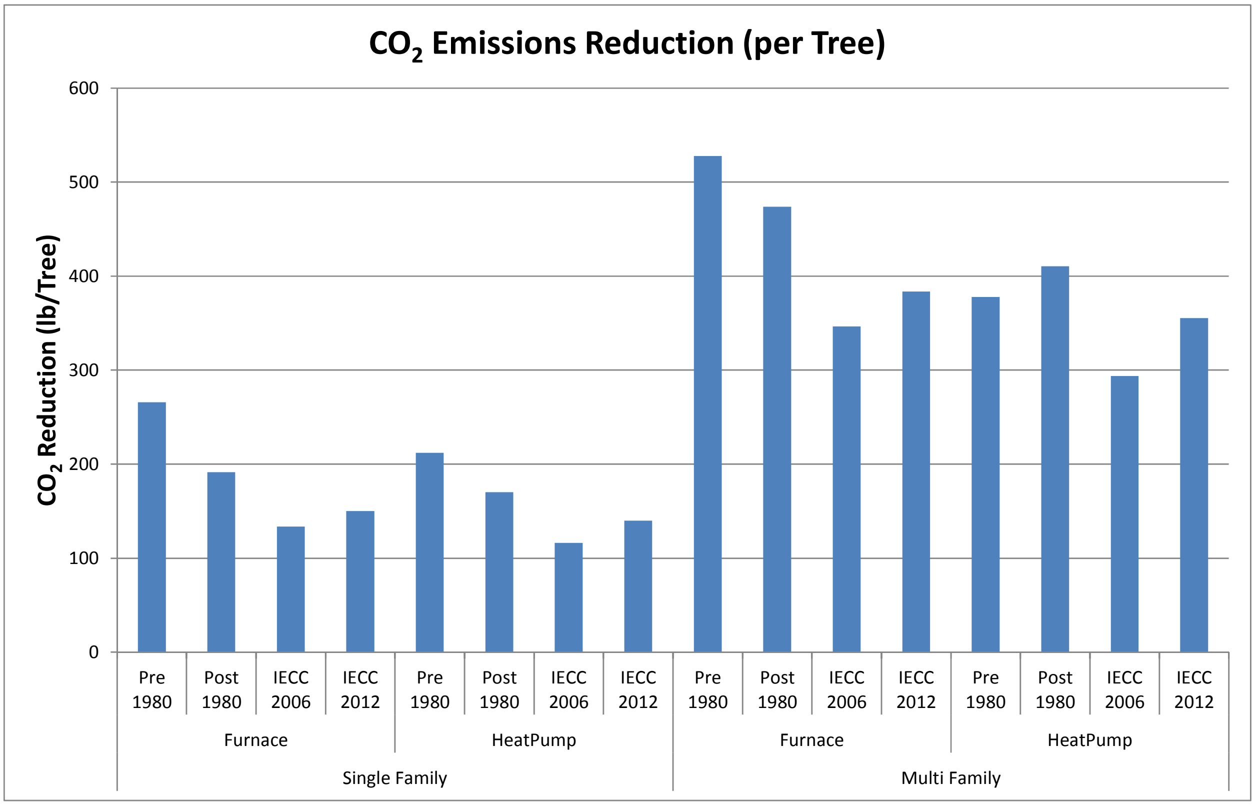

Benefit-Cost Ratio
B-C Ratio
6
5
4
3
2
1
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

Measure RS-2

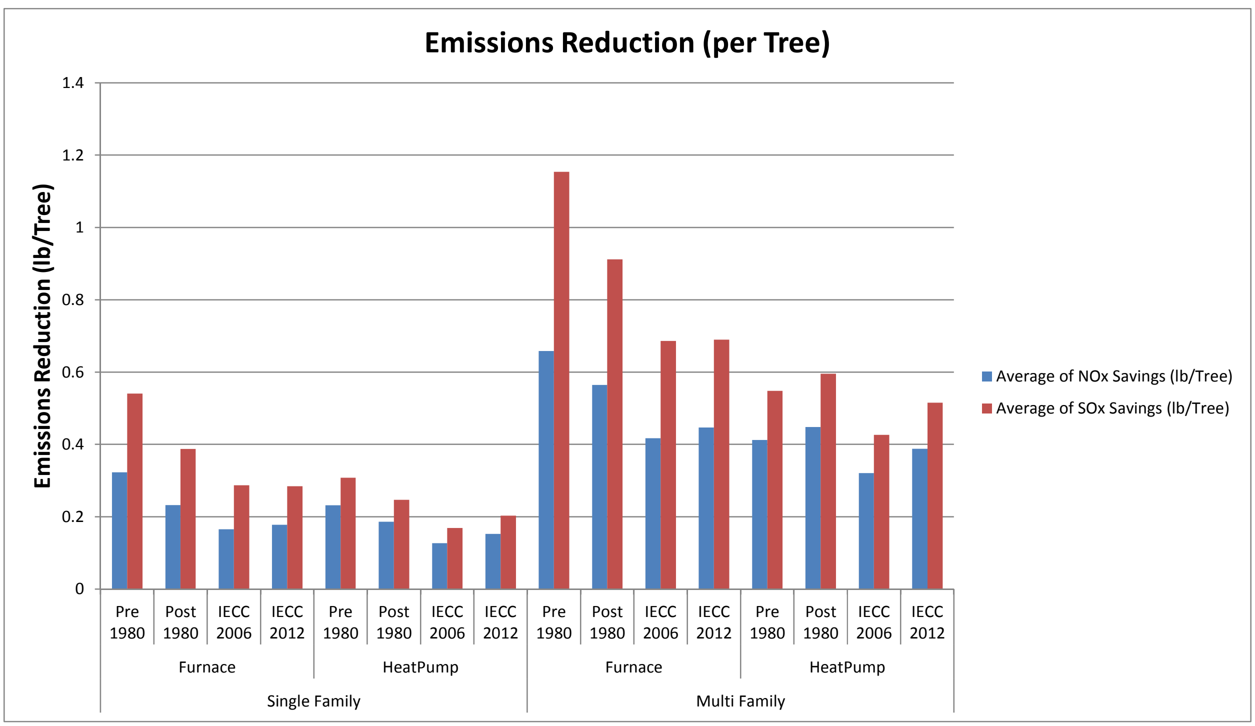

Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
-$30
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)


Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

Measure RS-2

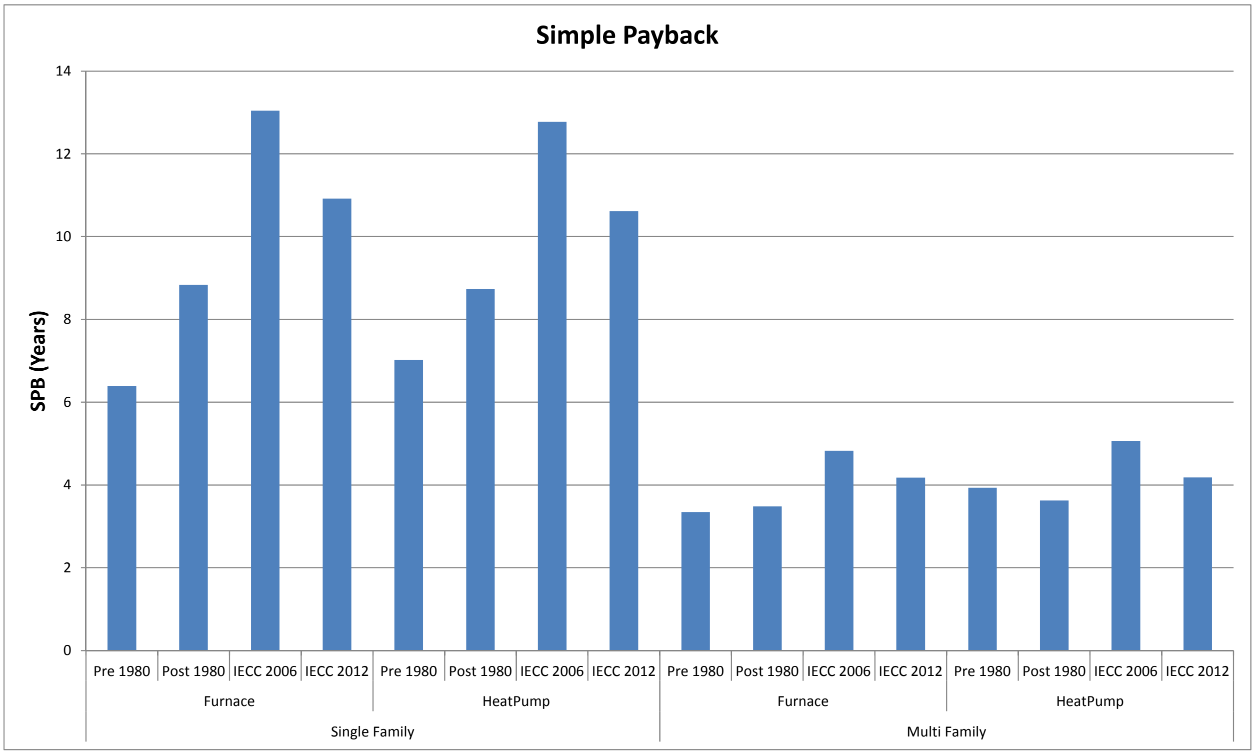


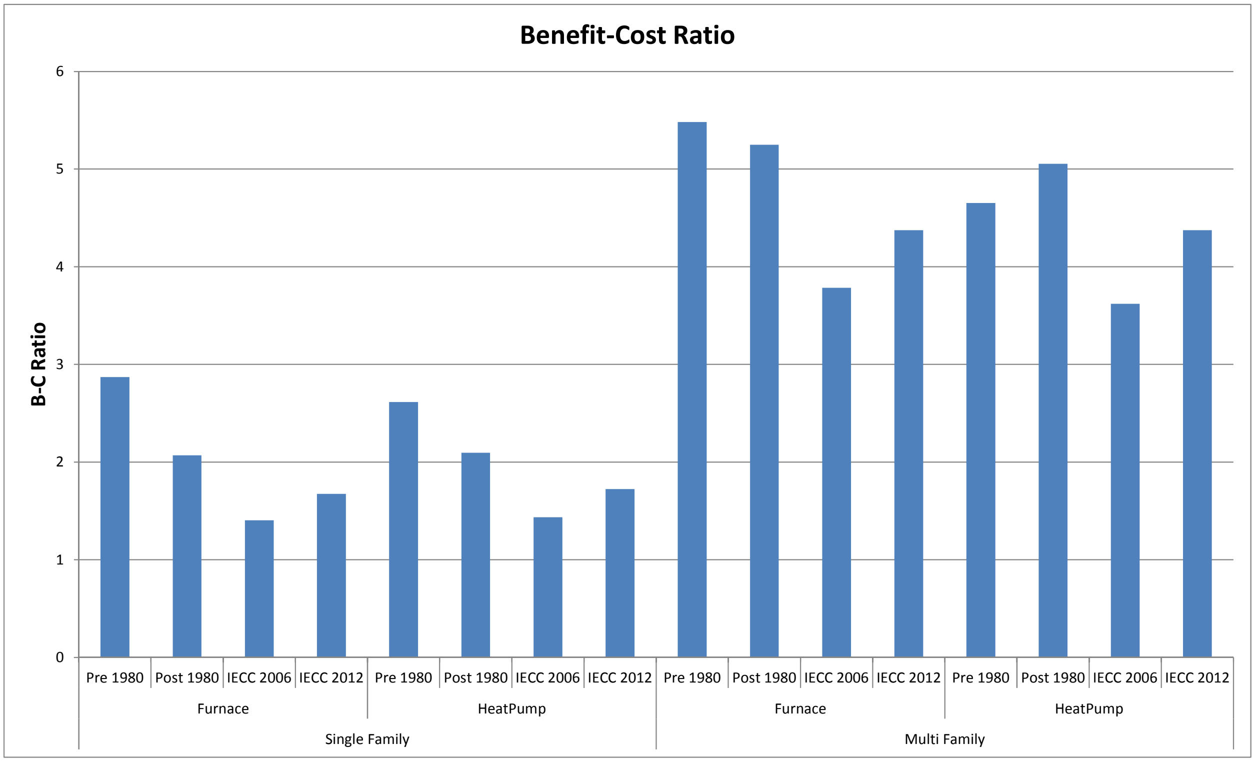
CO_2 Emissions Reduction (per Tree)
CO_2 Reduction (lb/Tree)
600
500
400
300
200
100
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family



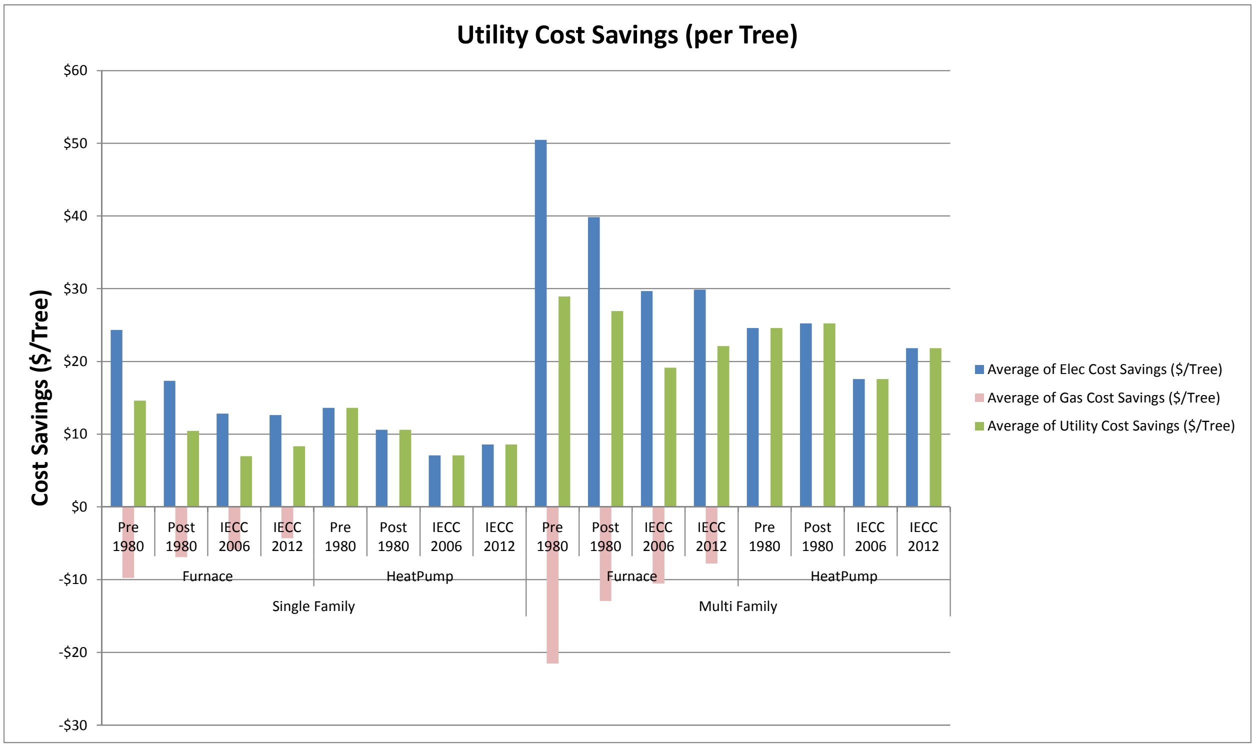
Emissions Reduction (per Tree)
Emissions Reduction (lb/Tree)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)

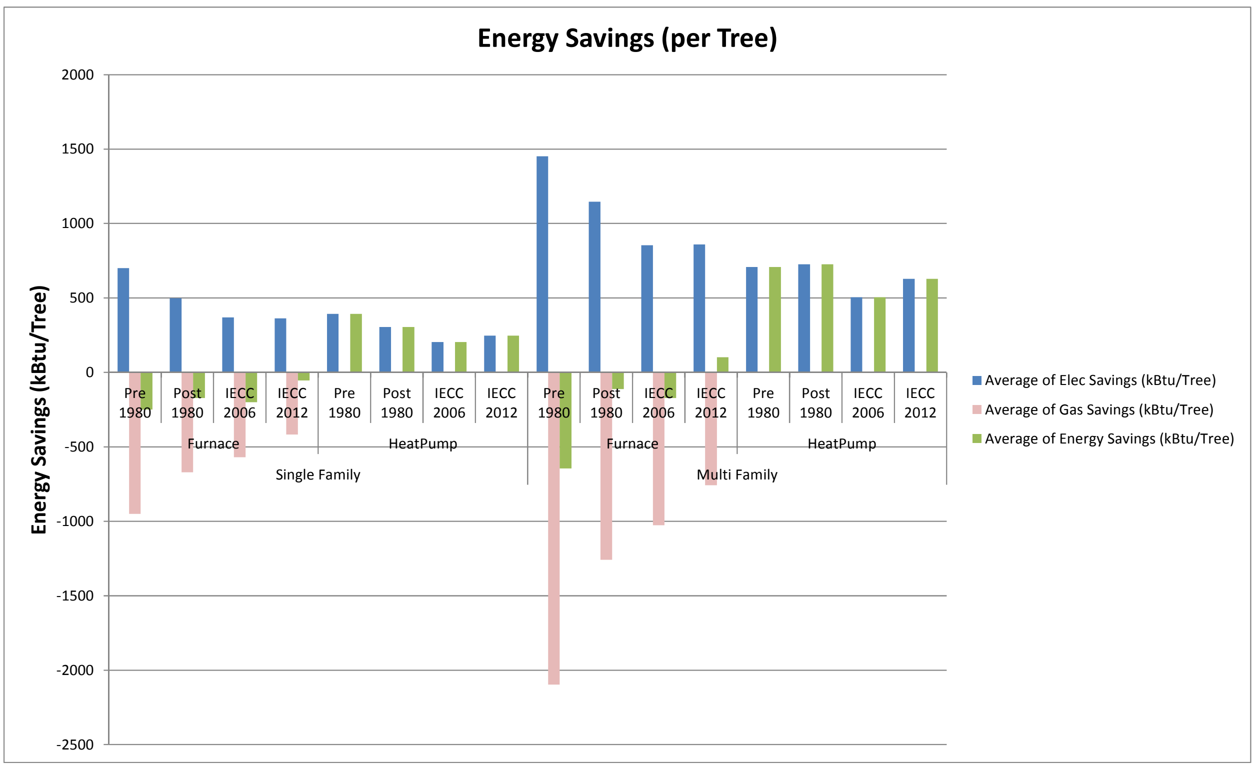
Measure RS-2


Simple Payback
SPB (Years)
0
2
4
6
8
10
12
14
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

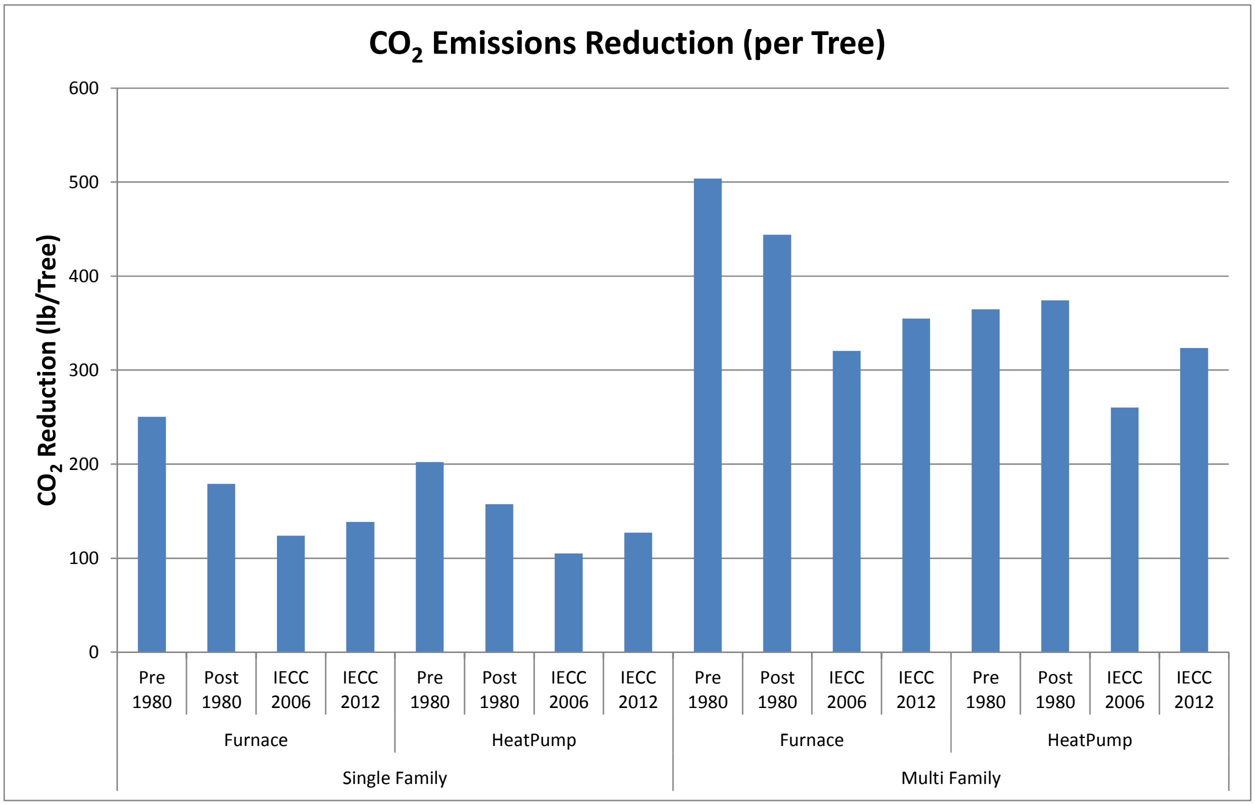

Benefit-Cost Ratio
B-C Ratio
0
1
2
3
4
5
6
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

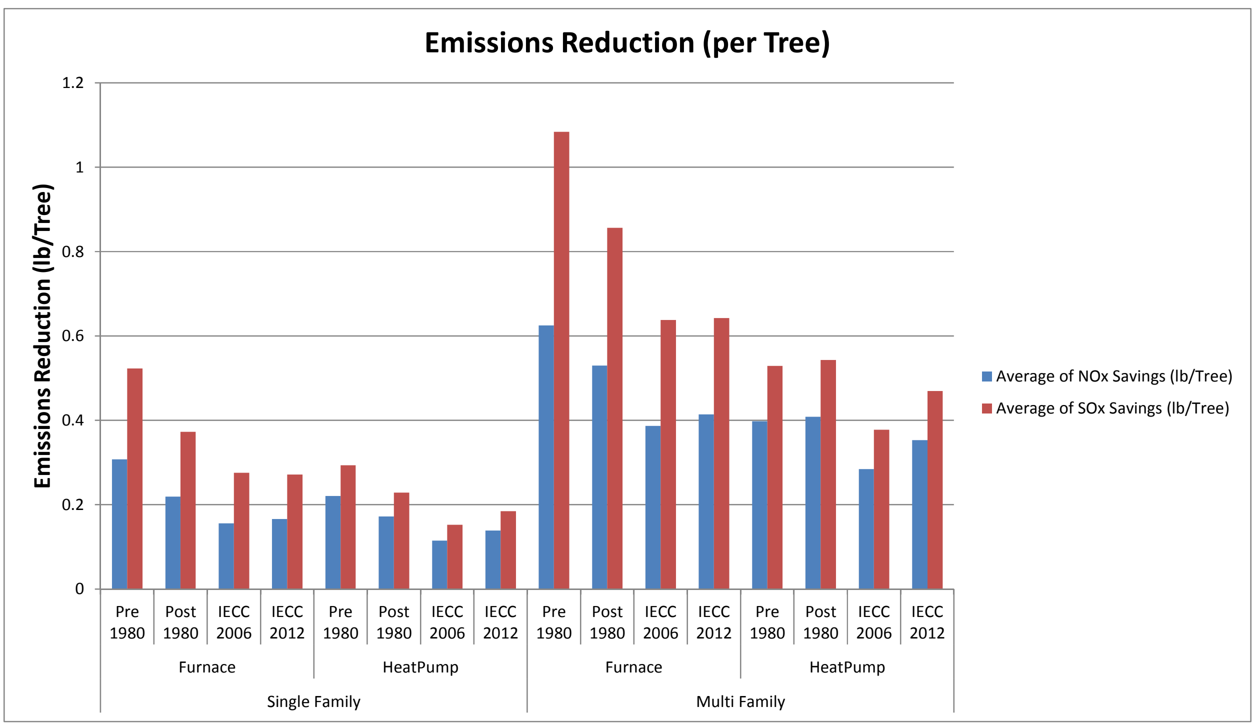
Measure RS-3


Utility Cost Savings (per Tree)
Cost Savings ($/Tree)
$60
$50
$40
$30
$20
$10
$0
-$10
-$20
-$30
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Cost Savings ($/Tree)
Average of Gas Cost Savings ($/Tree)
Average of Utility Cost Savings ($/Tree)

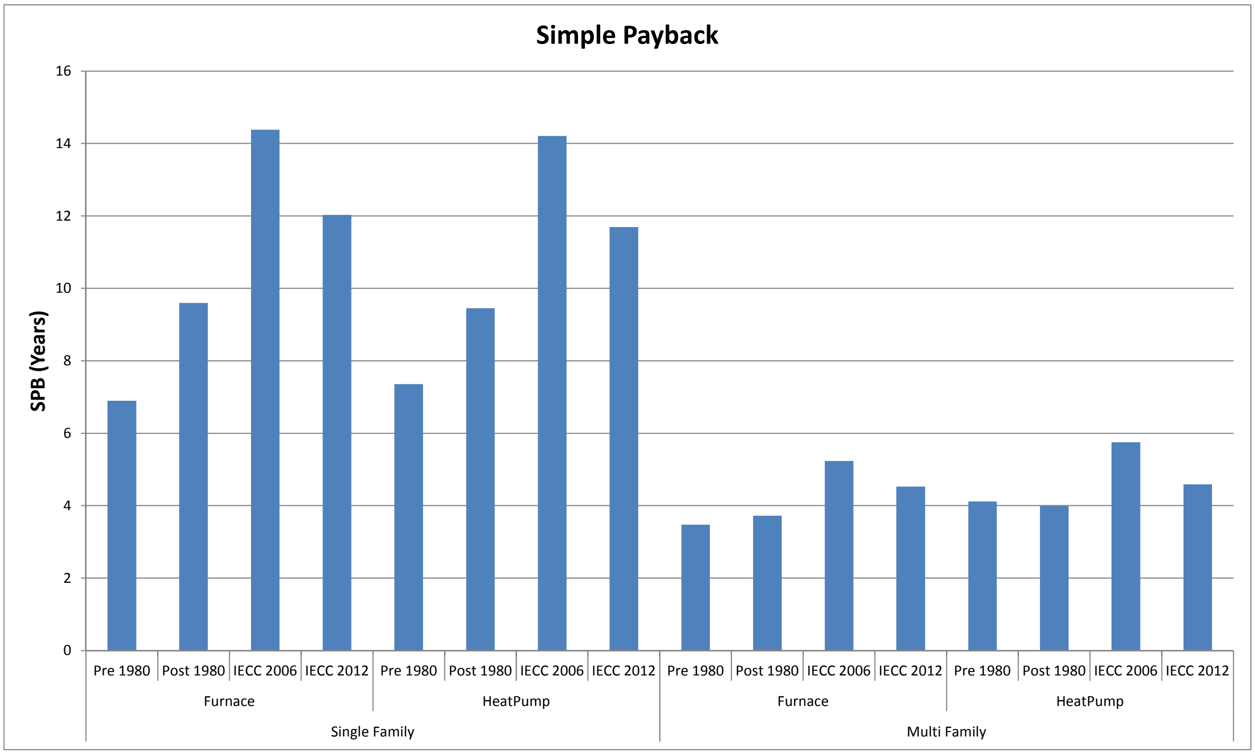

Energy Savings (per Tree)
Energy Savings (kBtu/Tree)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of Elec Savings (kBtu/Tree)
Average of Gas Savings (kBtu/Tree)
Average of Energy Savings (kBtu/Tree)

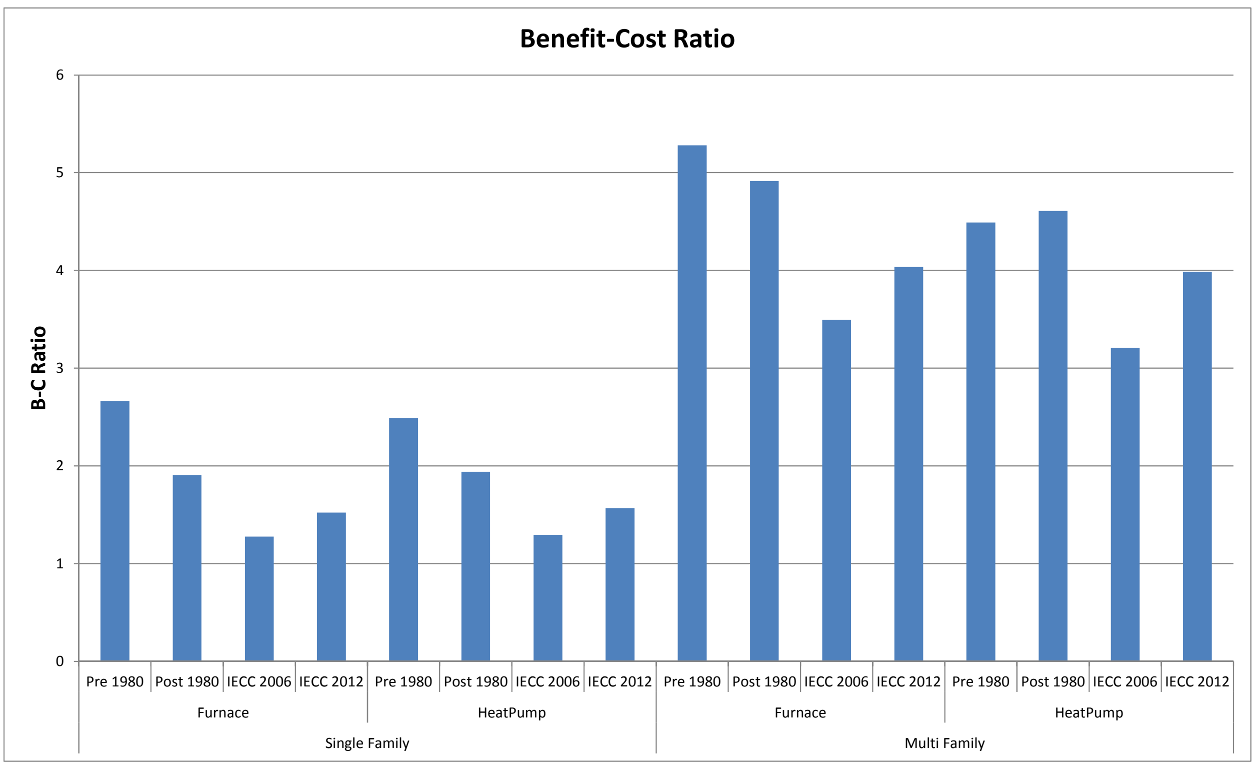
Measure RS-3


CO2 Emissions Reduction (per Tree)
CO2 Reduction (lb/Tree)
600
500
400
300
200
100
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family


Emissions Reduction (per Tree)
Emissions Reduction (lb/Tree)
1.2
1
0.8
0.6
0.4
0.2
0
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family
Average of NOx Savings (lb/Tree)
Average of SOx Savings (lb/Tree)

Measure RS-3


Simple Payback
SPB (Years)
0
2
4
6
8
10
12
14
16
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

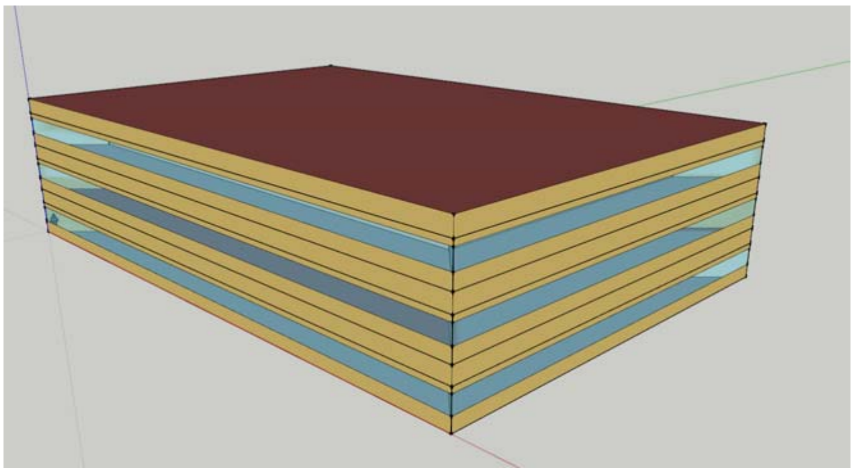

Benefit-Cost Ratio
B-C Ratio
0
1
2
3
4
5
6
Pre 1980
Post 1980
IECC 2006
IECC 2012
Furnace
HeatPump
Single Family
Multi Family

Appendix C: Commercial Prototype Buildings

Medium Office

- 53,628 ft^2
- 3 floors
- 0.33 Window-to-Wall Ratio

Building Image



Typical Floor Plan

Space Types

Offices

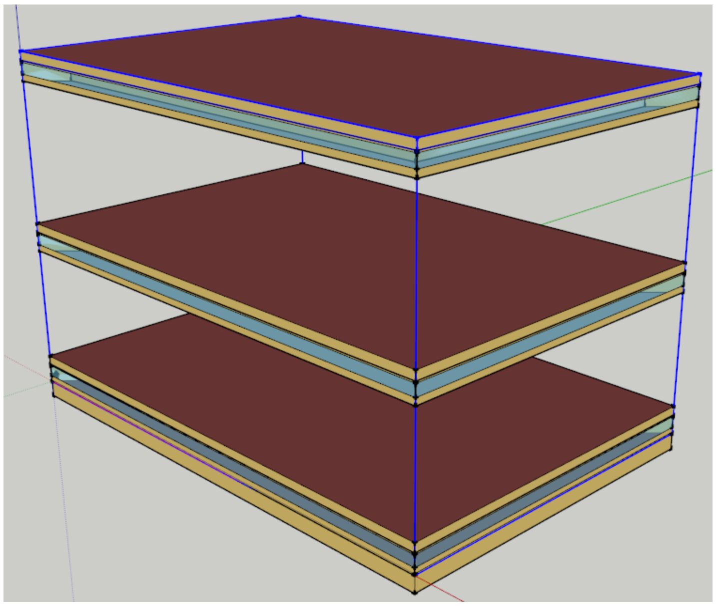
Construction Vintages

	Pre 1980	Post 1980	New Construction
Wall Construction	Steel frame	Steel frame	Steel frame
Wall Insulation	R-3.8 (effective) U-0.178 assembly	R-6.2 (effective) U-0.124 assembly	R-9.4 (effective) U-0.089 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

Large Office

- 498,588 ft^2
- 12 floors plus basement
  - o Middle floor in image below has a multiplier of 10 to fill in the space between the bottom and top floors
- 0.38 Window-to-Wall Ratio

Building Image



Typical Floor Plan

Space Types

Offices

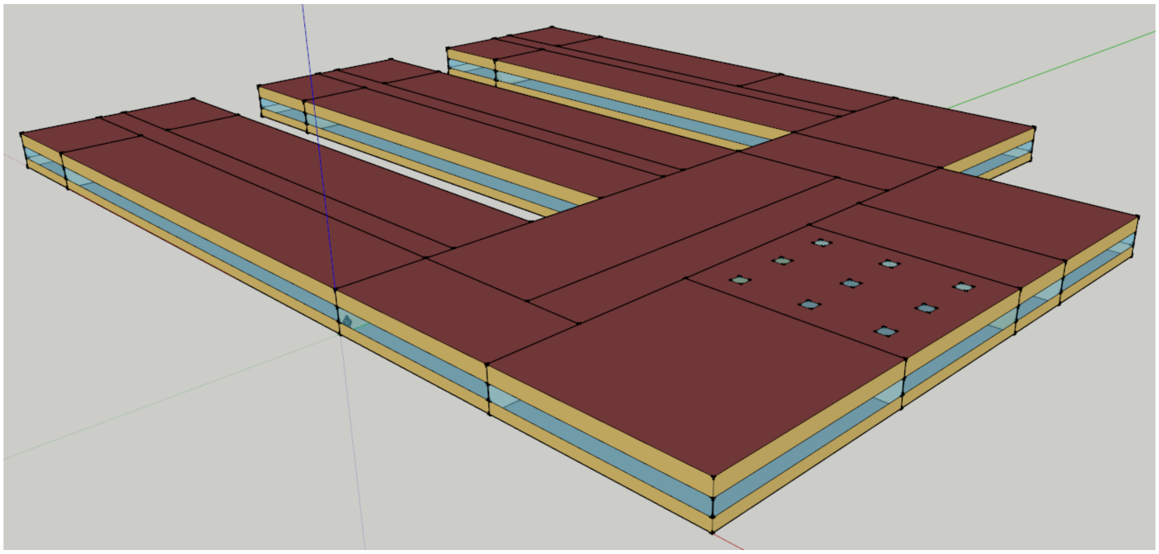
Construction Vintages

	Pre 1980	**Post 1980**	**New Construction**
Wall Construction	Mass	Mass	Mass
Wall Insulation	R-3.2 (effective) U-0.178 assembly	R-4.2 (effective) U-0.58 assembly	R-5.9 (effective) U-0.120 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

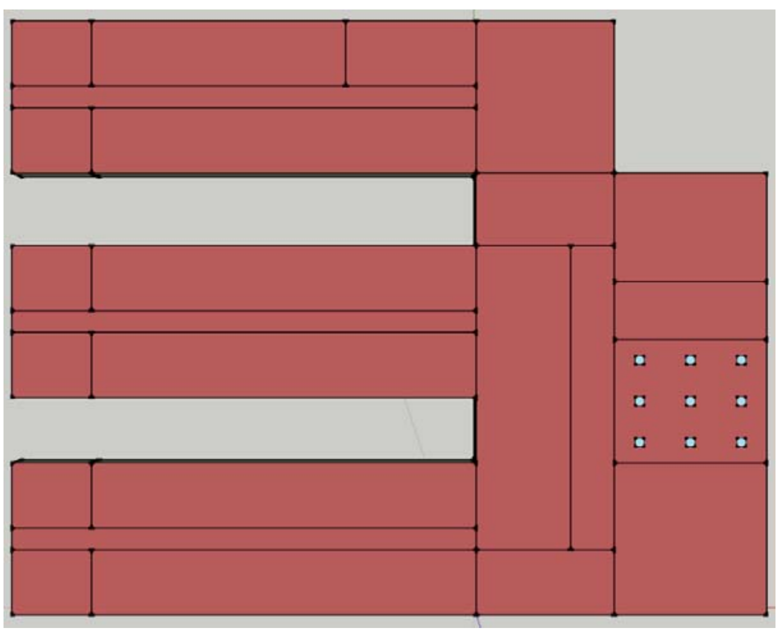
Primary School

- 73,960 ft^2
- 1 floor
- 0.35 Window-to-Wall Ratio
- Secondary School is similar, but with 2 floors, and 210,887 ft^2

Building Image



Typical Floor Plan



Space Types

Classrooms, cafeteria, restrooms, corridor, gym, kitchen, library, computer class, mechanical, offices, lobby

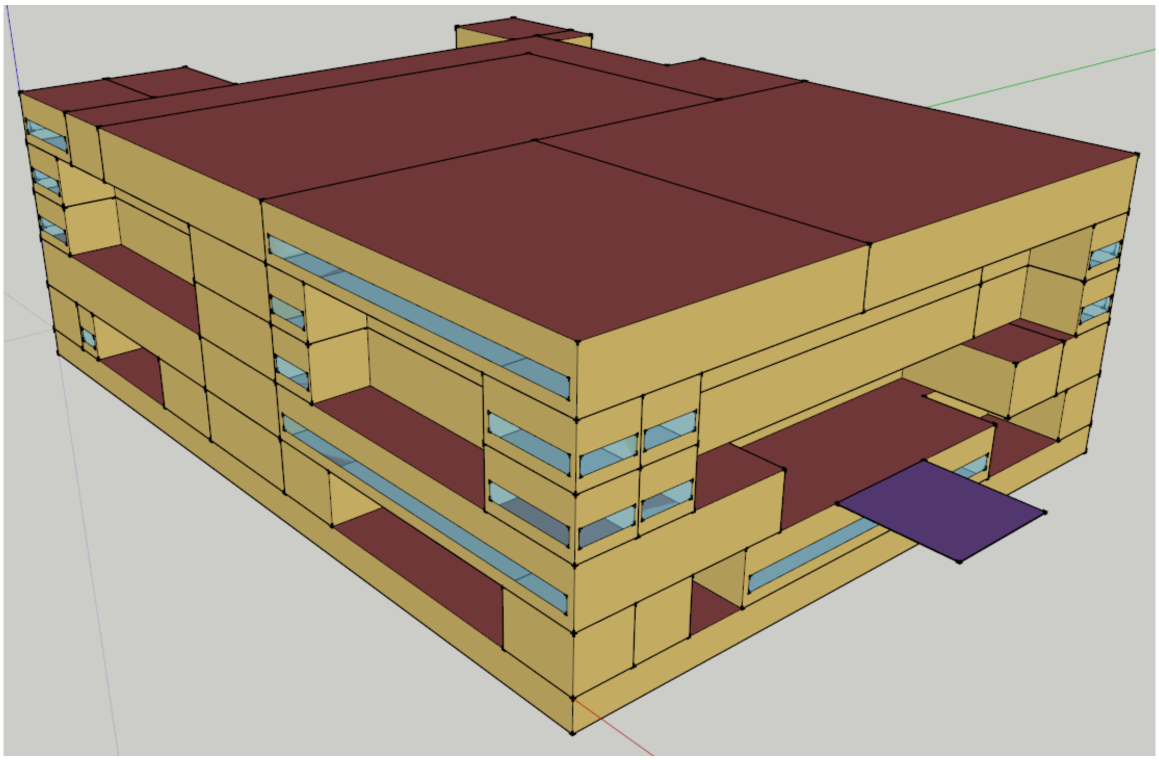
Construction Vintages

	Pre 1980	**Post 1980**	**New Construction**
Wall Construction	Steel frame	Steel frame	Steel frame
Wall Insulation	R-3.8 (effective) U-0.178 assembly	R-6.2 (effective) U-0.124 assembly	R-9.4 (effective) U-0.089 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

Hospital

- 241,351 ft^2
- 5 floors plus basement
    - Numerous rooms use multipliers, which fills in the blank spaces in the image below
- 0.15 Window-to-Wall Ratio

Building Image



Typical Floor Plan

- Varies by floor
- Patient floors and OR floors

Space Types

Basement, corridors, dining, kitchen, exam rooms, nurses stations, trauma rooms, triage, patient rooms, ICU, labs, lobby, offices, operating rooms, physical therapy, radiology

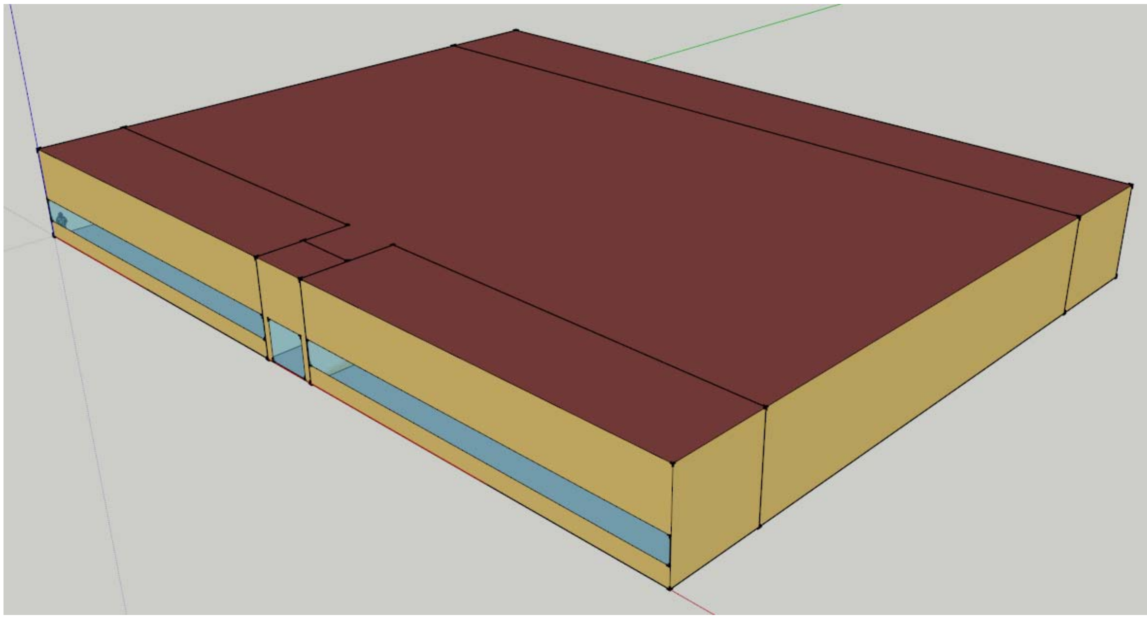
Construction Vintages

	Pre 1980	**Post 1980**	**New Construction**
Wall Construction	Mass	Mass	Mass
Wall Insulation	R-3.2 (effective) U-0.178 assembly	R-4.2 (effective) U-0.58 assembly	R-5.9 (effective) U-0.120 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

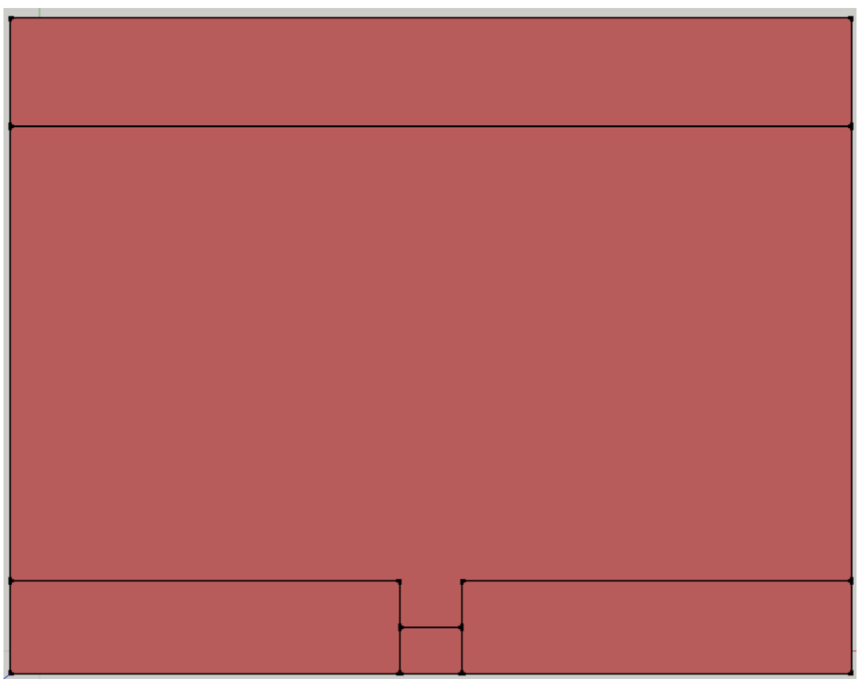
Stand-Alone Retail

- 24,962 ft^2
- 1 floor
- 0.07 Window-to-Wall Ratio

Building Image



Typical Floor Plan



Space Types

Retail, point of sale, front entry, back space

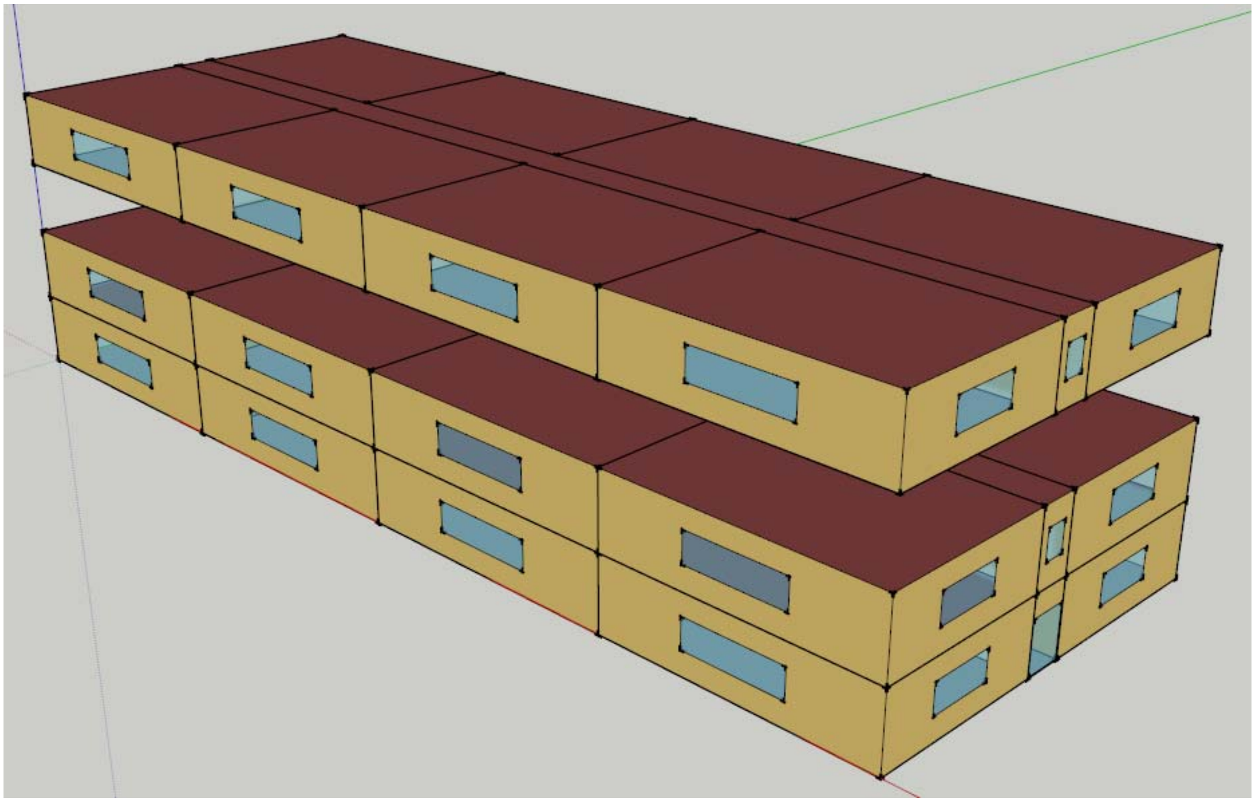
Construction Vintages

	Pre 1980	**Post 1980**	**New Construction**
Wall Construction	Steel frame	Mass	Mass
Wall Insulation	R-3.8 (effective) U-0.178 assembly	R-4.2 (effective) U-0.58 assembly	R-5.9 (effective) U-0.120 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

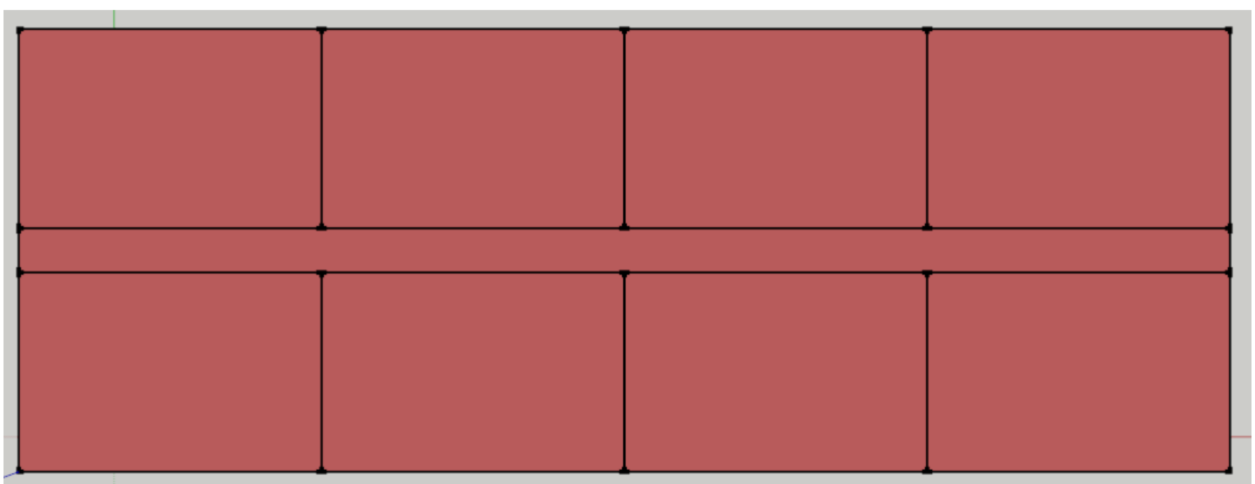
Mid Rise Apartment

- 33,740 ft^2
- 4 floors
  - o Middle floor has a multiplier of 2
- 0.15 Window-to-Wall Ratio

Building Image



Typical Floor Plan



Space Types

Corridor, apartments, rental office

Construction Vintages

	Pre 1980	Post 1980	New Construction
Wall Construction	Steel frame	Steel frame	Steel frame
Wall Insulation	R-3.8 (effective) U-0.178 assembly	R-6.2 (effective) U-0.124 assembly	R-9.4 (effective) U-0.089 assembly
Roof Construction	Insulation entirely above deck	Insulation entirely above deck	Insulation entirely above deck
Window Assembly U-Value	1.22	0.59	0.57
Window SHGC	0.54	0.36	0.39

Miscellaneous

Additional inputs can be found in the following document:

http://www.nrel.gov/docs/fy11osti/46861.pdf

Changes to Energy Simulation Models from DOE Prototypes

All Models

- Changed design day data to match Kansas City, MO
- Changed water mains and ground temps to match Kansas City, MO
- Changed window construction methodology to provide more flexibility
- Changed Post 1980 Wall insulation to be between Pre 1980 and New Construction (average of two)
- Changed Pre 1980 Window properties to ASHRAE 90.1 Table A8.2 single pane clear properties
    - U-0.125
    - SHGC-0.82
    - VLT-0.76
- Changed Post 1980 Window properties to ASHRAE 90.1 Table A8.2 metal frame double pane tinted properties
    - U-0.90
    - SHGC-0.50
    - VLT-0.40

Medium Office

- Changed VAV reheat to hot water, added boiler, hot water reheat coils, and variable speed pump
- Changed system type to VAV RTU with HW reheat to be consistent with Post 1980 and New Construction models

Midrise Apartment

- Changed electric heating coils to gas heating coils

Primary School

- Added skylights to Pre 1980 and Post 1980 to be consistent with New Construction model

Stand-Alone Retail

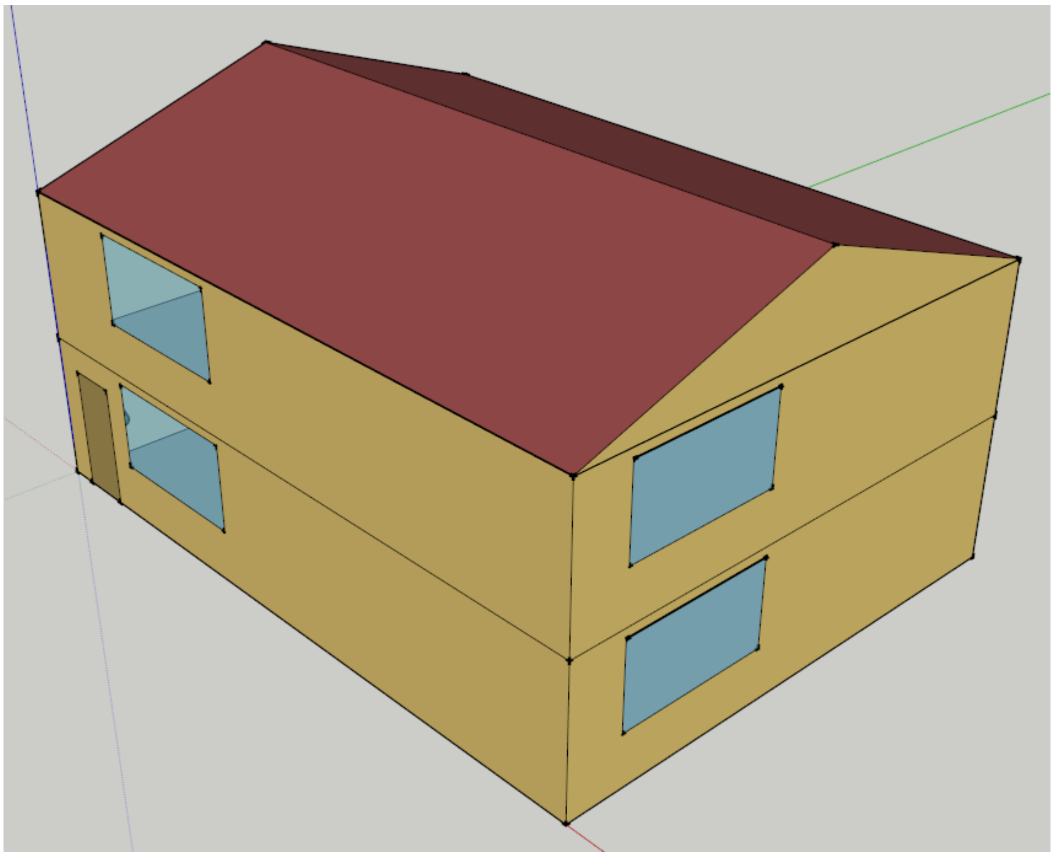
- Changed electric heating coils to gas heating coils
- Changed New Construction and Post 1980 wall construction to steel frame to be consistent with Pre 1980

Appendix D: Residential Prototype Buildings

Single Family

- 2,400 ft^2
- 2 floors plus attic
    - o Option of on slab construction, heated basement, unheated basement, and crawlspace
    - o Since the study focuses on roof material, site shading, and surrounding pavement/vegetation, the basement construction is not important. Slab is the easiest to change and run.
- 0.14 Window-to-Wall Ratio

Building Image



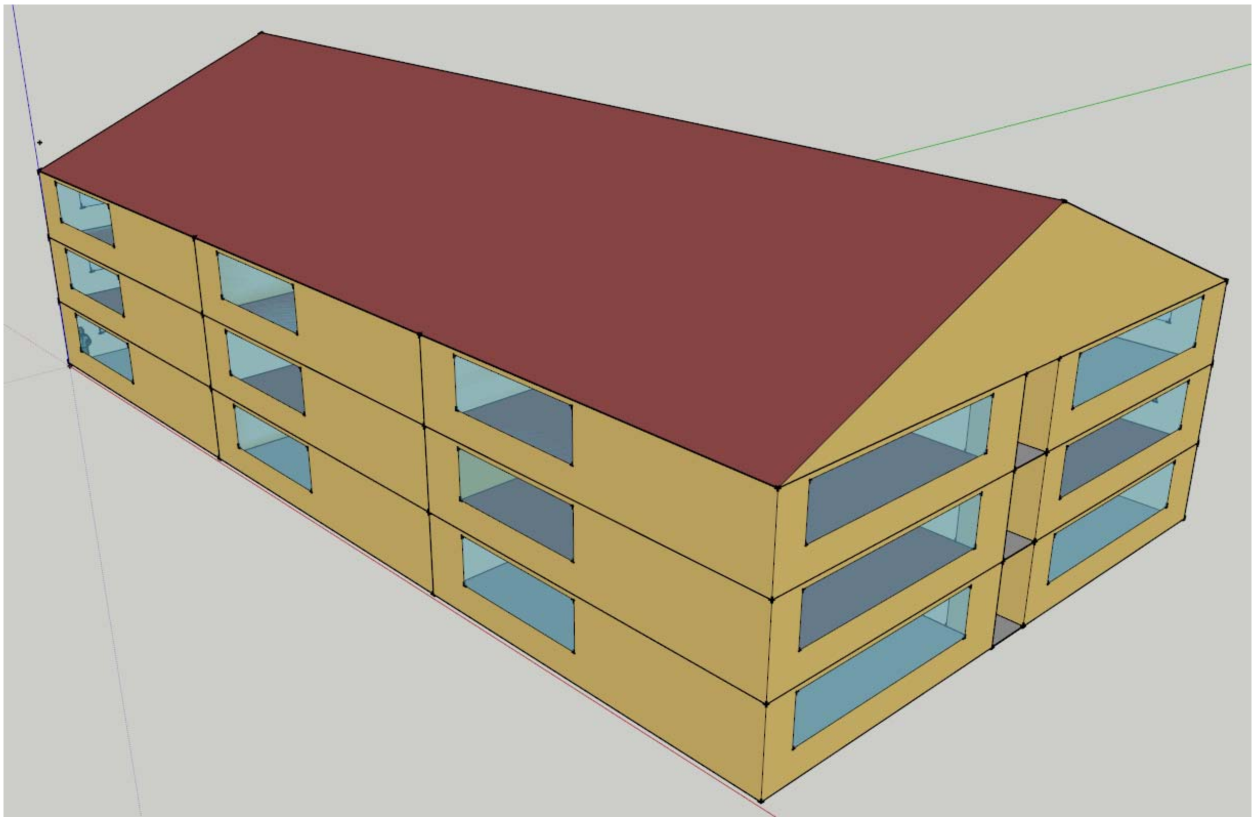
Construction Vintages

Component	Pre-1980	Post-1980	IECC 2006	IECC 2012
Wall Construction	Wood Frame	Wood Frame	Wood Frame	Wood Frame
Wall Insulation	none	R-11 batt	R-13 batt	R-13 batt + R-5 continuous
Roof Construction	Attic	Attic	Attic	Attic
Window Assembly U-Value	1.25	0.6	0.4	0.35
Window SHGC	0.82	0.59	0.59	0.4
Heating Efficiency				
Furnace (Thermal Efficiency, %)	75%	75%	78%	80%
Heat Pump (HSPF)	6.8	6.8	7.7	8.2
Cooling SEER	9	10	13	14

Multi Family

- 21,610 ft^2
- 3 floors plus attic
  - o Option of on slab construction, heated basement, unheated basement, and crawlspace. Heated basement is not used for living space.
  - o Since the study focuses on roof material, site shading, and surrounding pavement/vegetation, the basement construction is not important. Slab is the easiest to change and run.
- 18 living units
- 0.16 Window-to-Wall Ratio

Building Image



Construction Vintages

Component	Pre-1980	Post-1980	IECC 2006	IECC 2012
Wall Construction	Wood Frame	Wood Frame	Wood Frame	Wood Frame
Wall Insulation	none	R-11 batt	R-13 batt	R-13 batt + R-5 continuous
Roof Construction	Attic	Attic	Attic	Attic
Window Assembly U-Value	1.25	0.6	0.4	0.35
Window SHGC	0.82	0.59	0.59	0.4
Heating Efficiency				
Furnace (Thermal Efficiency, %)	75%	75%	78%	80%
Heat Pump (HSPF)	6.8	6.8	7.7	8.2
Cooling SEER	9	10	13	14

Miscellaneous

More information can be found at:

https://www.energycodes.gov/development/residential/iecc_models