Fiscal Note for
2018 NC Energy Conservation Code and Energy Provisions of 2018 NC Residential Code

Agency: NC Building Code Council

Statute: G.S. 143-136; 143-138

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Impact: Federal Government: No
State Government: Yes
Local Government: Minimal
Small Business: Yes
Substantial Impact: Yes

Purpose:

The *North Carolina Energy Conservation Code (NCECC)* is a model code that regulates minimum energy conservation requirements for new buildings. The NCECC addresses energy conservation requirements for all aspects of energy uses in both commercial and residential construction, including heating and ventilating, lighting, water heating, and power usage for appliances and building systems.

The NCECC is a design document. For example, before one constructs a building, the designer must determine the minimum insulation *R*-values and fenestration *U*-factors for the building exterior envelope. Depending on whether the building is for residential use or for commercial use, the NCECC sets forth minimum requirements for exterior envelope insulation, window and door *U*-factors and SHGC ratings, duct insulation, lighting and power efficiency, and water distribution insulation.

In 2008 North Carolina received a contract from the U.S. Department of Energy with a target that the state would develop an energy conservation code that is at least 30% more energy efficient than the 2006 International Energy Conservation Code (IECC). Appalachian State University and Mathis Consulting (The Project Team) used the 2009 IECC as the base document to move forward proposals to that end. After conducting a large number of energy modeling runs and economic analyses, the Project Team recommended a package of improvements to the NC Building Code Council's ad hoc and standing committees. The committees debated many of the provisions resulting in some modifications. The committee recommendations were then moved forward to the NC Building Code Council for approval as the 2012 NC Energy Conservation Code.

Because of significant opposition expressed by the NC Home Builders Association during the public comment period and at the meetings of the NC Building Code Council, the proposed minimum efficiency requirements for one- and two- family dwellings and townhouses were reduced through compromise to be approximately 10%-15% more energy efficient than the 2006 IECC, which is representative of the efficiency improvement that would be gained by adoption of the 2009 IECC. The 30% efficiency improvement recommendations for the commercial construction remained intact.

In 2015 the NC Building Code Council initiated review of the 2015 IECC as the base document for the 2018 NC Energy Conservation Code. Insignificant and minor impact is expected for commercial buildings as detailed in **Appendix A**. A significant impact is expected for residential buildings to get closer to the 2008 target 30% efficiency improvement.

The 2018 NC Energy Conservation Code & Residential Energy Provisions are available at:
http://www.ncdoi.com/OSFM/Engineering_and_Codes/Documents/BCC_Documents/Minutes_ah/2018%20NC%20Energy%20Conservation%20Code%20-%20Proposed.pdf

Impact:

***Federal Government*:**

The State of North Carolina received Federal Stimulus money as part of the American Recovery and Reinvestment Act of 2009 based on development and implementation of an Energy Conservation Code that provides 30% energy improvement over the 2006 IECC. The stimulus funds were awarded in the form of grants for Code development and training. Training is aimed at all sectors of construction, including Code Officials, Contractors, and Designers. The State Energy Office will be required to show 90% compliance with these improved efficiencies in 2017. It is assumed that there will be some penalty, payback, or loss of future funding if the compliance goals are not met.

Federal buildings in North Carolina would not be affected by the changes in the Code as they are not required to comply with State requirements. Most Federal branches, however, do follow local laws as a matter of policy, so some cost increases from increases in energy efficiency are expected. At this point, it is unknown how many federal buildings are planned in North Carolina for the upcoming years.

***State Government*:**

The impact on State Government would be minimal. Code Official training would continue to take place through the existing Community College programs. There are no expected changes in time or cost associated with curriculum updates as the annual training is updated regularly, independent of rule changes. There are also continuing education requirements in place to supplement the Code Official's knowledge. There are no expected cost increases for Code enforcement.

State-owned buildings must be designed, constructed, and certified to exceed the energy efficiency requirements of ANSI/ASHRAE/IES (American Society of Heating, Refrigeration, and Air Conditioning Engineers) 90.1. **Appendix B** provides tabulated values for incremental first costs, annual energy savings, and simple payback periods. The costs and benefits are likely to be comparable to those incurred for private commercial buildings (see section below).

The Department of Administration, through the State Energy Office, has developed a comprehensive program to help State agencies and State institutions of higher learning manage their energy consumption.

***Local Government*:**

The primary impact to local government would be the purchase of additional copies of the 2018 Code edition for enforcement (each local Code enforcement agency receives a complete set of NC State Building Codes at no charge). The cost for an additional copy of the 2018 NCECC is expected to be $35. It is difficult to estimate how many additional copies local governments would require.

The impact on Code Officials who are employed by local governments is expected to be minimal, if any. Currently, each Code Official is required 6-hours of continuing education per Certificate per year, so the yearly training would cover changes to the 2018 Codes, creating no additional cost. There are no expected cost increases for Code enforcement.

The Building Code Council has no knowledge at the present of the number of buildings local governments plan to erect in the future, so it is hard to estimate the additional construction costs and energy savings local governments would incur. The costs and benefits are likely to be comparable to those incurred for private commercial buildings. In the case that local governments would engage in building low-income housing, the costs and benefits would resemble more those expected for private residential buildings (see section below).

***Private*:**

Commercial Buildings:

The 2012 Commercial Energy Conservation Code was approved to reduce energy use by 30%. The 2018 Commercial Energy Conservation Code incrementally improves that efficiency. Both are accomplished primarily through Code Development and education of Code Officials, Contractors and Designers. Air barrier detailing and system commissioning may have higher cost impact in some buildings. While builders would initially bear the cost of the new energy efficiency measures, they should be able to pass that cost onto building owners. The building owners are the ones who would incur the benefits of reduced energy bills.

The Pacific Northwest report in **Appendix B** modeled a variety of uses to evaluate the costs and benefits of increased energy saving features. The ANSI/ASHRAE/IES 90.1-2013 was used as the baseline for comparison. The energy savings are projected to exceed the cost, with a payback range of immediate to 15-years for most buildings (22-years extreme). See **Table 1** below for projected costs and savings for different types of commercial building in Zone 4A (in terms of 2014 dollars). This Zone was chosen for comparison because it represents the highest initial construction costs.

This analysis assumes an inflation-adjusted average annual increase of 2% in energy costs[1] and 2.4% in construction costs.[2]

[1] U.S. Department of Energy. (2016). *Energy Escalation Rate Calculator 2.0-16*. Accessed at http://energy.gov/eere/femp/energy-escalation-rate-calculator-download

[2] Zarenski, Ed. (September, 2016). *Construction Cost Inflation – Midyear Report 2016*. Accessed at https://edzarenski.com/2016/09/12/construction-cost-inflation-midyear-report-2016/

Table 1. Estimates Costs and Savings for Commercial Buildings

Type of Building	Additional Cost (% of construction costs)	Annual Energy Savings	30-yr NPV, 3% discount rate	30-yr NPV, 7% discount rate
Small Office (1-story 5,500-sf)	$13,100 -1.72%	$535	$780	($3,587)
Large Office (12-story 498,640-sf)	$103,069 -0.12%	$16,476	$296,856	$123,803
Stand-alone retail (1-story 24,690-sf)	($10,488) (-0.44%)	$4,294	$111,300	$61,400
Primary School (1-story 73,970-sf)	$176,377 -1.64%	$11,045	$101,547	($684)
Small Hotel (4-story 43,210-sf)	$34,076 -0.68%	$4,329	$71,648	$27,075
Mid-rise Apartment (4-story 33,740-sf)	$13,541 -0.33%	$1,763	$29,474	$11,284

Residential Buildings:

The 2012 Residential Energy provisions were approved to reduce energy use by approximately 15%. The proposed 2018 Residential Energy provisions get closer to the 2008 target 30% efficiency improvement. The builders would incur additional costs in ensuring the house meets the energy efficiency reduction; homeowners would face an increased mortgage payment, as well as a decreased utility bill and an overall reduction in monthly expenditure in most scenarios. The total payback period is estimated to range from 2 to 6 years for most buildings (8-years extreme), assuming the initial investment in the energy use reduction is borne by the builder and passed on to the homeowner. **Appendix C** provides additional information about what energy efficiency measures where assumed and what line item costs and energy savings.

Appendix C estimates show initial cost ranging from $204 (Zone 5) to $611 (Zone 3) for a 2,526-sf heated area house. Using the higher estimate of $611, the monthly mortgage increase for a 30-year loan at 4.5% is $3. Using the lower estimate of $204, the monthly mortgage increase for the same loan is $1.

The average net annual energy savings is estimated at $81 from reduction in energy use for a 2,526-sf heated area house constructed on crawl space in Zone 3. The payback period is expected to decrease as the house size increases and annual energy savings increases.

While the cost of building would increase as a result of this change, companies that provide energy efficiency related goods and services are projected to see a boost in their revenue, which might lead to job creation.

The following summary table estimates the total costs and savings for residential homes constructed in North Carolina from 2019-2028. The impact of the proposed rules is net benefit of $28.93 million to $59.68 million (2016 dollars) over 10 years at a 7% discount rate. The range reflects low and high estimates of the new construction costs.

Net impact estimates are based on a low projected additional cost of $418 per house, a high projected additional cost of $611 per house, and annual savings of $81.[3] Inflation-adjusted construction costs are assumed to increase at an annual rate of 2.4%,[4] while energy costs are assumed to increase at 1.5% per year.[5] The number of homes constructed in each year is based on HIS Markit long-term forecasts for annual housing starts in the state.[6] This analysis assumes a 4.5% mortgage rate in 2016[7] and applies mortgage rate growth projections from HIS Markit forecasts to future years.

Table 2: Estimated Costs and Savings for Single-Family Residential Buildings

	Zone 3	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**10-yr NPV, 2016 dollars**
Housing Starts	1	66,791	69,359	70,895	71,231	71,866	71,546	70,358	69,614	71,038	72,947	
Cost – Low (Million$)	418	$7.49	$9.43	$11.39	$13.26	$15.20	$17.07	$18.83	$20.64	$22.75	$24.99	$86.27
Cost - High (Million$)	611	$10.95	$13.79	$14.51	$17.25	$20.08	$22.81	$25.38	$28.03	$31.11	$34.47	$117.03
Savings - High (Millions$)	81	$-	$5.73	$11.86	$18.30	$24.96	$31.86	$38.93	$46.09	$53.39	$61.02	$145.95
Net Impact – Low Construction Cost (Millions$)												**$59.68**
Net Impact – High Construction Cost (Millions$)												**$28.93**

*NPV calculated using a 7% discount rate

[3] Tiller, Jeff and Chuck Perry. (September 2016). *Fiscal Analysis of Residential Efficiency Measures for the Proposed 2018 North Carolina Energy Code*.

[4] Zarenski, Ed. (September, 2016). *Construction Cost Inflation – Midyear Report 2016*. Accessed at: https://edzarenski.com/2016/09/12/construction-cost-inflation-midyear-report-2016/

[5] U.S. Department of Commerce. (2016). *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2016*. Accessed at http://nvlpubs.nist.gov/nistpubs/ir/2016/NIST.IR.85-3273-31.pdf

[6] IHS Markit. (October, 2016). North Carolina Long Term Forecast Data.

[7] Tiller, Jeff and Chuck Perry. (September 2016). *Fiscal Analysis of Residential Efficiency Measures for the Proposed 2018 North Carolina Energy Code*.

Risks and Alternatives:

The options available are (1) to remain at the current level of energy conservation based on the 2009 IECC for 0% additional energy savings, (2) to increase the level of energy conservation based on the 2009 IECC plus incremental measures provided in the 2012/2015 IECC for additional energy savings, or (3) to increase the level of energy conservation based on the 2015 IECC for additional energy savings beyond the 2009 IECC level. These options were considered for both commercial and residential applications. Failure to comply with the 2008 target of 30% efficiency improvement could result in repayment of funds to the Federal Government or witholding of future funds.

Option (1) was discarded since it does not provide additional savings and does not contribute to the 2017 goal. It is assumed that there will be some penalty, payback, or loss of future funding if the compliance goals are not met. Option (2) is the level of energy conservation proposed in the 2018 NC Energy Conservation Code. Option (3) includes additional costs and savings, but was also discarded. The Committee concluded that the additional costs did not justify the additional savings.

In commercial buildings, the increased initial cost would be absorbed and amortized over the depreciation schedule. The building owner's risk is that the energy payback period may exceed the depreciation schedule. The costs and benefits for Federal and State owned buildings are likely to be comparable to those incurred for private commercial buildings.

In privately-owned dwellings, the homeowner's immediate utility bill reduction exceeds the mortgage payment increase. The contractor risks profit loss if the appraisal does not justify an increase in the approved mortgage amount.

Another uncertainty related to the numbers presented above is that these numbers assume the regulated community will comply with all the changes in the code and therefore the energy efficiency savings would be incurred. This assumption can lead to costs and savings being overestimates, since perfect compliance is rare. Also, given that NC is supposed to show a compliance of 90% by 2017, this creates an extra risk if future federal funding is withheld for not reaching the goal, or if paybacks or penalties are assessed.

Sensitivity Analysis

The estimated economic impacts of the proposed rules are based on the costs and savings from representative structures. In implementation, the impact will vary among structures of the same type. Initial construction compliance costs may be high or low for a given structure, and energy savings will vary by the size, location, and design of the structure. Furthermore, the estimates rely on assumptions about future construction costs, energy prices, housing starts, and mortgage rates. The tables below show how different assumptions about key parameters affects the net impact of the proposed rules.

Residential Buildings:

This analysis assumes that energy costs increase by 1.5% annually. If energy costs increase more slowly than expected, net benefits will be lower than projected. High-costs structures in particular may not all break even over 10 years if energy costs increase and 0.5% or less over inflation.

Avg Energy Cost Growth	0.5%	1.0%	**1.5%**	2.5%	3.0%
Net Impact - Low Construction Cost*	$47.6	$53.7	**$59.7**	$73.8	$81.1
Net Impact - High Construction Cost*	$16.8	$23.0	**$28.9**	$43.1	$50.4

*All net impact estimates are in millions$, accounting for all private residential homes built from 2019-2028.

Similarly, if the estimated annual energy savings are lower than the anticipated $81 per structure, the proposed rules may create a net cost for homeowners facing high construction costs.

Energy Savings	$65	$73	**$81**	$89	$97
Net Impact - Low Construction Cost*	$30.5	$45.1	**$59.7**	$74.3	$88.9
Net Impact - High Construction Cost*	($0.3)	$14.3	**$28.9**	$43.5	$58.1

*All net impact estimates are in millions$, accounting for all private residential homes built from 2019-2028.

Commercial Buildings:

As with residential buildings, slower-than-expected growth in energy costs result in lower net benefits (or higher net costs). This analysis assumes 2% annual growth.

Average Energy Cost Growth	1.0%	1.5%	**2.0%**	2.5%	3.0%
Small office	($4,466)	($4,046)	**($3,587)**	($3,086)	($2,537)
Large office	$96,720	$109,669	**$123,803**	$139,246	$156,138
Retail	$54,341	$57,716	**$61,400**	$65,425	$69,827
Primary School	($18,839)	($10,159)	**($684)**	$9,668	$20,992
Hotel	$19,959	$23,362	**$27,075**	$31,133	$35,572
Mid-rise Apartment	$8,386	$9,772	**$11,284**	$12,936	$14,743

All net impact estimates are presented on a per-structure basis.

If construction costs are higher than expected, net benefits decrease and net costs increase for each structure type. Retail buildings are an exception because the proposed rules result in construction cost savings for these structures. The table below shows how net benefits and costs change if construction costs are 80% lower to 120% higher than expected each year.

Primary schools are particularly sensitive to construction cost changes due to their high initial construction costs and comparatively low energy savings.

Construction Costs	80%	90%	**Model**	110%	120%
Small office	($1,543)	($2,565)	**($3,587)**	($4,609)	($5,630)
Large office	$139,880	$131,841	**$123,803**	$115,764	$107,725
Retail	$59,764	$60,582	**$61,400**	$62,218	$63,036
Primary School	$26,828	$13,072	**($684)**	($14,440)	($28,197)
Hotel	$32,391	$29,733	**$27,075**	$24,418	$21,760
Mid-rise Apartment	$13,396	$12,340	**$11,284**	$10,228	$9,172

All net impact estimates are presented on a per-structure basis.

The opposite effect can be seen in the table below showing net costs and benefits under high and low assumptions about energy savings.

Annual Energy Savings	80%	90%	**Model**	110%	120%
Small office	($4,913)	($4,250)	**($3,587)**	($2,924)	($2,261)
Large office	$82,965	$103,384	**$123,803**	$144,222	$164,641
Retail	$50,756	$56,078	**$61,400**	$66,722	$72,043
Primary School	($28,060)	($14,372)	**($684)**	$13,004	$26,692
Hotel	$27,075	$27,075	**$27,075**	$27,075	$27,075
Mid-rise Apartment	$11,284	$11,284	**$11,284**	$11,284	$11,284

All net impact estimates are presented on a per-structure basis.

Appendix A:
"Fiscal Analysis of Residential Efficiency Measures for the Proposed 2018 North Carolina Energy Code," Jeff Tiller and Chuck Perry,
Department of Sustainable Technology and the Built Environment,
North Carolina Energy Efficiency Alliance,
ASU Energy Center, Appalachian State University

Appendix B:
"National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2013,"
Pacific Northwest National Laboratory, Battelle, United States Department of Energy,
January 2015

Appendix C:
"Commercial Fiscal Analysis,"
Appalachian State University

Appendix A

Final

Fiscal Analysis of Residential Efficiency Measures for the Proposed 2018 North Carolina Energy Code

Prepared by Jeff Tiller and Chuck Perry

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Introduction

This fiscal analysis evaluates the installed costs and energy savings of the primary measures that changed between the 2012 NC Energy Code and the new proposed 2018 North Carolina Energy Code. The report includes an analysis of the specific measures proposed by the Ad Hoc Energy Code Committee. The analysis considers a model home for which construction cost estimating, energy modeling, and economic evaluation were conducted.

The committee compared the values in the 2012 NC Energy Code, the 2012 HERO Code, and the 2015 IECC as shown in Table 1. The group then considered each of the measures in the 2015 IECC, compared it to the 2012 NC Energy Code, and determined the proposed measures with input from cost and energy analysis.

Table 1: Comparison of 2012 NC Energy Code, 2012 HERO Code, 2015 IECC

Climate Zone	Code	Glazed Fenestration U-Factor [bl]	Skylight [b]	Glazed Fenestration SHGC [bm]	Ceiling R-value [k]	Wood Framed Wall R-value [e]	Mass Wall R-value [i]	Floor R-value	Basement Wall R-value [c]	Slab R-value [d]	Crawl Space Wall R-value [c]
3	2012 NC	0.35	0.65	0.3	30	13	5/10	19	10/13[f]	0	10/13[f]
	2012 HERO	0.32	0.65	0.25	38	19/ 13+5/ 15+3	5/10	19	10/13[f]	5	10/13[f]
	2018 Proposed	0.35	0.55	0.3	38	15/ 13+2.5	5/13	19	5/13[f]	0	5/13[f]
	2015 IECC	0.35	0.55	0.25	38	20 or 13+5	8/13	19	5/13	0	5/13
4	2012 NC	0.35	0.6	0.3	38	15/ 13+2.5	5/10	19	10/13[f]	10	10/13[f]
	2012 HERO	0.32	0.6	0.25	38	19/ 13+5/ 15+3	5/10	19	10/13[f]	10	10/13[f]
	2018 Proposed	0.35	0.55	0.3	38	15/ 13+2.5	5/13	19	10/15[f]	10	10/15[f]
	2015 IECC	0.35	0.55	0.4	49	20 or 13+5	8/13	19	10/13[f]	10	10/13
5	2012 NC	0.35	0.6	NR	38	19/ 13+5/ 15+3	13/17[f]	30	10/13[f]	10	10/13[f]
	2012 HERO	0.32	0.6	NR	38	19/ 13+5/ 15+3	13/17[f]	30	10/13[f]	10	15/19
	2018 Proposed	0.35	0.55	NR	38	19/ 13+5/ 15+3	13/17[f]	30[g]	10/15[f]	10	10/19[f]
	2015 IECC	0.32	0.55	NR	49	20 or 13+5	13/17[f]	30	15/19	10	15/19

Measures highlighted in red-orange background are more efficient than previous code.

Measures highlighted in blueish background are less efficient than previous code.

This report is being prepared concurrently with the deliberation process of the Ad Hoc Energy Code Committee of the North Carolina Building Codes Council in its efforts to develop a proposed 2018 North Carolina Energy Code. The Working Group has selected specific upgrades to consider for insulation and window efficiency measures. The analysis in this section focuses specifically on those upgrades.

The committee used data from the recent survey of about 250 new homes in North Carolina that was conducted by Appalachian State University as part of a contract with the U.S. Department of Energy. The results of the survey are summarized in Appendix 1.

In the sections that follow, ASU projected the energy savings for each measure using REMRate software for a base home of 2,526 square feet. The dimensions of the home used for the analysis are as follows:

- Conditioned Space: 2,526 sq ft
- Slab Floors: 1,080 sq ft
- Floor Over Unheated Space (over Garage): 402 sq ft
- Rim and Band Joist Area: 290 sq ft
- Above Grade Walls: 2,676 sq ft
  - First and second floor walls to exterior = 2,306.8 sq ft
  - Gable walls to exterior from conditioned space = 21.4 sq ft
  - Gable walls to attic from conditioned space = 21.4 sq ft
  - Walls from conditioned space to garage = 325.7 sq ft
- Windows: 343.3 sq ft
  - North: 163.3 sq ft
  - East: 15 sq ft
  - South: 105 sq ft
  - West: 60 sq ft
- Solid Doors: 40 sq ft
- Ceilings Under Attics (or Integral with roofs): 1,475 sq ft
  - 1,000 square feet R-38 flat attic
  - 205 square feet R-30 near the eaves of the attic
  - 8 square feet R-5 attic dropped stair
  - 262 square feet R-30 vaulted
- Duct Area: 700 sq ft

The photo to the right shows typical construction for the model house.

Cost Estimates and Economic Analysis

After selecting the home and conducting a takeoff of the dimensions and energy features, we estimated the additional costs (or savings) using values obtained by interviewing contractors or building supply companies in the state. In some cases, we used R.S. Means Construction Data. After estimating the costs for each measure, we conducted an economic analysis and calculated the following criteria:

1. Simple Payback Period
2. Change in the cash flow for a typical mortgage
3. Comparison of the additional annual mortgage cost compared to the energy savings
4. Internal rate of return for the added investment

The analysis did not include the tax implications of the energy code – most notably that the mortgage deduction would increase, thus providing an additional benefit. In addition, we did not include operation and maintenance costs, as most of the measures actually reduce the maintenance needs of a home (low-e windows shield ultraviolet radiation which reduces fabric fading, improved air sealing and duct sealing keeps more dust and pests out of the interior of the home, and high efficacy lighting lasts 3 to 9 times more than standard lighting). None of the measures increases operation or maintenance – the insulation, windows, and duct system would have the same maintenance costs as a home meeting the 2012 NC Energy Code.

Appendix 2 shows more detail on the different forms of economic analysis in this report. The appendix includes a discussion that shows how the Simple Payback Period provides a somewhat negative evaluation of an energy efficient investment in a new home. The primary reason is that the Simple Payback Period uses the total cost of the efficiency measure as the basis for comparison, when in reality virtually all homes are purchased with mortgage loans. The main upfront cost for the homebuyer is the downpayment. We evaluated the cash flow for the additional costs of a mortgage loan for a house with energy efficient features and calculated the annual rate of return on the investment. We feel that the rate of return on the mortgage and future energy savings is a more accurate indicator of the economic attractiveness of an energy investment.

Using the approach summarized in the appendix, a home with a Simple Payback Period of 7 years (such as an efficiency measure that costs $700 and saves $100 per year in energy costs) will pay back the additional downpayment of in only 2.6 years and earn an annual return on investment of 40% (per year). Thus, the 7-year Simple Payback Period is an extremely attractive investment. An efficiency measure with a 10-year Simple Payback Period yields a 23% annual internal rate of return, and a 12-year payback investment provides a 15% annual return.

Summary of the Results for Residential Energy Code Measures

N1102.1.2 (R402.1.2) Insulation and fenestration criteria
Increased building thermal envelope insulation requirements.

1. Skylight U-factor in Zone 3 changed from U-0.65 to U-0.55.
   Estimated Additional Cost: Negligible
   For a house with three skylights measuring 2' by 4', the cost for the code change would be negligible. Checking on Lowe's and Home Depot Websites, the skylights available all had Argon gas fill. The U-factors were 0.49 (Velux) and 0.43 (Fakro). The only skylight with a higher U-factor (Sunoptics with U-0.74) cost more than the Velux or Fakro products.

2. Skylight U-factor in Zones 4 & 5 changed from U-0.60 to U-0.55.
   See above.

3. Ceiling insulation R-value for Zone 3 changed from R-30 to R-38 or R-30 ci (continuous insulation).
   Estimated Additional Cost: $70
   We received three estimates for attic insulation. Based on the values received, the average additional cost of going from R-30 to R-38 was $0.064/ sq ft. With Overhead and Profit of 20% added, the total is $0.078/ sq ft. For the sample home we evaluated, the additional cost would be $70, which is below the $80 threshold.
   Estimated Energy Savings: $7 per year
   Simple Payback Period: 10 years
   Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 23% per year

4. Wood frame wall R-value for Zone 3 changed R-13 to R-15 or R13 + 2.5ci
   Estimated Additional Cost: $142 to $320
   We received three estimates for wall insulation. A large Raleigh-area installer estimated the additional costs at $0.04/ sq ft. The other contractors were in the range of $0.09/ sq ft. The costs are for a house with about 2,960 sq ft of exterior wall area, including exterior walls, band joists, garage walls, and walls common to the attic. The costs shown include 20% overhead and profit. Note that the cost estimates received are from estimates over the phone; thus, they are not negotiated contractor prices.
   Estimated Energy Savings: $30 per year
   Simple Payback Period: 4.7 to 10.7 years
   Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 20% to 67% per year

5. Mass wall R-value for Zone 3 and Zone 4 changed from R-5/**10** to R-5/**13**
   - *The second value (after the slash) is typically for insulation interior to the mass wall. In most cases, the wall would be insulated with a stud wall with an insulation batt, for which the minimum value is R-13. The primary additional cost would be when the interior wall does not contain a framed wall and uses foam board or vinyl-backed fiberglass insulation. In such cases, the additional cost is estimated at $0.10 to $0.18 per*

sq ft. The wall assumed in the analysis is 530 sq ft, so the cost of the measure, including 20% overhead and profit, would be $64 to $119.

- *<u>Analysis for Mass Wall with Insulated Cavity Wall on the Interior</u> (The committee felt most homes with mass walls would fall in this category.)*
  - *Estimated Additional Cost: $0*
  - *Estimated Energy Savings: $7 per year*
  - *Simple Payback Period and Rate of Return – not applicable, but since the cost is nil, it's a very positive investment*
- *<u>Analysis for Mass Wall with Foamboard on the Interior</u>*
  - *Estimated Additional Cost: $64 to $119*
  - *Estimated Energy Savings: $7 per year*
  - *Simple Payback Period: 9 to 17 years*
  - *Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 5% to 26%/ year*

6. Basement wall R-value for Zone 3 changed **R-10**/13 to **R-5**/13
   - *Estimated Additional Cost (Savings): $0 to -$318 (cost reduction)*
   - *Common foam insulation board products range substantially in cost. Extruded polystyrene and polyisocyanurate typically cost approximately $16 to 19 for R-5 for a 4' x 8' sheet and $32 to $35 for the same sized R-10 sheet. The marketplace now offers a commonly used expanded polystyrene product that costs $16 to $18 for an R-10 sheet. Thus, there is no cost savings in going from R-5 to R-10 if switching from the more expensive product to the less expensive product. However, if trying to use the more expensive R-10 product and switching to R-5, there would be savings of about $16/ sheet, or about $0.50 per square foot. The wall assumed in the analysis is 530 sq ft, so the cost savings of the measure, including 20% overhead and profit, would be $318.*
   - *Estimated Energy Savings (Losses if negative): -$7 per year*
   - *Simple Payback Period: Not applicable*
   - *Rate of Return on Additional Cost Assuming Homebuyer Mortgage: Not applicable*

7. Basement wall R-value for Zone 3 and 4 changed from R-10/**13** to R-10/**15**
   The measure is an increase in the insulation requirement for cavity walls on the interior side of basement walls in Zones 3 and 4. The additional cost of R-15 insulation varies, depending on the installer, as described previously, from $0.04 to $0.09 per sq ft. The total extra cost for the 530 sq ft wall, including overhead and profit rate of 20%, would be $25 to $57.
   - *Installed Cost including Overhead and Profit: $25 to $57*
   - *Estimated Energy Savings: $5 to $6/ year*
   - *Simple Payback Period = 4.2 to 10.2 years*
   - *Rate of Return on Additional Cost Assuming Homebuyer Mortgage = 22% to 77% per year*

8. Basement wall R-value for Zone 5 changed from R-10/**13** to R-10/**15**

The measure is an increase in the insulation requirement for cavity walls on the interior side of basement walls in Zone 5. As in the previous calculation, the total extra cost for the 530 sq ft wall, including overhead and profit rate of 20%, would be $37 to $64.

- *Installed Cost including Overhead and Profit: $25 to $57*
- *Estimated Energy Savings: $5 to $6/ year*
- *Simple Payback Period = 4.2 to 10.2 years*
- *Rate of Return on Additional Cost Assuming Homebuyer Mortgage = 22% to 77% per year*

9. Crawlspace wall R-value in Zone 3 and 4 changed from R-10/**13** to R-10/**15**
   The measure is an increase in the insulation requirement for the interior side of cavity walls in closed crawl spaces in Zones 3 and 4. The additional cost of R-15 insulation varies, depending on the installer, as described previously, from $0.04 to $0.09 per sq ft. The total extra cost for the 530 sq ft wall, including overhead and profit rate of 20%, would be $25 to $50.
   - *Installed Cost including Overhead and Profit: $25 to $50*
   - *Estimated Energy Savings: $5 to $6/ year*
   - *Simple Payback Period = 4.1 to 9.9 years*
   - *Rate of Return on Additional Cost Assuming Homebuyer Mortgage = 23% to 79% per year*

10. Crawlspace wall R-value in Zone 5 changed from R-10/**13** to R-10/**19** (see measure 8 above)
    The measure increases crawl space wall insulation Zone 5. In crawl spaces, insulation against masonry walls is usually draped so there would not be the additional cost for 2x6 framing. In some crawl spaces, there is a combination of framed walls above grade and masonry walls extending below grade. In a few cases, builders would have to switch from 2x4 to 2x6 walls, which would cost about $0.04/ sq ft. The cost of going from R-13 to R-19 insulation is only about $0.02 (two installers) to $0.04 (one installer) per square foot. The additional costs would be in the range of $0.06 per sq ft. For the 530 sq ft wall, the cost would be $38, including overhead and profit.
    - *Installed Cost including Overhead and Profit: $38*
    - *Estimated Energy Savings: $10/ year*
    - *Simple Payback Period = 3.8 years*
    - *Rate of Return on Additional Cost Assuming Homebuyer Mortgage = 87% per year*

N1102.2.15 (R402.2.15) Attic knee walls.

Air seal attic knee walls enclosure to reduce air infiltration/exfiltration.

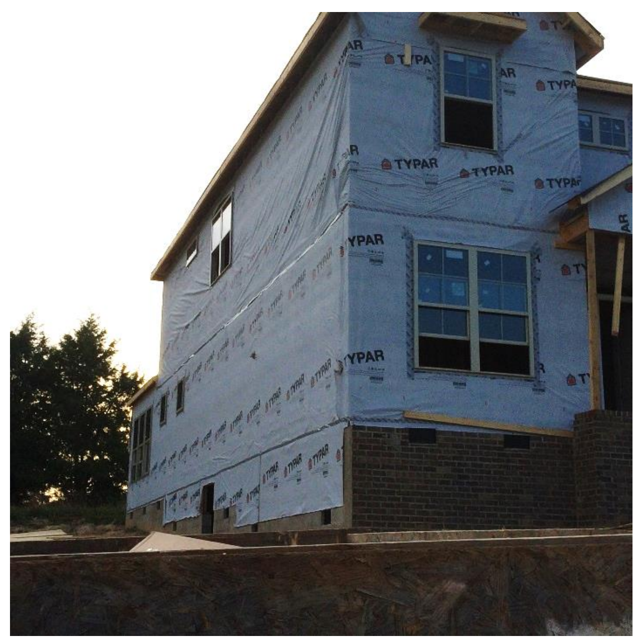
The estimate is based on sealing the backing for knee walls in a house with 320 sq ft of knee wall. The lower cost of sealing is for taping all housewrap seams. The higher cost is for sealing solid panels that measure about 4' by 8'. More information is in the discussion of sealing exterior air barriers below.

- *Estimated Additional Cost: $20 to $37*
- *Estimated Energy Savings: $14 per year*

- *Simple Payback Period: 1.4 to 2.8 years*
- *Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 130% to 260% per year*

N1102.4.1 (R402.4.1) Building thermal envelope.
Add air sealing/taping of exterior wall sheathing/housewrap to reduce air infiltration/exfiltration.

1. **Sealing <u>horizontal</u> seams in the exterior air barrier** was estimated as follows:
    - We assumed that the air barrier consisted of housewrap with all vertical and horizontal seams sealed using housewrap tape, except the bottom seal to allow for drainage. Housewrap specifications for moisture protection require that vertical seams are sealed, so we assumed only horizontal seams would have to be sealed to follow housewrap specifications for an air barrier (in addition to the requirements for moisture protection).
    - RS Means estimated that a 2-person crew can install 1,000 linear feet of caulking per hour.
    - Labor costs for an air-sealing crew, with a substantial margin for overhead and profit, were estimated at $30 per hour.
    - Housewrap tape costs $11 retail per 164-foot roll.
    - A typical two-story house with a slab on grade foundation has a housewrap seam at the gable roof (see photo on the next page) and eave, at the ceiling joist level on the second floor, at the band joist between the first and second floor, and at the slab, where no seal is required. The total length for the model home is as follows:
        - Top of gable ends = 93 ft
        - Seam between attic and second floor on gable end = 80 ft
        - Seam at top of wall under eaves = 82 ft
        - Seam between first and second floor = 162 ft
        - Misc. seams (20% of subtotal of above) = 83 ft
        - Total length = 500 ft
    - Total labor time = 0.5 hour for two-person crew
    - Total rolls of tape = 500/164 = 3 rolls
    - Base cost = 0.5 hours * $60/ hour + 3 rolls * $11 (retail price) = $63
    - Overhead and profit of 20% added = $13



- Total cost = $76

2. Sealing all housewrap seams

- *Some builders are not following specifications for installing housewrap as a moisture barrier and are failing to seal the vertical seams. For them, the new code provision will require sealing all seams.*
- *The above cost of $76 for 500 linear feet of horizontal seams equals $0.152 per linear foot. Note in the photos that there are not many vertical seams since housewrap comes in a 100-foot roll. If we assume that there are an equivalent of 2 vertical seams on the gable sides and 2 vertical seams on the sides of the house with eaves, there would be a total of:*
  - *2 gable sides * 30 vertical feet = 60 vertical feet*
  - *2 eave sides * 18 vertical feet = 36 vertical feet*
  - *Total = 96 vertical feet, or about 100 vertical feet*
  - *Additional cost for the vertical seams = about $15*
  - *Total cost for horizontal and vertical seams = $101*
  - *Additional 20% for waste, set-up, etc. takes total to $122*

3. **Sealing electrical and exhaust fan boxes** in the attic:

- *Time required = less than one hour = $30 with substantial overhead and profit included*
- *Materials required = 1 can of fire-rated foam sealant = $10 retail*
- *Total cost = $40*
- *Total with additional 20% for contractor overhead and profit = $48*

Energy savings and economic analysis of exterior air barrier and sealing electrical boxes

- *Total cost = $120 to $170 (depending on whether contractor is already sealing vertical seams, as is recommended for moisture protection.)*
- *Estimated reduction in air leakage from 5 ACH50 to 4 ACH50 based on research on test walls at Appalachian State University*
- *Energy savings = $23 in Climate Zone 3 and $30 in Climate Zone 4, and $69 in Climate Zone 5; weighted average based on new home construction patterns in the state = $27.9*
- *Simple Payback Period = 4.3 to 6.1 years*
- *Rate of Return on Additional Cost Assuming Homebuyer Mortgage for additional mortgage = 48% to 75% per year*

N1103.2.9 (R403.2) Hot water boiler temperature setback.

New controls requirement adopted from model code to provide opportunity for improving the operating efficiency of a hot water boiler.

- *Estimated Additional Cost: $50*
  (The primary cost is for the labor to install the outside temperature sensor.)
- *Estimated Energy Savings: $15 to $30 per year, depending on location*
- *Simple Payback Period: 1.7 to 3.3 years*

- *Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 102% to 222% per year*

N1103.3.3 (R403.3.3) Duct leakage (Prescriptive) and duct testing (Mandatory).
More stringent duct testing requirements. Duct testing revised from 6 CFM25/100 sq ft to 5 cfm/100 sq ft total duct leakage or 4 CFM25/100 sq ft duct leakage to the outside.

One hour of additional labor should be more than adequate for a trained duct sealing contractor. At a labor cost of $40 per hour, the total would be $40. We assumed that an additional gallon of mastic would be required, which costs about $10. In addition, some UL-121 tape might be needed and add an additional $5. The total cost should be at most $55. With 20% overhead and profit added, the cost would be about $66.

- *Estimated Additional Cost: $66*
- *Estimated Energy Savings: $15 to $30 per year, depending on location*
- *Simple Payback Period: 1.7 to 3.3 years*
- *Rate of Return on Additional Cost Assuming Homebuyer Mortgage: 102% to 222% per year*

Summary of the Impact of the Measures for Individual Homes

Table 3 summarizes the projected additional installed costs and energy savings for the model home that met the proposed 2018 North Carolina Energy Code versus the model home that met the 2012 North Carolina Energy Code.

Table 3: Summary of Overall Savings and Costs for 2018 Energy Code Measures

Energy Use (Million Btu)	**CZ3 2012**	**CZ3 2018**	**CZ4 2012**	**CZ4 2018**	**CZ5 2012**	**CZ5 2018**
Heating	22.5	20.1	19.1	17.6	38.8	35.5
Cooling	12.3	11.6	10.8	10.3	4.9	4.7
Hot water	14.1	14.1	14.3	14.3	16.4	16.4
Appliances and lighting	28.9	28.9	28.9	28.9	28.7	28.7
Total Energy Use/ Year	**77.8**	**74.7**	**73.1**	**71.1**	**88.8**	**85.3**
Total Energy Cost	$1,986	$1,905	$1,869	$1,817	$2,293	$2,202
HERS Rating	78	75	81	79	84	82
Annual Energy Savings ($)		**$81.0**		**$52.0**		**$91.0**

Table 4 summarizes the economic analysis for homes going from the 2012 North Carolina Energy Code to the proposed 2018 North Carolina Energy Code. As shown, the payback periods are less than 8 years, and in most cases, less than 6 years. The annual rate of return for a homeowner mortgaging the home is excellent, ranging from 36% to 161% per year. As shown earlier, the investment for the homeowner is solely the downpayment on the additional costs along with some minor financing costs. When these initial extra costs are evaluated with the net annual savings for the measures (energy savings – additional mortgage payments), the annual rate of return for energy efficiency measures with simple payback periods of 12 years or less is quite positive.

Table 4: Summary of Economic Analysis for the 2018 Energy Code Measures

	Climate Zone 3 Measures		**Climate Zone 4 Measures**		**Climate Zone 4 Measures**	
	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Cost
Estimated Cost	**$418**	**$611**	**$204**	**$229**	**$204**	**$229**
Simple Payback Period	5.2 years	7.5 years	3.9 years	4.4 years	2.2 years	2.5 years
Rate of Return/ Year	60%	36%	36%	84%	73%	161%

Projected Statewide Impact of the Proposed 2018 Energy Code

The analysis of the projected statewide impact of the proposed measures is complicated because many new homes already meet, and in some cases exceed the proposed measures. The average new home in the state is approximately 2,500 sq ft of conditioned space, so we used the model home to depict the statewide average. Of course, homes will vary in terms of square footages for different wall, ceiling, floor, and window systems, so the analysis is quite approximate.

Table 5 shows the projected actual cost and savings of the measures, recognizing that many homes already meet some of the energy code measures. The percentages of homes that do not currently meet the 2016 energy code are based on the 250-home survey that Appalachian State conducted statewide. We assumed that approximately 29,000 new homes would be built in Climate Zone 3, another 29,000 in Climate Zone 4, and 2,000 in Climate Zone 5.

Table 5: Estimated Costs and Energy Savings for 2018 North Carolina Energy Code Measures

Estimated Cost of Measures in Climate Zone 3				
	% of Homes Without Measure	**Cost of Measure**	**Number of Homes Built in Zone 3**	**Total Cost in Zone 3**
R-15 Walls	86%	$230.9	29,000	$5,738,061
R-38 Ceilings	92%	70.0	29,000	1,857,450
Sealed housewrap -- horizontal seams	18.65%	76.0	29,000	411,046
Sealed housewrap -- all seams	18.65%	122.0	29,000	659,837
Sealed electrical boxes	37.30%	48.0	29,000	519,216
4 CFM25 duct leakage	16.90%	66.0	29,000	323,466
Crawl space walls: R-13 to R-15	1.50%	37.5	29,000	16,313
Mass wall: R-10 to R-5	0.95%	-135.0	29,000	-37,193
Basement walls: R-13 to R-15	3.80%	37.5	29,000	41,325
Total				**$9,529,521**

Estimated Energy Savings in Climate Zone 3				
Measures for Climate Zone 3	**% of Homes Without Measure**	**Energy Savings**	**Number of Homes Built in Zone 3**	**Total Cost in Zone 3**
R-15 Walls	86%	$30.0	29,000	$745,590
R-38 Ceilings	92%	7.0	29,000	185,745
Sealed housewrap and elec boxes	37.30%	23.0	29,000	248,791
4 CFM25 duct leakage	16.90%	31.0	29,000	151,931
Crawl space walls: R-13 to R-15	1.50%	5.0	29,000	2,175
Mass wall: R-10 to R-5	0.95%	-7.0	29,000	-1,929
Basement walls: R-13 to R-15	3.80%	6.0	29,000	6,612
Total				**$1,338,916**

Estimated Cost of Measures in Climate Zone 4				
	% of Homes Without Measure	**Cost of Measure**	**Number of Homes Built in Zone 4**	**Total Cost in Zone 4**
Sealed housewrap -- horizontal seams	18.65%	$76.0	29,000	$411,046
Sealed housewrap -- all seams	18.65%	122.0	29,000	659,837
Sealed electrical boxes	37.30%	48.0	29,000	519,216
4 CFM25 duct leakage	16.90%	66.0	29,000	323,466
Crawl space walls: R-13 to R-15	1.50%	37.5	29,000	16,313
Mass wall: R-10 to R-5	0.95%	-135.0	29,000	-37,193
Basement walls: R-13 to R-15	3.80%	37.5	29,000	41,325
Total				**$1,934,010**

Estimated Energy Savings in Climate Zone 4				
Measures for Climate Zone 4	**% of Homes Without Measure**	**Energy Savings**	**Number of Homes Built in Zone 4**	**Total Cost in Zone 4**
Sealed housewrap and elec boxes	37.30%	$30.0	29,000	$324,510
4 CFM25 duct leakage	16.90%	46.0	29,000	225,446
Crawl space walls: R-13 to R-15	1.50%	6.0	29,000	2,610
Mass wall: R-10 to R-5	0.95%	-7.0	29,000	-1,929
Basement walls: R-13 to R-15	3.80%	13.0	29,000	14,326
Total				**$564,964**

Table 5: Estimated Costs and Energy Savings for 2018 North Carolina Energy Code Measures (continued)

Estimated Cost of Measures in Climate Zone 5 *				
	% of Homes Without Measure	**Cost of Measure**	**Number of Homes Built in Zone 5**	**Total Cost in Zone 5**
Sealed housewrap -- horizontal seams	18.65%	$76.0	2,000	$28,348
Sealed housewrap -- all seams	18.65%	122.0	2,000	45,506
Sealed electrical boxes	37.30%	48.0	2,000	35,808
4 CFM25 duct leakage	16.90%	66.0	2,000	22,308
Crawl space walls: R-13 to R-19	4.00%	37.5	2,000	3,000
Basement walls: R-13 to R-19	9.00%	50.5	2,000	9,090
Total				**$144,060**

Estimated Energy Savings in Climate Zone 5				
Measures for Climate Zone 5	**% of Homes Without Measure**	**Energy Savings**	**Number of Homes Built in Zone 5**	**Total Cost in Zone 5**
Sealed housewrap and elec boxes	37.30%	$27.9	2,000	$20,826
4 CFM25 duct leakage	16.90%	44.0	2,000	14,872
Crawl space walls: R-13 to R-15	4.00%	3.0	2,000	240
Basement walls: R-13 to R-19	9.00%	10.0	2,000	1,800
Total				**$37,738**
* Climate Zone 5 has more homes with crawl spaces and basements than Climate Zones 3 and 4.				

Table 6: Summary of Projected Additional Costs and Energy Savings

	Climate Zone 3	**Climate Zone 4**	**Climate Zone 5**	**Grand Total**
Projected Cost for All Measures	$9,529,521	$1,934,010	$144,060	$11,607,591
Annual Energy Savings for All Measures	1,338,916	564,964	37,738	$1,941,617
Total Energy Savings over 30 Years				$58,248,505
Simple Payback Period (years)				6.0
Annual Rate of Return on Mortgage Investment				47%

Table 6 above summarizes the projected total net impact. The approximately $11.6 million in additional construction costs would generate an annual savings of about $1.9 million, which would provide an attractive rate of return, well within the goal set by the committee of a simple payback period of 7 years or less. The return to the homeowner who is offsetting the invested downpayment with annual net energy savings (energy savings – mortgage costs) is quite high at 47% per year. The total energy savings over a 30-year mortgage are over $58 million, which does not include future increases in energy prices.

Appendix A1

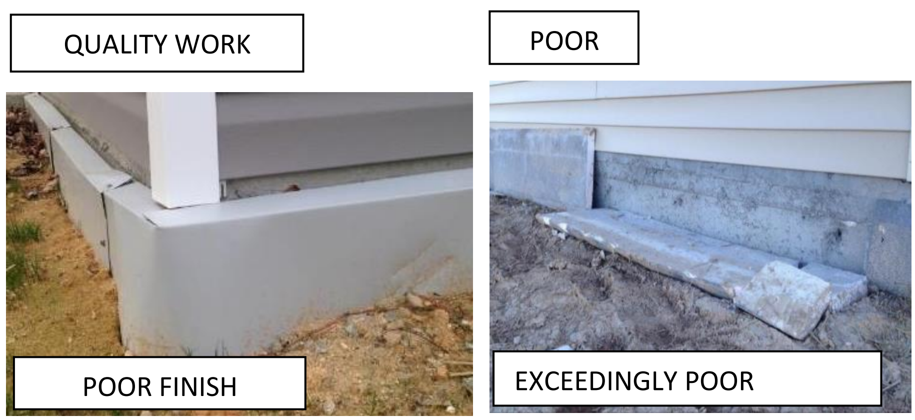
Summary of Appalachian State University Survey of New Homes in North Carolina

Summary of 2015-2016 Survey of New Home Construction

The 2012 North Carolina Energy Code has been in effect for approximately 4 years. A recent survey conducted by Appalachian State University conducted site visits to 250 new homes in the state. The survey found the following:

- Most builders are complying with R-value requirements for ceilings, walls, and floors; however, the insulation quality is often not a Grade I, as shown in Table 1.
- All but one home with observable window NFRC values were in compliance, many homes had U-factors and Solar Heat Gain Coefficients substantially below the energy code maximum.
- Slab insulation was required in Climate Zones 4 and 5, but was missing in 24% of homes where observation was possible. Where installed, the quality of the installation was sometimes quite low. Photos of typical installation practices are shown in Figure 1.
- The average air leakage rate was 3.91 ACH50, which was 22% lower than the code maximum of 5 ACH50. Only 8 (12%) of the 67 homes tested did not meet the code's prescribed air leakage rates. The air leakage test is an option as an alternative to meeting a complete visual inspection of all measures.
- The average duct leakage rate was 5.85 CFM25 per 100 square feet of conditioned area, just barely below the maximum of 6 CFM25. Of the 65 homes tested, 24 (37%) exceeded the maximum. However, North Carolina allows testing duct leakage to the exterior (using combined blower door and duct testing blower). For this test, the average leakage rate was 2.9 CFM 25/ 100 square feet and no home exceeded the maximum of 6 CFM25.
- In a total of 81% of the 137 homes with field observations about location of supply ductwork, at least half of the supply ducts were in unconditioned attics.

Figure 1: Good and Poor Quality Slab-on-Grade Insulation (with 2" termite inspection strip at top)



Appendix A2

Discussion of Economic Analysis Measures

Discussion of Economic Analysis Measures

During the discussions of the working group, some of the committee members supported the idea that energy efficiency measures with Simple Payback Periods of 7 years or less are acceptable for inclusion in the energy code. The Simple Payback Period is not the best criteria for measuring the value of an investment. It ignores the time rate of money (such as the interest rate on a mortgage loan), the actual cash flow of the investment, and the increase in expenses over time (such as escalating costs for energy).

Consider the cash flow for an efficiency measure that adds $700 to the principal and saves $100 per year in energy costs. The Simple Payback Period is $700 / $100 = 7 years. Is this investment a good deal for the homeowner?

The homeowner would pay extra on the down payment and a little extra on the mortgage costs each year. They would also reap the benefits of the energy savings, which could well increase over time. Thus the limit of a maximum 7-year Simple Payback Period does not really provide a fair evaluation of an investment in energy efficiency. We feel a fairer measure is the rate of return which could be calculated over a 7-year period rather than over the 30-year mortgage. Table 2 shows the cash flow for an energy efficiency investment for the above measure that provides a 7-year payback. The cash flow assumes that the additional cost for the energy measures is wrapped into a household mortgage. The assumptions are:

- Additional cost of the home = $700 (extra cost of the efficiency measures)
- Mortgage rate = 4.5% (current rates are 3.5 to 3.875%; higher rate covers other loan costs)
- Term of the loan = 30-years
- Down payment = 25% of principal = $175 (initial cost of investment)
- Remaining principal = $525
- Total annual loan payments on remaining principal = $32/ year
- Annual energy savings = $100, assumed to escalate at 0.5% per year
- Net Savings in Year 1 = $
- 100 – $32 = $68 (Energy savings – Mortgage payment)

The annual rate of return on the investment:

- Annual Rate of Return for 30 years for Cash Flow Shown Below = 40% per year
- Annual Rate of Return for 7 years for Cash Flow Shown Below = 34% per year

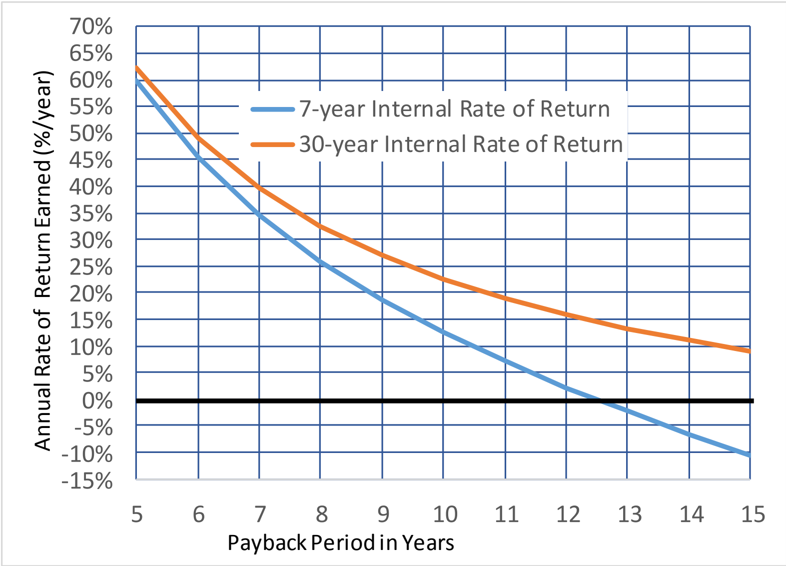
Table 2: Cash Flow for 7-year Payback Energy Efficiency Measures

Year	Amount
Begin	-$175
1	68
2	69
3	69
4	70
5	70
6	71
7	71
10	72
15	72
20	73
25	73
30	74

Figure 2 compares using a similar analysis the Simple Payback Period to the annual rate of return for a variety of energy investments with different Simple Payback Periods. As would be expected for the rate of return evaluated over just seven years, as the Simple Payback Period stretches beyond 7 years, the return on the investment drops. However, an investment with a 10-year payback still earns 13% annually when only seven years of savings are considered (and 23% over 30 years). Thus, a 10-year Simple Payback Period would still provide an excellent investment, even when only seven years of savings are taken into account.

In summary, what many would consider an excellent investment – say an annual 15% return over 7 years of incoming revenue – has a Simple Payback Period of about 10 years, which is substantially higher than the 7-year limit that the Energy Code Working Group is considering.

Figure 2: Payback Period vs. Annual Rate of Return



Appendix A3

Analysis of Higher Efficiency Windows

Introduction to Window Efficiency Analysis

We investigated the energy savings and costs of different window efficiency options. For each option, we evaluated the base model 2-story house with 2,526 sq ft of conditioned space and 343 sq ft of windows. A summary of the analysis of several cases is as follows.

1. Change from U-0.35/ Solar Heat Gain Coefficient (SHGC)-0.30 to U-0.32/ SHGC-0.25
   - Extra costs:
     - From ENERGYSTAR estimates -- $0.24 per square foot
     - Dan Tingen window supplier (U-0.34 to U-0.30) -- $0.43/ square foot ($131 for 305 sq ft of glass)
   - Extra cost for 2,526 sq ft home with 343 sq ft of glass: Lower = $82, Higher = $148
   - Energy Savings for 2,526 sq ft home $18 per year in both Charlotte and Raleigh
   - Simple Payback Period: Lower = 4.6 years, Higher = 8.2 years
   - Annual Rate of Return for Mortgaged Costs = 11.9% to 32.4%

2. Change from U-0.35/ SHGC-0.30 → U-0.35 (remains the same)/ SHGC-0.25
   - From PlyGem estimates -- $0.13 per square foot – ($2 for a 3' x 5' window)
   - Extra cost for 2,526 sq ft home with 343 sq ft of glass = $46
   - Energy Savings for 2,526 sq ft home: $5 per year in both Charlotte and Raleigh
   - Simple Payback Period = 9.2 years
   - Annual Rate of Return for Mortgaged Costs = 27.3%

3. Actual House Under Construction (by Dan Tingen) with U-0.34/ SHGC-0.23 windows currently
   a. Change to U-0.30 / SHGC-0.23 (remains the same) windows
      - From vendor estimates -- $131 for approximately 305 sq ft of windows
      - Energy Savings = $18 per year in both Charlotte and Raleigh (more details at end)
      - Simple Payback Period =7.3 years
      - Annual Rate of Return for Mortgaged Costs = 38.5%

   b. Change to U-0.34 (remains the same)/ SHGC-0.20 windows
      - From vendor estimates -- $33 for approximately 305 sq ft of windows
      - Energy Savings = $4.72 per year in both Charlotte and Raleigh (more details at end)
      - Simple Payback Period = 7 years
      - Annual Rate of Return for Mortgaged Costs = 40.7%

<u>Conclusions and Observations:</u>

1. Reducing window U-factors saves considerably more energy and dollars than reducing the Solar Heat Gain Coefficient.
2. The annual rates of return and Simple Payback Periods appear to be reasonable.
3. Injecting Argon gas into a sealed window unit is not an expensive process.
4. The typical rate of escape for Argon gas is about 1% per year, so in 50 years, the efficiency gains may be reduced by half.

5. The process of adding more efficient spacers between windows does not add any time to the manufacturing process.
6. The estimated costs for energy code efficiency improvements such as Argon gas and more efficient spacers are difficult to establish from current vendor estimates for completed window units because the more efficient units may not be produced on as large a scale as less efficient windows for some window companies.

Comparison of Energy Savings and Economic Analysis for House Currently Under Construction

Dan Tingen Homes -- Window Analysis			
	Base -- U-0.34/ SHGC-0.23 windows	**U-0.30/ SHGC-0.23**	**U-0.34/ SHGC-0.20**
U-factor	0.34	0.30	0.34
SHGC	0.23	0.23	0.20
Energy Use ($/ year)			
Heating	$605	$587	$612
Cooling	387	387	375
Hot Water	419	419	419
Appliances and Lighting	865	865	865
Total	**$2,276**	**$2,258**	**$2,271**
Energy Savings ($/year)		18.00	4.72

Window U-value/ Solar Heat Gain Coefficient	**U-0.30/ SHGC-0.23**	**U-0.34/ SHGC-0.20**
Cost	$131	$33
Annual Energy Savings	18	4.72
Payback Period	7.3	7.0
30-Year Energy Savings	$581	$152
Rate of Return/ Year	38.5%	40.7%
Savings for the state ($/yr for 60,000 homes)	$1,080,000	$283,200

Appendix A4

Analysis of Other Efficiency Measures

Summary of the Impact of the Measures for Individual Homes

a. **R-19 wall insulation** in place of R-15 in Climate Zone 4
   i. We examined the costs and savings of going to 2x6 walls framed 24 inches on center. According to builders and RS Means, the additional cost of framing and R-19 insulation is minimal. The main cost is for jamb extenders for windows. In many homes in North Carolina, jamb extenders would not be necessary, as the builders use drywall returns inside the window openings rather than wood trim.
   ii. RS Means estimates the cost of 2x4 walls framed 16 inches on center as $3.61 per sq ft and 2x6 walls framed 24 inches on center as $3.64 per sq ft for a difference of only $0.03 per sq ft or $80 in additional costs for the model home.
   iii. The insulation costs we received estimated that R-19 batts were actually about $0.06 per sq ft cheaper than R-15 batts or $160 in savings for the model home.
   iv. The jamb extenders for the 2x6 walls added about $540 in cost in homes that did not use drywall returns.
   v. The total additional cost with jamb extenders is $480.
   vi. With overhead and profit, the total extra cost with jamb extenders would be $576, while for homes with drywall returns, the house with 2x6 walls may actually be cheaper, assuming walls can be framed 24 inches on center.
   vii. The estimated energy savings in Climate Zone 4 are $44 annually.
   viii. Simple Payback Period is instantaneous to 12.2 years.
   ix. Rate of return on mortgaged investment to homeowner: Very high (with no added cost to 15% per year).

2. **Sealing and insulating a mechanical closet**
   a. We assumed that the closet measures 4 feet by 6 feet with one of the narrow walls on the exterior. We also assumed that the closet was on the second floor. The ceiling would not have to be insulated, but we assumed that the homeowners would prefer that it was. The floor over conditioned space below would need to be insulated.
   b. Assuming that one of the narrow walls is on the exterior, there would be 16 linear feet of wall or about 112 square feet. The cost of installing R-15 wall insulation would be about $0.40 per sq ft, or about $50.
   c. There is no additional cost of installing attic insulation, since the attic would be insulated anyway.
   d. The cost of insulating the 24 sq ft floor would be $10.
   e. The cost of sill seal for the bottom plates is $0.10 per linear foot ($4.67 for a 50-foot roll retail). Air sealing the base of the wall and the top plates would cost about $4 in materials and at most $10 of labor for a total of $14.
   f. The total labor and materials cost is $74.
   g. With 20% overhead and profit added, the cost would be about $90 for the sealed and insulated closet.
   h. Annual energy savings according to the computer model are $24.50 in Climate Zone 3, $22.8 in Climate Zone 4, and 47.30 in Climate Zone 5.
   i. Simple Payback Period ranges from 25% to 93%.

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National Cost-effectiveness of ANSI/ASHRAE/IES Standard 90.1-2013

January 2015

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99352

Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the upgrade and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and greenhouse gas emissions for the life of buildings. Continuous improvement of building energy efficiency is achieved by periodically updating model energy codes for commercial and residential buildings. Through consensus-based code development processes, DOE recommends revisions and amendments, supporting technologically feasible and economically justified energy efficiency measures. Ensuring that model code changes impacting the cost of building construction, maintenance, and energy services are cost-effective also encourages their adoption and implementation at the state and local levels. Pacific Northwest National Laboratory (PNNL) prepared this analysis to support DOE in evaluating the energy and economic impacts associated with updated codes in commercial buildings.

The purpose of this analysis is to examine the cost-effectiveness of the 2013 edition of ANSI/ASHRAE/IES[1] Standard 90.1 (ANSI/ASHRAE/IES 2013). Standard 90.1 is developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard Standing Project Committee (SSPC) 90.1. It is the model energy standard for commercial and multi-family residential buildings over three floors (42 USC 6833). PNNL analyzed the cost-effectiveness of changes in Standard 90.1 from 90.1-2010 to 90.1-2013, as applied in commercial buildings across the United States. During the development of new editions of Standard 90.1, the cost-effectiveness of individual changes (addenda) is often calculated to support the deliberations of ASHRAE Standard Standing Project Committee (SSPC) 90.1. The ASHRAE process, however, does not include analysis of the cost-effectiveness of the entire package of addenda from one edition of the standard to the next, which is of particular interest to adopting State and local governments. Providing States with an analysis of cost-effectiveness may encourage more rapid adoption of newer editions of energy codes based on Standard 90.1. This information may also inform the development of future editions of Standard 90.1.

To establish the cost-effectiveness of Standard 90.1-2013, three main tasks were addressed:

- Identification of building elements impacted by the updated standard
- Allocation of associated installation, maintenance, and replacement costs
- Cost-effectiveness analysis of required changes

In addition to installation, maintenance, and replacement costs, energy cost differences were needed to determine cost-effectiveness. The energy costs for each edition of Standard 90.1 were determined previously under the development of Standard 90.1-2013, as described below.

The current analysis builds on the previous PNNL analysis (as outlined in Section 5.2) of the energy use and energy cost saving impacts of Standard 90.1-2013 compared to previous editions. The overall energy savings analysis of Standard 90.1 utilized a suite of 16 prototype EnergyPlus building models in 15 climate locations representing all eight U.S. climate zones. Detailed methodology and overall energy

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

saving results from Standard 90.1-2013 are documented in the PNNL technical report titled *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis* (Halverson et al. 2014).

The cost-effectiveness analysis in this report used a subset of prototypes and climate locations, providing coverage of nearly all of the changes in Standard 90.1 from the 2010 to 2013 edition that affect energy savings, equipment and construction costs, and maintenance, including conventional HVAC systems used in commercial buildings. The changes included and excluded are described in Section 3.0. The following prototype buildings and climate locations were selected for the analysis, using the rationale described in Section 2.1:

Prototype Buildings	**Climate Locations**
Small Office	2A Houston, Texas (hot, humid)
Large Office	3A Memphis, Tennessee (warm, humid)
Standalone Retail	3B El Paso, Texas (hot, dry)
Primary School	4A Baltimore, Maryland (mixed, humid)
Small Hotel	5A Chicago, Illinois (cool, humid)
Mid-rise Apartment	

The subset of selected prototypes represents the energy impact of five of the eight commercial principal building activities that account for 74% of the new construction by floor area. Each of the 6 selected prototype buildings was analyzed in the 5 selected climate locations for a total of 30 cost-effectiveness assessments. A primary input to the cost-effectiveness analysis was the incremental costs for the addenda to Standard 90.1-2010 that were included in Standard 90.1-2013. Of the 110 total addenda to 90.1-2010, 33 were found to have quantified energy savings that could be modeled in the 90.1-2013 energy savings analysis. The remaining addenda were not considered to have quantifiable energy savings, or did not directly affect building energy usage. Of the addenda with quantified energy savings, 28 were modeled in the six prototypes at the five climate locations and were included with the cost estimate. The remaining five addenda affect prototypes that were not included in the cost-effectiveness analysis, and are not expected to have a significant impact on the cost-effectiveness as described in Section 3.0.

The methodology for cost-effectiveness assessments has been established[1] for analysis of prior editions of Standard 90.1 (Hart and Liu 2015). Three economic metrics are used in this report:

- Life-cycle cost analysis (LCCA)
- SSPC 90.1 Scalar Method
- Simple payback

Table ES.1 summarizes the cost-effectiveness results. Findings demonstrate that the 2013 edition of Standard 90.1 is cost-effective overall relative to the 2010 edition under the LCCA and modified SSPC 90.1 Scalar Method for the representative prototypes and climate locations.

[1] See methodology at: http://www.energycodes.gov/development/commercial/methodology.

Table ES.1. Summary of Cost-effectiveness Analysis

Prototype		Climate Zone and Location				
		2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
Life Cycle Cost Net Savings						
Small Office	Total	$21,600	$15,200	$10,800	$2,900	$5,000
	$/ft^2	$3.93	$2.76	$1.96	$0.53	$0.91
Large Office	Total	$740,000	$1,650,000	$2,540,000	$300,000	$1,340,000
	$/ft^2	$1.48	$3.31	$5.09	$0.60	$2.69
Standalone Retail	Total	$84,000	$81,400	$53,800	$67,000	$79,000
	$/ft^2	$3.40	$3.30	$2.18	$2.71	$3.20
Primary School	Total	$246,000	$116,000	$398,000	$70,000	$54,000
	$/ft^2	$3.33	$1.57	$5.38	$0.95	$0.73
Small Hotel	Total	$96,410	$76,000	$78,000	$62,600	$57,000
	$/ft^2	$2.23	$1.76	$1.81	$1.45	$1.32
Mid-rise Apartment	Total	$59,600	$22,600	$23,800	$29,200	$28,500
	$/ft^2	$1.77	$0.67	$0.71	$0.87	$0.84
Simple Payback (years)						
Small Office		Immediate	Immediate	Immediate	22.0	17.0
Large Office		6.8	Immediate	Immediate	5.1	Immediate
Standalone Retail		Immediate	Immediate	Immediate	Immediate	Immediate
Primary School		5.5	9.5	0.6	14.3	15.6
Small Hotel		3.9	4.1	4.0	7.2	8.7
Mid-rise Apartment		1.9	11.7	11.4	7.2	9.7
Scalar Ratio, Limit = 21.85						
Small Office		(4.9)	(2.8)	(6.3)	20.0	15.1
Large Office		5.6	(44.7)	(53.7)	3.0	(86.8)
Standalone Retail		(1.9)	(1.6)	(2.0)	4.2	3.8
Primary School		5.1	11.1	(1.2)	15.3	16.7
Small Hotel		3.8	4.5	4.4	7.5	8.9
Mid-rise Apartment		2.2	11.3	11.1	7.0	9.5

Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank David Cohan, Jeremy Williams, and Mohammed Khan at DOE for providing oversight. The authors would like to thank the members of the ASHRAE Standing Standards Project Committee (SSPC) for 90.1 for their review of the cost estimates. The authors also recognize Bing Liu, Manager of the Building Energy Codes Program at PNNL. This work was truly a team effort, and the authors would like to express their deep appreciation to everyone from the PNNL codes team who contributed to its completion, including Jing Wei Zhuge, Jian Zhang, Weimin Wang, and Rosemarie Bartlett.

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Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
Btu	British thermal units
Btu/h	British thermal units per hour
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CFM	cubic feet per minute
CHW	chilled water
CU	coefficient of utilization
DCV	demand controlled ventilation
DDC	direct digital control
DOE	U.S. Department of Energy
DX	direct expansion
EER	energy efficiency ratio
EIA	Energy Information Administration
EPAct	Energy Policy Act
ERV	energy recovery ventilator
Et	thermal efficiency
FEMP	Federal Energy Management Program
ft	feet or foot
ft2	square feet or square foot
gpm	gallons per minute
hp	horsepower
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
LBNL	Lawrence Berkeley National Laboratory
LCCA	life-cycle cost analysis
lm	lumens
LPD	lighting power density
LSC	Lighting Subcommittee (SSPC 90.1)
mph	miles per hour
MSC	Mechanical Subcommittee (SSPC 90.1)
NC3	National Commercial Construction Characteristics

NFRC	National Fenestration Rating Council
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
PNNL	Pacific Northwest National Laboratory
PTAC	packaged terminal air conditioner
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SMACNA	Sheet Metal and Air Conditioning Contractors Association
SSPC	Standing Standard Project Committee
VAV	variable air volume
W	watt
w.c.	water column
WWR	window-to-wall ratio

Contents

Figures

Tables

1.0 Introduction

This study was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy (DOE) Building Energy Codes Program (BECP). BECP was founded in 1993 in response to the *Energy Policy Act of 1992*, which mandated that DOE participate in the development process for national model codes and that DOE help states adopt and implement progressive energy codes. DOE has supported the development and implementation of more stringent building energy codes since the 1970s, but the BECP was the first DOE program assigned specific mandates with regard to energy codes.

Building energy codes set baseline minimum requirements for energy efficient design and construction for new and renovated buildings, and impact energy use and emissions for the life of the buildings. Energy codes are part of the greater collection of documents which govern the design, construction, and operation of buildings for the health and life safety of occupants. Improving these documents generates consistent and long-lasting energy savings.

This report concerns *ANSI/ASHRAE/IES 90.1-2013, Energy Standard for Buildings Except Low-Rise Residential Buildings*, the latest national model energy standard for commercial and multi-family residential buildings with more than three floors. The 2010 and 2013 editions of Standard 90.1 are the primary focus of this report (ANSI/ASHRAE/IES 2010, 2013). These standards are referred to as 90.1-2010 and 90.1-2013 respectively, or as Standard 90.1 when referring to multiple editions of the Standard.

DOE supports the incremental upgrading of the model energy codes, and states' adoption, implementation, and enforcement of the upgraded codes. When the model energy codes are being updated, DOE takes an active leadership role, by participating in the processes that update and maintain these documents and seeking adoption of all technologically feasible and economically justified energy efficiency measures

PNNL has played a major role in supporting DOE code efforts, and is closely involved in the upgrading of the model codes. Specifically, PNNL provides significant assistance to the ASHRAE Standing Standard Project Committee for 90.1 (SSPC 90.1), which is responsible for developing Standard 90.1. This assistance ranges from providing voting committee members and leadership to developing change proposals (addenda) for codes. In support of DOE code activities, PNNL also conducts requested analyses and supports DOE determinations published in the *Federal Register.* Determinations confirm whether or not each new edition of the model codes will improve the energy efficiency of buildings.[1]

The process used by ASHRAE for developing new editions of Standard 90.1 does not include analysis of the cost-effectiveness of the combined changes from one edition to the next. The cost-effectiveness of individual changes, known as addenda, is often evaluated to inform SSPC 90.1 decisions. DOE therefore asked PNNL to analyze the cost-effectiveness of 90.1-2013 as a whole compared to 90.1-2010, using a life-cycle cost analysis (LCCA). By doing this, DOE seeks to provide states with cost-effectiveness information to encourage more rapid adoption of newer editions of commercial energy codes based on Standard 90.1, as well as to be used in the development of future editions of the Standard. The cost-effectiveness analysis is the subject of this report.

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[1] For more information on the DOE Determination of energy savings, see http://www.energycodes.gov/regulations/determinations

1.1 Supporting State Energy Code Adoption

DOE is required to provide technical assistance to states to help them review and update state energy codes, as well as to implement, enforce, and evaluate compliance with state codes. The cost-effectiveness analysis covered in this report is considered part of DOE's technical assistance effort to encourage states to adopt the newest edition of Standard 90.1 or its equivalent. States are at various stages of incorporating the latest edition of Standard 90.1 or its equivalent into their building codes. Figure 1.1 shows the current applicable energy standard or code that most closely matches the state's regulation (DOE 2014a).

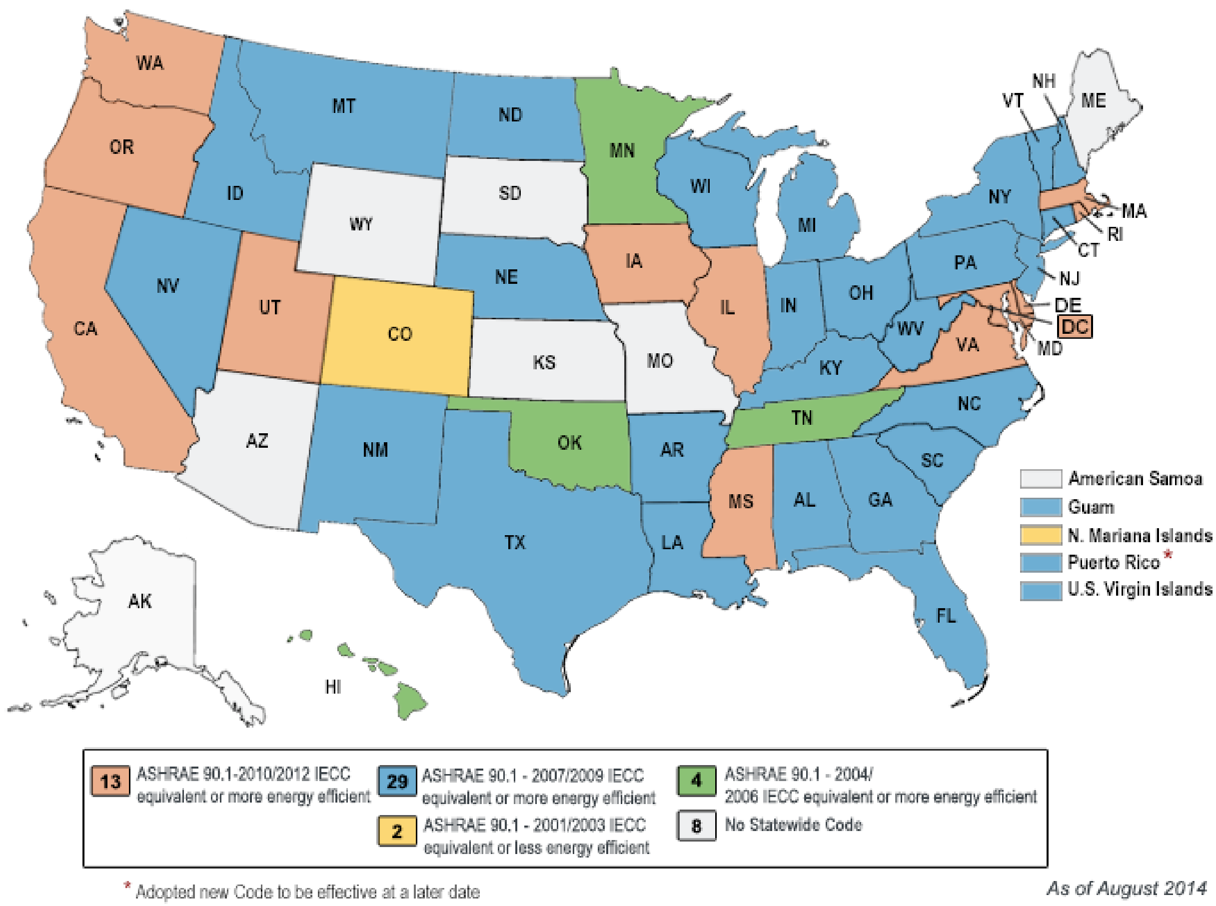

Figure 1.1. Current Commercial Building Energy Code Adoption Status

1.2 Contents of the Report

This report documents the approach and results for PNNL's analysis of the cost-effectiveness of 90.1-2013 compared to 90.1-2010. Much of the work builds on the previously completed cost-effectiveness comparison between 90.1-2007 and 90.1-2010 (Thornton et al. 2013, ANSI/ASHRAE/IESNA 2007, ANSI/ASHRAE/IES 2010). The cost-effectiveness analysis began with the energy savings analysis for development of 90.1-2013 which included energy model simulation using 16 prototype models in 17 climate locations and is discussed further in Section 5.2.

Development of the prototypes and simulation structure was originally completed during the energy savings analysis of 90.1-2010 compared to 90.1-2004 and 90.1-2007. The technical analysis process, model descriptions and results were presented in PNNL's technical report titled *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*, referred to in this report as *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011). The prototype models used in the analysis, their development, and the climate locations were described in detail in the quantitative determination and are available for download[1] (Halverson et al. 2014; DOE 2014b).

Six prototypes and five climate locations were chosen from those used for the energy savings analysis to represent the building construction, energy, and maintenance cost impacts of the changes from 90.1-2010 to 90.1-2013. Chapter 2 provides an overview of the selected prototypes and climate locations utilized for this analysis. Chapter 3 describes the included addenda.

Costs were developed for each of the addenda items included in the cost-effectiveness analysis. The cost estimate methodology and cost items are described in Chapter 4, with a summary of the incremental costs provided. An expanded summary of the incremental costs is also included in Appendix B of this report. The complete cost estimates are available in a spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2013-Cost Estimate* (PNNL 2014). The cost-effectiveness analysis methodology and results are presented in Chapter 5.

The report has three appendixes. Appendix A includes prototype building descriptions for the six prototypes considered, adapted from *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*. Appendix B includes a summary of incremental cost estimate data. Appendix C includes the energy analysis results for 90.1-2013 compared to 90.1-2010.

[1] Download from http://www.energycodes.gov/development/commercial/90.1_models.

2.0 Building Prototypes and Climate Locations

As part of its technical support to SSPC 90.1, PNNL quantified the energy savings of 90.1-2013 compared to 90.1-2010. The analysis used 16 prototype building models which were simulated in 15 climate locations, and developed in collaboration with SSPC 90.1. These prototype models, their development, and the climate locations were described in detail in the quantitative determination and are available for download (Halverson et al. 2014; DOE 2014b). PNNL selected six of the prototype buildings and developed cost estimates for them in five climate locations. The resulting cost-effectiveness analysis represents most of the energy and cost impacts of the changes in Standard 90.1. The results are presented in Chapter 5 and Appendix C.

2.1 Selection of Prototype Buildings

The six prototypes selected for the cost-effectiveness analysis are shown in bold font with all 16 prototypes in Table 2.1. They were chosen because they:

- provide a good representation of the overall code cost effectiveness, without requiring simulation of all 16
- represent most of the energy and cost impacts of the changes in Standard 90.1[1]
- include nearly all of the HVAC systems that were simulated in the 16 prototype models

Table 2.1. Prototype Buildings

Principal Building Activity	Building Prototype	Included in Current Analysis
Office	***Small Office***	**Yes**
	Medium Office	No
	Large Office	**Yes**
Mercantile	***Standalone Retail***	**Yes**
	Strip Mall	No
Education	***Primary School***	**Yes**
	Secondary School	No
Healthcare	Outpatient Healthcare	No
	Hospital	No
Lodging	***Small Hotel***	**Yes**
	Large Hotel	No
Warehouse	Warehouse (non-refrigerated)	No
Food Service	Quick-service Restaurant	No
	Full-service Restaurant	No
Apartment	***Mid-rise Apartment***	**Yes**
	High-rise Apartment	No

[1] An analysis of the 6 prototype presented at the interim SSPC 90.1 meeting on October 19, 2011 showed savings for 90.1-2010 v. 2004 to be within 2.5% of the full set of 16 prototype analysis.

- capture 28 of the 33 addenda to 90.1-2010 that were included in PNNL's simulation of energy savings for 90.1-2013. The remaining five addenda affect prototypes were not included in the cost-effectiveness analysis, as discussed in Section 3.0
- represent the energy impact of five of the eight commercial principal building activities that account for 74% of the new construction by floor area covered by the full suite of 16 prototypes.

Table 2.2 shows the six prototypes and their corresponding HVAC systems.

Table 2.2. HVAC Systems in Selected Prototypes

Building Prototype	Heating	Cooling	Primary System
Small Office	Heat pump	Unitary direct expansion (DX)	Packaged constant air volume (CAV)
Large Office	Boiler	Chiller, cooling tower	Variable air volume (VAV) with reheat
Standalone Retail	Gas furnace	Unitary DX	Packaged CAV
Primary School	Boiler/Gas furnace	Unitary DX	Packaged VAV
Small Hotel	Electricity	DX	Packaged terminal air conditioner (PTAC)
Mid-rise Apartment	Gas	DX	Split DX system

2.2 Selection of Climate Locations

As energy usage varies with climate, there are multiple climate zones[1] used by ASHRAE for residential and commercial standards. They cover the entire United States, as shown in Figure 2.1 (Briggs et al. 2003).

For analysis of Standard 90.1, a specific climate location (city) is selected as a representative of each climate zone. A set of 15 cities is used to represent the climate conditions identified in Standard 90.1 in the United States. Cities for zones 1B and 5C are listed, even though these zones are outside the United States.

[1] Thermal climate zones are numbered from 1 to 8, from hottest to coldest categorized by cooling and heating degree days. Letters designate moisture characteristics: (A) moist, (B) dry, and (C) marine.

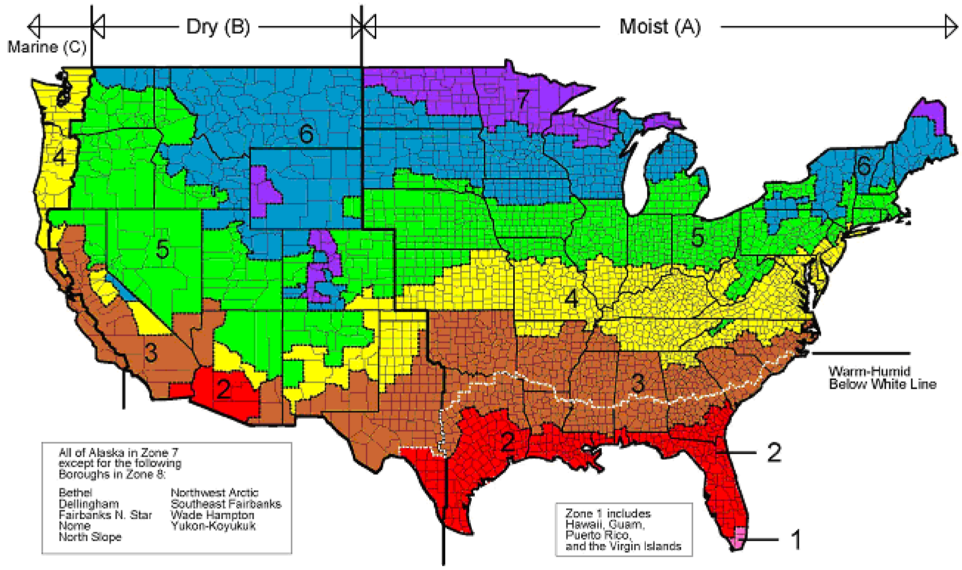

Figure 2.1. United States Climate Zone Map

The cities representing climate zones are listed in Table 2.3 with the five selected for the cost-effectiveness analysis shown in bold font. The selected zones cover most of the high population regions of the United States and include 79% of new construction by floor area (Thornton et al. 2011).

Table 2.3. Climate Locations by Climate Subzones

Climate Zone	Climate Zone Type	Representative City	Included in Current Analysis
1A	Very Hot, Humid	Miami, FL	No
1B	Very Hot, Dry	Riyadh, Saudi Arabia	No
2A	**Hot, Humid**	**Houston, TX**	**Yes**
2B	Hot, Dry	Phoenix, AR	No
3A	**Warm, Humid**	**Memphis, TN**	**Yes**
3B	**Warm, Dry**	**El Paso, TX**	**Yes**
3C	Warm, Marine	San Francisco, CA	No
4A	**Mixed, Humid**	**Baltimore, MD**	**Yes**
4B	Mixed, Dry	Albuquerque, NM	No
4C	Mixed, Marine	Salem, OR	No
5A	**Cool, Humid**	**Chicago, IL**	**Yes**
5B	Cool, Dry	Boise, ID	No
5C	Cool, Marine	Vancouver, B.C., Canada	No
6A	Cool, Humid	Burlington, VT	No
6B	Cold, Dry	Helena, MT	No
7	Very Cold	Duluth, MN	No
8	Subarctic	Fairbanks, AK	No

2.3 Description of Selected Prototypes

Table 2.4 provides a brief overview of the six selected prototypes. *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* provides further information. Included in Appendix A are profiles of each of the selected prototypes. These six profiles and similar profiles for the other ten prototypes as well as the EnergyPlus input files and detailed modeling information for all the prototypes are available for download[1] (DOE 2014b).

Table 2.4. Overview of Six Selected Prototypes

Building Prototype	Floor area (ft^2)	Number of Floors	Window to Wall Ratio (WWR)	Floor-to-Floor Height (ft)	Roof	Exterior Wall	Occupancy (people/ 1000 ft^2)	Plug Loads (W/ft^2)	Interior Lighting		Exterior Lighting	
									2010 (W/ft^2)	2013 (W/ft^2)	2010 (kW)	2013 (kW)
Small Office	5,500	1	15%	10	Attic and Other	Wood Framed	5.6	0.63	0.90	0.82	0.94	0.94
Large Office	498,640	12[1]	40%	13	Insulation above deck	Mass	5.0	0.73	0.90	0.82	56.28	56.28
Standalone Retail	24,690	1	7%	20	Insulation above deck	Mass	15.0	0.50	1.51	1.32	4.74	4.74
Primary School	73,970	1	35%	13	Insulation above deck	Steel Framed	20.0	1.00[3]	1.05	1.05	3.49	3.49
Small Hotel	43,210	4	11%	9 11[2]	Insulation above deck	Steel Framed	6.0	0.95[3]	0.77	0.87	4.18	4.18
Mid-rise Apartment	33,740	4	20%	10	Insulation above deck	Steel Framed	2.3	0.56	0.53	0.53	2.55	2.55

[1] These buildings also include a basement which is not included in the number of floors
[2] First floor only
[3] Excludes any kitchen and or laundry electrical equipment

[1] Download from http://www.energycodes.gov/development/commercial/90.1_models.

3.0 Cost Estimate Items from 90.1-2010 Addenda

Of the 110 addenda included in 90.1-2013, 33 were considered to have quantifiable energy savings, and were modeled in the 90.1-2013 energy savings analysis. The other addenda do not have quantifiable savings, had no savings, do not directly affect building energy usage, or they could not be quantified during the determination quantitative analysis. The addenda are described in more detail in the report documenting the determination quantitative analysis (Halverson et al. 2014).

As described in Section 2.1, the cost effectiveness analysis method uses a subset of six representative prototypes to quantify savings and costs. Of the 33 addenda with quantified savings, 28 were modeled in the six prototypes being used for the cost estimate. The remaining five addenda affect prototypes not included in the six selected for the cost-effectiveness analysis or were not applicable to the prototype as modeled. These are listed in Table 3.2 along with the reason for non-inclusion. Figure 3.1 shows the breakdown of addenda captured in the cost estimate by chapter of the standard.[1]

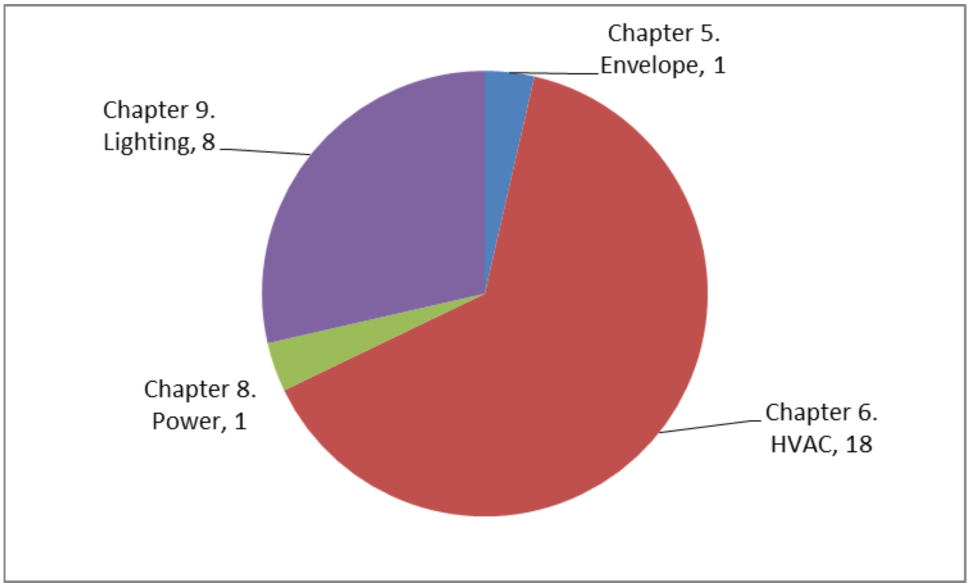

Figure 3.1. Quantity of Addenda Included in the Cost Estimate by Standard 90.1 Chapter

Table 3.1 provides a listing and a brief description of all the addenda included in the cost estimates, and the prototypes to which they apply. The changes due to these addenda are described in Chapter 4 of this report. Costs for HVAC were separated out for HVAC systems because there are adjustments in HVAC system capacities due to the other changes in the models, particularly reduced heat gains from lighting power reductions.

Throughout this report, each addendum to 90.1-2010 is named according to a convention that begins with 90.1-10, followed by the letter identifier of the addendum (e.g., 90.1-10bb).

[1] Chapter 7 (Service Water Heating) and Chapter 10 (Other Equipment) have no addenda to 90.1-2010 with quantifiable savings.

Table 3.1. 90.1-2010 Addenda Cost Items

90.1 Addenda and Other Cost Items	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
	Standard 90.1 Chapter 5 Envelope						
90.1-10bb	Modifies building envelope requirements for opaque assemblies and fenestration. Adds new visible transmittance (VT) requirement.	X	X	X	X	X	X
	Standard 90.1 Chapter 6 Heating Ventilating and Air Conditioning						
HVAC System Capacity Changes	Changes in system equipment and ductwork capacity due to HVAC load differences.	X	X	X	X	X	
90.1-10ca	Adds control requirements for heating systems in vestibules.			X			
90.1-10g	Adds efficiency requirements for commercial refrigeration.				X		
90.1-10dv	Establishes chiller and boiler isolation requirements.		X				
90.1-10af	Requires that cooling tower variable speed fans operate all fans at the same speed.		X				
90.1-10aj	Increases efficiency of fractional horsepower motors ≥1/12 hp .		X		X	X	X
90.1-10am	Establishes minimum turndown for boiler plants ≥ 1,000,000 Btu/h.		X				
90.1-10aq	Increases scope of fan speed control for cooling systems and enhances integrated economizer control.			X	X		
90.1-10ar	Adds efficiency requirements for walk-in coolers and freezers and refrigerated cases.				X		
90.1-10as	Requires insulation and preheat shut off for in-duct humidifiers.		X				
90.1-10au	Tightens fan power limitation requirements.		X		X		
90.1-10az	Increases the efficiency of open circuit axial fan cooling towers and includes accessories in the efficiency rating.		X				
90.1-10ba	Requires door switches to reduce mechanical heating or cooling when doors are open.					X	X
90.1-10bi	Increases efficiency of smaller air conditioners and heat pumps.	X		X	X	X	X
90.1-10bk	Increases cooling efficiency for PTACs.					X	
90.1-10bs	Reduces occupancy threshold for demand controlled ventilation.				X		
90.1-10bt	Reduces thresholds at which energy recovery is required.		X	X	X		
90.1-10cb	Expands night setback requirements and modifies optimum start requirement.		X	X	X		
90.1-10ch	Increases chiller efficiencies.		X				

Table 3.1. (continued)

90.1 Addenda and Other Cost Items	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
Standard 90.1 Chapter 8 Power							
90.1-10bf	Expands automatic receptacle control.	X	X	X	X	X	
Standard 90.1 Chapter 9 Lighting							
90.1-10ay	Modifies daylighting requirements.	X	X		X	X	
90.1-10bc	Modifies guestroom automatic lighting control.					X	
90.1-10bh, co, cr, dj, dl	Modify Lighting Power Densities (LPD).	X	X	X	X	X	X
90.1-10by	Increases application of some lighting controls and reduces lag time for occupancy sensors. Reformats lighting controls requirement presentation.	X	X	X	X	X	X

Table 3.2. 90.1-2010 Addenda Not Included In Cost-Effectiveness Analysis

90.1 Addenda	Description	Reason
90.1-10h	Water-to-air heat pump efficiency.	Does not apply to prototypes included in analysis.
90.1-10bw	Orientation SHGC tradeoff.	Affected prototypes already meet requirement.
90.1-10cz	Increases boiler efficiency for residential sized (NAECA covered) equipment, <3,000 Btu/h	Does not apply to prototypes included in analysis.
90.1-10cy	Energy recovery for 24/7 occupancies.	Does not apply to prototypes included in analysis.
90.1-10di	Limits humidity controls.	Does not apply to prototypes included in analysis.

4.0 Incremental Cost Estimates

This chapter describes the approach used for developing the incremental cost estimates, the description of the individual cost estimates, and a summary of the total incremental cost estimate results. The incremental cost estimates were developed for the sole purpose of evaluating the cost-effectiveness of the changes between 90.1-2010 and 90.1-2013. They should not be applied to actual building projects or used for any other purpose.

4.1 Incremental Cost Estimate Approach

The first step in developing the incremental cost estimates was to define the items to be estimated, such as specific pieces of equipment and their installation. Part of the cost item information was extracted from the prototype building energy model inputs and outputs, and from addenda descriptions in the determination quantitative analysis report (Halverson et al. 2014). In some cases, the prototype models do not include sufficient design detail to provide the basis for cost estimates, and additional details were developed to support the cost estimating effort. These are described in Section 4.2 of this report along with the costs. A summary of the incremental costs is included in Appendix B of this report. The cost estimates are available in the spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2013-Cost Estimate* (PNNL 2014).

The second step in the cost estimating process began by defining the types of costs to be collected including material, labor, construction equipment, commissioning, maintenance, and overhead and profit. These were estimated for both initial construction as well as for replacing equipment or components at the end of the useful life.

The third step was to compile the unit and assembly costs needed for the cost estimates. PNNL worked with a cost estimating consulting firm, a mechanical, electrical and plumbing (MEP) consulting engineering firm, a daylighting consultant, and utilized its own expertise to develop cost information during the development of the cost-effectiveness comparison between 90.1-2010 and 90.1-2007 (Thornton et al. 2013). Since those estimates were recently completed, for this report PNNL limited its efforts to updating the prior costs where appropriate and completing in-house estimates where needed. RS Means cost handbooks were used extensively and provided nearly all of the labor costs (RS Means 2014a, 2014b, 2014c). Comparison with RS Means cost handbooks from 2012 provided specific technology inflation factors where the costs developed in 2012 were used (RS Means 2012a, 2012b, 2012c). While specific references are included in the cost estimate spreadsheet, in this report the RS Means cost handbooks are referred to as *RS Means 2014* and *RS Means 2012*, and the specific handbook used can be inferred from the type of cost item being discussed. Cost estimates for new work and later replacements were developed to approximate what a general contractor typically submits to the developer or owner and include sub-contractor and contractor costs and markups. Maintenance costs were intended to reflect what a maintenance firm would charge, rather than in-house maintenance labor. Once initial costs were developed, a technical review was conducted by members of the 90.1 lighting and mechanical subcommittees, and PNNL internal sources.

4.1.1 Source of Cost Estimates

Many of the general HVAC costs were originally developed while analyzing the cost-effectiveness of 90.1-2010 compared to 90.1-2007. Table 4.1 includes a description of all sources of cost estimates by category of costs (e.g., HVAC). HVAC cost items were developed primarily by two consulting firms during prior analysis (Thornton 2013). The cost estimating firm provided the cost for HVAC systems including packaged DX and chilled and hot water systems as well as central plant equipment. The engineering consulting firm provided most of the ductwork and piping costs, and most of the controls items. These cost estimates from 2012 have been brought forward to 2014 by applying inflation factors developed using RS Means Cost Handbooks from 2012 and 2014 (RS Means 2012a, 2012b, 2012c, 2014a, 2014b, 2014c).

For lighting and some HVAC items, PNNL developed new cost estimates. Online sources and an outside consultant for daylighting costs were used together with input from the 90.1 SSPC lighting subcommittee (LSC). For envelope items, national costs collected for the prior analysis by a cost estimating contractor were updated. In addition to these summary tables, specific sources such as the name of product suppliers are included in the cost estimate spreadsheet (PNNL 2014).

Table 4.1. Sources of Cost Estimates by Cost Category

Cost Category	Source
HVAC Motors included in this category	Cost estimator and PNNL staff used quotes from suppliers and manufacturers, online sources, and their own experience.*
HVAC Ductwork, piping, selected controls items	MEP consulting engineers provided ductwork and plumbing costs based on one-line diagrams they created, and the model outputs, including system airflows, capacity and other factors, and provided detailed costs by duct and piping components using *RS Means 2012*. The MEP consulting engineers also provided costs for several control items.*
HVAC Selected items	PNNL utilized staff expertise and experience supplemented with online sources.*
Lighting Interior lighting power allowance and occupancy sensors	PNNL staff with oversight from chairman of 90.1 LSC. Product catalogs were used for consistency with some other online sources where needed.
Lighting Daylighting	PNNL staff and daylighting consulting firm.
Envelope; Opaque insulation and fenestration	Costs dataset developed by specialist cost estimator.*
Commissioning	Cost estimator, RS Means, MEP consulting engineers, or PNNL staff expertise.
Labor	*RS Means 2014* and the MEP consulting engineers for commissioning rate.
Replacement life	Lighting equipment including lamps, and ballasts from product catalogs. Mechanical from 90.1 Mechanical Subcommittee protocol for cost analysis.
Maintenance	From the originator of the other costs for the affected items, or PNNL staff expertise.

* Where detailed costs were developed in 2012, they were updated to 2014 using inflation factors developed from RS Means Handbooks.

4.1.2 Cost Parameters

Several general parameters applied to all of the cost estimates. These items included new construction material and labor cost adjustments, a replacement labor hour adjustment, replacement material and labor cost adjustments, and a project cost adjustment. These parameters are based on work by the cost estimating firm in the prior analysis and are described in Table 4.2.

Costs were not adjusted for climate locations. The climate location results were intended to represent an entire climate subzone even though climate data for a particular city is used for modeling purposes. Costs will vary significantly between a range of urban, suburban and rural areas within the five selected climate locations which cross multiple states. Costs can be adjusted for specific cities based on city cost index adjustments from *RS Means 2014* or other sources.

Table 4.2. Cost Estimate Adjustment Parameters

Cost Items	Value[1]	Description[2]
New construction labor cost adjustment	52.6%	Labor costs used are base wages with fringe benefits. Added to this is 19%: 16% for payroll, taxes and insurance including worker's comp, FICA, unemployment compensation and contractor's liability and 3% for small tools. The labor cost plus 19% is multiplied by 25%; 15% for home office overhead, and 10% for profit. A contingency of 2.56% is added as an allowance to cover wage increases resulting from new labor agreements.
New construction material cost adjustment	15.0% to 26.5%	Material costs are adjusted for a waste allowance set at 10% in most cases for building envelope materials. For other materials such as HVAC equipment, 0% waste is the basis. The material costs plus any waste allowance are multiplied by the sum of 10% profit on materials, and sales taxes. An average value for sales taxes of 5% is applied.
Replacement - additional labor allowance	65.0%	Added labor hours for replacement to cover demolition, protection, logistics, clean-up and lost productivity relative to new construction. Added prior to calculating replacement labor cost adjustment.
Replacement labor cost adjustment	62.3%	The replacement labor cost adjustment is used instead of the new construction labor cost adjustment for replacement costs. The adjustment is the same except for sub-contractor (home office) overhead, which is 23% instead of 15% to support small repair and replacement jobs.
Replacement material cost adjustment	26.5% to 38.0%	The replacement material cost adjustment is used instead of the new construction material cost adjustment for replacement costs. The adjustment is for purchase of smaller lots and replacement parts. 10% is added and then is adjusted for profit and sales taxes.
Project cost adjustment	28.8%	The combined labor, material and any incremental commissioning or construction costs are added together and adjusted for sub-contractor general conditions and for general contractor overhead and profit. Sub-contractor general conditions add 12% and include project management, job-site expenses, equipment rental and other items. A general contractor markup of 10% and a 5% contingency are added to the sub-contractor sub-total as an alternative to calculating detailed general contractor costs (RS Means 2014c).

1 Values shown and used are rounded to first decimal place.
2 Values provided by the cost estimator except where noted.

4.1.3 Cost Estimate Spreadsheet Workbook

The cost estimate spreadsheet (PNNL 2014) is organized in the following sections, some with multiple worksheets, each highlighted with a different colored tab described in the introduction to the spreadsheet:

1. Introduction
2. HVAC cost estimates
3. Lighting cost estimates
   a. Interior lighting power density
   b. Interior lighting occupancy related controls
   c. Daylighting controls
4. Envelope, Power, and Other cost estimates
5. Cost estimate summaries and cost-effectiveness analysis results

4.2 Cost Estimate Descriptions

Cost estimate items are tied to each specific 90.1-2010 addendum as identified in the descriptions of the cost items in this section and as listed in Table 3.1. The remaining portion of this section provides more detailed descriptions of the additional information developed to establish the basis for estimating costs, as well as information about the cost estimates themselves. These are organized in three major sections: (1) HVAC, (2) lighting, and (3) building envelope and power.

4.2.1 Heating, Ventilating and Air Conditioning

A substantial part of the HVAC system cost estimate was tied to changes in system and plant equipment capacity between 90.1-2010 and 90.1-2013 for corresponding prototype and climate location models. Costs for capacity changes for HVAC system and plant equipment are described together in Section 4.2.1.1 of this report.

Other cost estimates were tied to specific 90.1-2010 addenda. Changes in requirements for energy recovery ventilators (ERVs), fan speed control in packaged equipment and integration of economizers had a broad impact on HVAC systems in some prototypes. Refrigeration requirements related to maximum allowed energy consumption and efficiency of motors and lights were introduced in 90.1-2013 and affected the Primary School prototype. Plant equipment addenda primarily affected the Large Office prototype, with heating-related impacts on the Primary School prototype, which includes VAV systems with hot water reheat. In some cases there was a net decrease in HVAC costs due to the decreased cost from reductions in system capacity, airflow, and water flow offsetting the increased costs from other addenda.

Many of the HVAC items for which costs were determined remained the same in the current analysis as they were in the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For example, the change in equipment capacity requires costs for different equipment sizes. Costs for various sizes of equipment were obtained during the previous analysis. For this round of analysis, costs for

HVAC items from the previous analysis were brought forward to 2014 by applying inflation adjustment factors that were calculated by comparing corresponding items in *RS Means 2014* and *RS Means 2012*.

4.2.1.1 HVAC System and Plant Equipment Capacity Changes

Location in 90.1-2013:	Not covered by a specific section in 90.1-2013
Addenda:	None, but affected by all addenda that impact space HVAC loads such as lighting power density, 90.1-10bh
Prototypes Affected:	All

Costs were estimated to address changes in HVAC system and plant equipment capacity between the 90.1-2010 and 90.1-2013 prototype models. HVAC equipment capacity changes result from reductions in heating and cooling loads due to changes in opaque envelope insulation, fenestration U-factor and SHGC requirements, lighting power, and lighting controls. In some cases there may be a heating load increase as a result of reduced internal gains. The change in capacity is taken from the building simulations as an interactive effect of the other code changes implemented.

The HVAC capacity changes are a substantial part of the HVAC cost differences. The costs are developed for a range of equipment sizes corresponding to the prototype models. In most cases, equipment costs from two manufacturers were obtained and the average was used. As mentioned earlier, these costs were developed originally for the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For capacity changes going from 90.1-2010 to 90.1-2013, the same costs were used but were brought forward to 2014 by multiplying them by an adjustment factor. The inflation adjustment factors inflate the material costs and are calculated by comparing corresponding equipment costs in *RS Means 2014* with those in *RS Means 2012*. Labor costs were updated by using current labor crew rates from *RS Means 2014*.

Many of the HVAC capacity-related equipment costs in the component cost worksheet are the same for 90.1-2010 and 90.1-2013 for the same capacity equipment. The costs differ in the prototype-specific cost worksheets when there is a change in equipment capacity, based on data extracted from the simulation models. In the case of central plant equipment, required efficiency increases were captured along with changes in capacity. Ductwork and piping cost results were calculated separately as a total cost for each combination of prototype and climate location, and values for 90.1-2010 and 90.1-2013 are different, relative to system airflow or water flow.

Piping and ductwork costs were developed for the previous analysis by the MEP consulting engineers. This effort included developing schematic level single line representative layouts of the ductwork and piping for each prototype. Detailed costs were previously developed at the level of duct and pipe size and length, and all fittings based on the component-by-component costs from *RS Means 2012*. These costs are brought forward to 2014 by applying an inflation factor. Most of the incremental differences from 90.1-2010 to 90.1-2013 are based on changes in load and airflow and the cost estimates from the previous analysis are relevant. For some systems like PTACs in the Small Hotel prototype, the differences in capacity do not impact size selection, so costs are not adjusted for actual capacity requirements.

An example of the process for developing piping and ductwork costs is shown below. Figure 4.1 provides an exterior view of the Small Office prototype and an image of the air distribution layout provided by the MEP consulting engineers. Table 4.3 shows an example of the level of ductwork detail developed. Costs for each air distribution element were estimated (primarily from *RS Means 2012*) and then summed. For example, for the Chicago climate location the 90.1-2007 material cost is $5,561 and the 90.1-2010 cost is $5,573. Based on cost data from all the estimates, a curve fit was developed relating costs to airflow. Then the resulting airflow for each location, prototype, and code edition was used to generate specific air distribution material and labor costs. These costs were then brought forward to 2014 with separate inflation factors for material and labor.

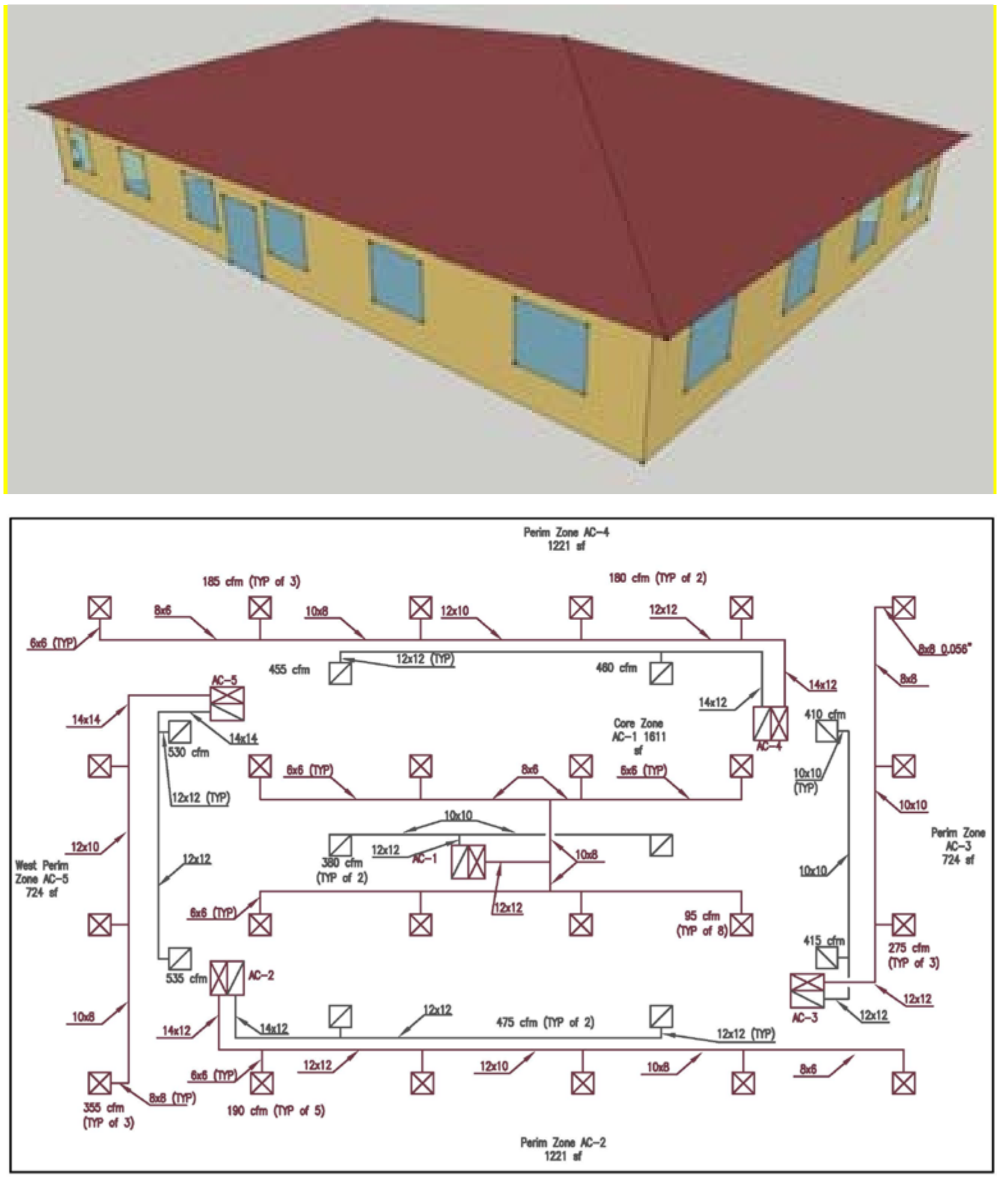

Figure 4.1. Small Office Air Distribution System

Table 4.3. Small Office Duct Details for One HVAC System

Description	Multiplier	Depth (in.)	Width (in.)	Area (ft^2)	Duct Length (ft.)	Depth + Width	Duct Weight (lb.)	Item Qty.
Supply Side								
12x12 Duct	1	12	12	1.00	6	24	34.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	1	10	8	0.56		18		17.3
10x8 Duct	2	10	8	0.56	4	18	34.7	
SR5-14 Dovetail WYE	1	8	6	0.33		14		20.9
8x6 Duct	4	8	6	0.33	7	14	85.5	
SR5-13 Tee, 45 degrees (Qs)	4	6	6	0.25		12		15.2
SR5-13 Tee, 45 degrees (Qb)	1	6	6	0.25		12		
6x6 Duct	4	6	6	0.25	20	12	182.4	
CR3-14 Elbow (1.5" Vane Spc)	4	6	6	0.25		12		4.0
6x6 Duct	8	6	6	0.25	2	12	36.5	
Damper Θ = 0°, 6x6	8							8.0
Diffuser, 6x6	8							8.0
Return Side								
12x12 Duct	8	12	12	1.00	2	24	92.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	2	10	10	0.69		20		38.7
10x10 Duct	2	10	10	0.69	15	20	145.2	
CR3-14 Elbow (1.5" Vane Spc)	2	10	10	0.69		20		2.0
10x10 Duct	2	10	10	0.69	2	20	19.4	
Damper Θ = 0°, 10x10	2							2.0
Grille, NC 30 10"x10"	2							2.0
						Duct Weight	631.26	

4.2.1.2 PTAC Equipment Efficiency

Location in 90.1-2013: Table 6.8.1-4

Addendum: 90.1-10bk

Prototype Affected: Small Hotel

Addendum 90.1-10bk modifies Table 6.8.1D in 90.1-2010 (now Table 6.8.1-4 in 90.1-2013) by raising the minimum cooling efficiency requirements for standard-size PTACs manufactured on or after January 1, 2015, to the same level as packaged terminal heat pumps.

Only the Small Hotel prototype is affected. All PTACs modeled have a capacity of 9,000 Btu/h. The 90.1-2010 efficiency is 11.1 EER; the 90.1-2013 efficiency is 11.3 EER. PTACs are commodity items, so PNNL searched online for prices of this equipment. Finding units that matched these exact minimum efficiency values and any that were as low as the 90.1-2010 minimum efficiency requirements proved to be difficult, as such units are no longer readily available. Costs were available for units with the same

0.2 EER difference, so the cost of an 11.3 EER PTAC was assigned to 90.1-2010 and the cost of an 11.5 EER unit to 90.1-2013. Costs from two different manufacturers were used from the same website resulting in a $35 higher material cost for the 90.1-2013 case (PTACunits 2014).

4.2.1.3 Single-Zone Fan Speed Control and Economizer Integration

Location in 90.1-2013: Sections 6.4 and 6.5

Addendum: 90.1-10aq

Prototypes Affected: Standalone Retail, Small Hotel, and Primary School

Addendum 90.1-10aq expands the single-zone fan speed control requirements and requires staged cooling for smaller capacity units. For packaged DX cooling units serving single zones, the threshold of cooling capacity for fan speed control is reduced from 110,000 Btu/h in 90.1-2010 to 65,000 Btu/h in 90.1-2013. Additionally, addendum 90.1-10aq requires cooling capacity to be staged for units larger than 65,000 Btu/h. While many larger units have at least 2 stages in standard practice, the requirement is for 3 and 4 stages on units that serve multiple zones with modulating air flows. Single zone units require at least 2 stages. The cost of adding a single stage of cooling to all units was deemed appropriate to capture the new requirements. For the cost estimate, data from an equipment survey developed by the Mechanical Subcommittee of SSPC 90.1 was curve fit independently for both the addition of cooling stages and upgrading to a two speed fan. To meet the multiple requirements added by 90.1-10aq, these factors were applied as follows:

- The fan speed cost was applied to 90.1-2010 units with cooling capacity at or above 110,000 Btu/h.
- The fan speed cost was applied to 90.1-2013 units with cooling capacity at or above 65,000 Btu/h.
- The added cooling staging cost was applied to 90.1-2013 units with cooling capacity at or above 65,000 Btu/h.

In the development of these cost estimates, unit capacities were extracted from the results of the applicable prototype simulations for the climate zones analyzed.

There are additional requirements that improve economizer integration whenever an economizer is installed. While this requirement applied to the Small Hotel prototype that did not require changes in fan speed or staging, current economizer controller technology can easily meet the requirements, so there are no cost additions for this portion of the addenda.

4.2.1.4 Exhaust Air Energy Recovery

Location in 90.1-2013: Tables 6.5.6.1-1

Addendum: 90.1-10bt

Prototypes Affected: Large Office, Standalone Retail, and Primary School

Addendum 90.1-10bt modifies the ERV requirements in 90.1-2010. In 90.1-2013, ERVs are required for smaller outdoor air fractions. ERVs are applied to prototypes based on their supply airflow rate and on the outdoor air fraction.

ERVs were added to HVAC systems in the selected prototypes for both 90.1-2010 and 90.1-2013 according to the ventilation thresholds specified in the two Standards. None of the systems in the Small Office, Small Hotel, and Mid-rise Apartment prototypes met the ventilation thresholds in 90.1-2010 or 90.1-2013 that require ERVs. ERVs were added to selected systems in Large Office, Standalone Retail and Primary School prototypes.

The cost estimate was based on energy recovery wheel type systems with similar equipment added to built-up air handling units or unitary air-conditioning equipment (Witte and Henninger 2006).

Maintenance for an ERV is similar to that for a packaged DX unit and includes lubrication, checking dampers, adjusting belts, replacing filters, checking door seals and cleaning coils. PNNL estimated annual maintenance costs from two sources. *RS Means 2012* provided a rough estimate for a set of routine packaged DX maintenance activities that total about 2.5 man-hours. Cleaning of the energy recovery media is also included with maintenance, and can take about 15 minutes with frequency from every six months to 10 years depending on conditions, so the estimate included 15 minutes each year (AirXchange 2012).

4.2.1.5 Vestibule Heating Control

Location in 90.1-2013: Section 6.4.3.9

Addendum: 90.1-10ca

Prototype Affected: Standalone Retail

Addendum 90.1-10ca requires heated vestibules to have controls to limit the heating temperature setpoint to a maximum of 60°F, and the vestibule heating system is required to include automatic controls configured to shut off the heating system when the outdoor air temperature is above 45°F. Addendum 90.1-10ca only impacts the Standalone Retail prototype building, which has a designated thermal zone serving the purpose of a vestibule, heated using a unit heater. The unit heater is fitted with a gas heating coil and follows the same thermostat setpoint and schedule as the rest of the building.

For 90.1-2010, a programmable thermostat or thermostat with a timed lockout are adequate to meet the vestibule heating control requirements. For 90.1-2013, adding an outside air lockout will not add any additional complexity if there is a direct digital control (DDC) system in place. Otherwise, the required control can be obtained with an outside air lockout thermostat combined with electro-mechanical controls. A setpoint limit or locking cover is also required. The incremental cost for outside air lockout, the associated wiring and a thermostat locking cover were collected from *RS Means 2014*.

4.2.1.6 Heat Rejection Equipment Control

Location in 90.1-2013: Section 6.5.5

Addendum: 90.1-10af

Prototype Affected: Large Office

Addendum 90.1-10af requires the following:

1. The maximum allowable number of variable-speed fans must operate in parallel in multi-cell heat rejection equipment installation to minimize energy.
2. Open-circuit cooling towers that are configured with multiple- or variable-speed condenser water pumps shall be designed so that all open-circuit cooling tower cells operate in parallel. Pump flow shall be the larger of 50% of the design flow for each cell or the flow that is produced by the smallest pump at its minimum expected flow rate.

The fan control requirement applies to air cooled chillers and cooling towers that have fans 7.5 horsepower (hp) or larger. None of the cooling tower fans in the prototypes is larger than 7.5 hp.

The Large Office prototype uses open-circuit cooling towers. The model has two variable-speed cooling towers. Each tower has one dedicated condenser water pump and two cells. Because the two cooling towers are equally sized, the two condenser water pumps have the same design flow rate. For 90.1-2010, the number of operating cooling towers and condenser water pumps correspond to the number of operating chillers. When one chiller operates, one cooling tower operates and the corresponding condenser water pump also operates. When both chillers operate, both cooling towers and both condenser water pumps run.

For 90.1-2013, the controls are configured so that both cooling towers are running even when a single chiller is running so that all fans are operating. This strategy also results in condenser water flow being reduced by 50% for each cell in comparison with running a single tower. All of these changes could be made using controls that are included in the 90.1-2010 model, so no costs were added for addendum 90.1-10af.

4.2.1.7 Refrigerator and Freezer Equipment Requirements

Location in 90.1-2013: Section 6.4.5 and Tables 6.8.1-12 and 6.8.1-13

Addenda: 90.1-10g and 90.1-10ar

Prototype Affected: Primary School

DOE has defined maximum energy consumption requirements for selected commercial refrigerators and freezers. Additional requirements for commercial refrigeration equipment have also been defined and approved per 10 Code of Federal Regulations (CFR) part 431. These requirements went into effect on January 1, 2010. Addendum 90.1-10g adds these requirements to Standard 90.1. Affected equipment in the prototype models includes commercial reach-in refrigerators with solid doors and commercial reach-in freezers with solid doors that are modeled in the Primary School prototype as part of the kitchens.

Addendum 90.1-10g defines the energy use limits in kWh/day as a function of the volume (V) in ft^3 of the freezer or refrigerator. These limits are converted to input power and modeled as a plug load with a constant operation schedule in EnergyPlus. To develop inputs for the 90.1-2010 prototype models, the California Title 20 requirement (CEC 2008), effective March 1, 2003, was used to calculate the energy use limits without addendum 90.1-10g. Table 4.4 shows the energy use limits used to calculate the input power of commercial refrigerators and freezers for the 90.1-2010 and 90.1-2013 models.

Table 4.4. Summary of Energy Use Limits for Commercial Refrigerators and Freezers in Prototypes

Equipment	Energy Use Limits 90.1-2010 (kWh/day)	Energy Use Limits 90.1-2013 (kWh/day)
Reach-in refrigerators with solid doors	0.125V+4.22	0.10V + 2.04
Reach-in freezers with solid doors	0.398V+2.83	0.40V + 1.38

In the model, the Primary School prototype has two refrigerators, each with a volume of 48 ft^3 and two freezers, each with a volume of 24 ft^3. Costs were obtained for two-door refrigerators and single-door freezers with daily energy usage listed in Table 4.4. Costs from multiple manufacturers were collected from RS Means Green Building 2014 (RS Means 2014d) as well as from five refrigeration equipment websites. An average of the collected costs was used in the cost estimate.

Addendum 90.1-10ar expands the scope of Standard 90.1 to cover requirements for refrigeration equipment including walk-in coolers and freezers and refrigeration systems. The new requirements for walk-in coolers and freezers have been defined and legislated as the national manufacturing standard and described in federal regulations (10 CFR 431.306). The requirements for walk-ins include doors, insulation, evaporator fan motor, lighting, anti-sweat heater, condenser fan motor, and their controls. The requirements for refrigeration systems include fan-powered condenser controls and a minimum saturated condensing temperature setpoint.

The Primary School prototype is affected by the requirements of addendum 90.1-10ar because the model has a walk-in cooler and freezer in the kitchen. The modeled walk-in coolers and freezers are packaged and without remote compressors and condensers, so some of the more complex refrigeration system requirements of addendum 90.1-2010ar do not apply.

Navigant developed characteristics of baseline walk-in coolers and freezers while evaluating potential energy savings from this equipment (Goetzler et al. 2009). It was found that the baseline characteristics either meet or exceed most requirements in addendum 90.1-10ar except the evaporator fan motor and the lighting requirements. To capture these new requirements, the evaporator fan motors in baseline models are shaded pole motors (1/20 hp) for walk-in coolers and shaded pole motors (1/40 hp) for walk-in freezers with a motor efficiency of 20%. The motors are changed to electronically commutated (EC) motors in the advanced models with a motor efficiency of 70%. Costs for shaded pole and EC motors of the sizes specified were obtained from the Grainger catalog and used in the cost estimate (Grainger 2014). For 90.1-2010, the shaded pole motor costs were used, whereas the EC motor costs were used for 90.1-2013.

Addendum 90.1-ar added requirements for either a high-efficacy light source or occupancy sensor controls. Light sources in the model did not meet the minimum efficacy of 40 lumens per Watt, therefore occupancy sensor control was added to the 90.1-2013 walk-ins to capture the impact of this addendum. The impact of the lighting control requirement is modeled as a 10% reduction in the hourly lighting schedule in the advanced models. This simulates the energy-saving benefits from an occupancy sensor-based lighting control. Costs of low-temperature occupancy sensors were gathered from the Grainger catalog, and an average cost was used for the 90.1-2013 models (Grainger 2014). The labor cost to install the occupancy sensor was also included. For 90.1-2010, there are no costs associated with lighting in the walk-ins.

4.2.1.8 Fractional Horsepower Motors

Location in 90.1-2013:	Section 6.5.3.5
Addendum:	90.1-10aj
Prototype Affected:	Large Office, Primary School, Small Hotel, and Mid-rise Apartment

Addendum 90.1-10aj requires motors from 1/12 horsepower (hp) to under 1 hp to be EC motors or have a minimum efficiency of 70%. The intention is to replace standard shaded pole and permanent-split capacitor (PSC) motors having efficiencies in the range of 15% to 65% with more-efficient EC motors. In the prototypes evaluated, the requirement affects toilet exhaust fans, small kitchen exhaust fans, fan-coil unit fans and elevator fans. For 90.1-2010, costs were obtained from the Grainger catalog for shaded pole and PSC motors for 5 motor sizes (1/12 hp to 1.0 hp). For 90.1-2013, corresponding costs for EC motors were collected from the Grainger catalog (Grainger 2014). Based on the brake horsepower (bhp) for each fan in the prototype models, the appropriate cost was assigned for 90.1-2010 and for 90.1-2013.

4.2.1.9 Boiler Turndown Controls

Location in 90.1-2013:	Section 6.5.4.6
Addendum:	90.1-10am
Prototype Affected:	Large Office

Addendum 90.1-10am requires that boiler systems with design input of at least 1,000,000 Btu/h include a minimum turndown ratio. Only the Primary School and Large office prototypes include boilers, and those in the Primary School prototype do not meet the size threshold. Therefore, this change in requirement applies only to the Large Office prototype.

The baseline control type for the prototype is modeled as a two-stage capacity control (Halverson et al. 2014), and modulating control of boiler capacity is included for the advanced case. Several boiler suppliers were polled and an incremental cost of between $800 and $1000 was quoted for using a modulating burner instead of a two-stage burner on boilers below 4 million Btus/hr capacity. An adder of $1000 was applied to the advanced case accounting for a modulating burner upgrade to meet the turndown requirements of 90.1-10 am.

4.2.1.10 Humidifier Dispersion Tube Insulation and Pre-heat Coil Control

Location in 90.1-2013: Section 6.5.2.4

Addendum: 90.1-10as

Prototype Affected: Large Office

Addendum 90.1-2010 as requires a minimum of R-0.5 insulation on humidifier steam dispersion assemblies and requires preheat coils to stop operation during cooling or economizing. The impact of insulation was modeled by reducing the rise in supply air temperature due to the presence of the steam dispersion assembly in the advanced case compared to the baseline case. The preheat coil savings was modeled by turning off the preheat coil during cooling or economizing operation in the advanced case.

Steam dispersion tube assemblies can be insulated using PVDF (polyvinylidene fluoride) insulation. The cost increment between non-PVDF steam dispersion assemblies and steam dispersion assemblies with PVDF was collected. This requirement applies only to the Large Office. The humidification load (395 lbs/hr), airflow rate (10,000 cfm) and duct size (40 in. x 40 in.) were used to size the steam dispersion assembly. Costs were collected by polling humidifier manufacturer representatives. For preheat coil control, existing controls are sufficient to enable this measure to be implemented. Thus, the preheat control requirement does not result in added cost.

4.2.1.11 Fan Power Pressure Drop Adjustment Credit

Location in 90.1-2013: Table 6.5.3.1-2

Addendum: 90.1-10au

Prototypes Affected: Large Office and Primary School

Addendum 90.1-10au adds deductions to pressure drop credits used to calculate the allowable fan power for a system. The deductions apply to systems without a central heating or cooling device. Systems without a central cooling device are required to deduct 0.6 inches water column (in. w.c.) from the allowed fan pressure drop, and systems without a central heating device are required to deduct 0.3 in. w.c. from the allowed fan pressure drop. This affects VAV systems in the Primary School and Large Office prototypes.

In the simulation, a preheat coil is used in zones where the mixed air temperature will be less than 55°F at design outside air conditions. When units do not have preheat or central heating coils, the fan design static pressure is reduced by 0.3 inches to calculate the energy impact in the prototype models. Reduced static pressure could be accounted for by improving the fan or motor efficiency or by reducing the pressure drop through air system components such as ductwork, filters, diffusers, and other components. Reducing ductwork pressure drop through increased duct size is the option chosen here for simplicity and uniformity of application to different prototypes. For those units without preheat coils, the ductwork is upsized in the advanced model, resulting in more sheet metal and more labor. Based on an analysis of ductwork sizing for multiple sizes of round ductwork, about 15% of the ductwork needs to be upsized to the next standard size to provide a 0.3-inch w.c. reduction in total system static pressure, resulting in an overall ductwork cost increase of 2.75%. The cost adders were applied to the ductwork costs for units without preheat coils.

4.2.1.12 Cooling Tower Efficiency

Location in 90.1-2013: Table 6.8.1-7

Addendum: 90.1-10az

Prototype Affected: Large Office

Addendum 90.1-10az increases the minimum efficiency of open-circuit axial fan cooling towers from 38.2 to 40.2 gpm/hp at rated conditions. The addendum applies to the Large Office prototype because it uses water-cooled chillers. The energy impact of addendum 90.1-10az is captured by converting the efficiency (gpm/hp) to fan power based on the design flow rate and inputting the fan power into EnergyPlus.

For 90.1-2010, costs developed for the previous analysis were brought forward to 2014. For 90.1-2013, separate costs were collected from two local manufacturer representatives to reflect the increase in efficiency requirements from 38.2 gpm/hp to 40.2 gpm/hp.

4.2.1.13 Door Switches

Location in 90.1-2013: Section 6.5.10

Addendum: 90.1-10ba

Prototype Affected: Mid-rise Apartment and Small Hotel

Addendum 90.1-10ba requires that doors opening to the outside, which do not close automatically, to have switches that connect to the HVAC system with automatic controls configured to put the HVAC system into deep setback (55°F for heating and 90°F for cooling) 5 minutes after the door is opened. Operable doors, such as those that open to balconies in apartments and hotel guestrooms that are operated by the occupants for fresh air, are the types of doors targeted by the addendum. The Mid-rise Apartment and Small Hotel prototypes, the two prototypes that are likely to have balconies, are affected by this addendum.

The control requirements are very similar to typical occupancy sensor-controlled thermostats and the cost of a door switch (Kele 2014) was found to be quite similar to an occupancy sensor. For 90.1-2013, the added cost is based on the cost of an adaptive programmable thermostat with an occupancy sensor, based on the cost of the door switch being equivalent to an occupancy sensor. For 90.1-2010, a standard programmable thermostat is sufficient. An additional half an hour is required to wire the door switch. The number of doors required to have door switches is based on commercial building characteristic data as discussed in the determination report (Halverson et al. 2014). The number of doors with door switches in the advanced model is representative of the share of buildings with balcony or patio doors. In the Mid-rise Apartment prototype, four doors require door switches, and in the Small Hotel prototype, one door requires a door switch.

4.2.1.14 Air Conditioner and Heat Pump Efficiency

Location in 90.1-2013:	Table 6.8.1-1
Addendum:	90.1-10bi
Prototype Affected:	Small Office, Standalone Retail, Primary School, Small Hotel, Mid-rise Apartment

Addendum 90.1-10bi increases the efficiency values for unitary air conditioners and heat pumps under 65,000 Btu/h cooling capacity manufactured on or after January 1, 2015. Minimum efficiency values are provided for equipment with different cooling capacities and different manufacturing time periods.

Costs developed in the previous analysis were used for 90.1-2010. The prior costs were brought forward to 2014 using an inflation factor. For 90.1-2013, a high-efficiency cost-increase factor was applied, based on a cost comparison of standard units (SEER 13 has been the Federal standard for some time) from RS Means Mechanical 2014 to RS Means Green Building 2014, where the stated efficiency was 14 SEER, as required for 90.1-2013 (RS Means 2014a, 2014d).

4.2.1.15 Demand Controlled Ventilation

Location in 90.1-2013:	Section 6.4.3.8
Addendum:	90.1-10bs
Prototype Affected:	Primary School

Addendum 90.1-10bs reduces the threshold at which demand controlled ventilation (DCV) is required from >40 to >25 people per 1000 ft^2 and also lowers the minimum system outdoor air threshold from 1200 to 750 cfm. Spaces meeting all the DCV requirements and the lower design occupancy threshold were only identified in the Primary School prototype.

Classrooms in the Primary School prototype qualify for DCV under the requirements of 90.1-10bs. A preliminary simulation run was performed to determine if the systems require an ERV because DCV control is not required if an ERV is installed. Cost for DCV control is based on a zone level CO_2 sensor wired to the building automation system. The system-level airflow is reduced when the sensor detects lower CO_2, implying fewer occupants in the zone. Costs were obtained based on staff review of recent bid and quote information. For 90.1-2010 and 90.1-2013, DCV costs were added where required.

4.2.1.16 Optimum Start Controls

Location in 90.1-2013:	Sections 6.4.3.3.2 and 6.4.3.3.3
Addenda:	90.1-10cb and 90.1-10aa
Prototype Affected:	Large Office, Standalone Retail and Primary School

Addendum 90.1-10cb introduces several new setback control requirements: heating and cooling setback is required in all climate zones, heating setback is required to be at least 10°F below occupied heating setpoint, cooling setback is required to be at least 5°F above occupied cooling setpoint, and radiant heating systems are required to have a setback of at least 4°F below occupied heating setpoint. New optimum start control requirements include the following: removal of the 10,000 cfm threshold, requiring optimum start for only those systems with DDC and setback control requirements, and requiring the optimum start control algorithm to include outside air temperature as an input and include floor temperature as an input for radiant floor systems.

Another addendum, 90.1-10aa, introduced new requirements that clearly spelled out the situations where DDC is required. Only packaged single-zone systems in the Standalone Retail prototype required DDC due to the requirements of addendum 90.1-10aa; all other systems already require DDC to operate and have DDC in all models (90.1-2010 and 90.1-2013). For the Standalone Retail prototype, addendum 90.1-10aa requires DDC control of the units. It is standard construction practice for most new buildings to include DDC. Therefore, it may not be appropriate to include the entire front end cost of a DDC system for the optimum start addenda in the Standalone Retail prototype. Instead, the difference in cost due to unit controls is captured. For 90.1-2013, DDC zone controllers were used for each package unit to meet the control requirements. The cost for the zone controllers was obtained from *RS Means 2014*. For 90.1-2010, programmable thermostats are adequate to meet the control requirements in the Standalone Retail prototype.

While these addenda also apply to the Large Office and Primary School prototypes, these buildings will likely have DDC based on the complexity of systems installed, so the cost of changing the optimum start controls is a simple change in programming that will be a standard module with no additional cost once the standard is adopted, as there are no new sensors required.

4.2.1.17 Chiller Efficiency

Location in 90.1-2013: Table 6.8.1-3

Addendum: 90.1-10ch

Prototype Affected: Large Office

Addendum 90.1-10ch changes the minimum efficiency requirements for air- and water-cooled chillers. This addendum involves both full-load and part-load efficiency changes. Due to the lack of reliable performance curves used to model part-load efficiency, only the full-load efficiency change impact is captured. The Large Office is the only prototype affected by this addendum.

Costs for a range of sizes for chillers that meet the new efficiency requirements were collected. Sources include local manufacturer representatives, PNNL's cost consultant for commercial components, online catalogs, and correspondence with SSPC 90.1 committee members. Costs from at least two chiller manufacturers were compiled and the average incremental cost was used. For 90.1-2010, the costs from the previous analyses were brought forward to 2014, and then incremental costs for the higher efficiency chiller were added to arrive at 90.1-2013 costs.

4.2.1.18 Chiller and Boiler Fluid Flow Isolation Controls

Location in 90.1-2013: Section 6.5.4.2

Addendum: 90.1-10dv

Prototype Affected: Large Office

Addendum 90.1-10dv requires that when multiple chiller or boilers are used, fluid flow through the chillers and boilers that are not operating must be automatically shut off. It also requires that when constant-speed pumps are used to serve multiple chillers or boilers, the number of pumps shall be equal to the number of chillers or boilers, and the pumps will be cycled on and off with the chiller or boiler they serve.

The Large Office prototype is modeled with two chillers. A single constant-speed pump serves the two chillers. To model the requirements of addendum 90.1-10dv, two constant-speed pumps (one for each chiller) are used in the advanced models. The pumps cycle on and off with the operation of the chiller they are serving, thus meeting both the requirements of addendum 90.1-10dv. The added cost is the differential between one large pump in the base case and two smaller pumps in the advanced case. Costs are sourced from *RS Means 2014* pump assemblies. The costing method is similar to the base capacity differential cost analysis, except that a single large pump is used for 90.1-2010 and two smaller pumps for 90.1-2013, with the required sizes extracted from the EnergyPlus models.

4.2.2 Lighting

90.1-2013 incorporates a number of addenda that reduce lighting energy usage. Basic LPD requirements were changed for interior lighting, and more coverage was provided for occupancy sensor controls including the introduction of an automatic partial off control. The daylighting control requirements that were first introduced in 90.1-2010 have been strengthened further. There were no changes to the exterior lighting requirements that impacted the prototype buildings.

4.2.2.1 Interior LPD Allowance

Location in 90.1-2013: Section 9.2.2.3 and Table 9.6.1 and Table 9.5.1

Addenda: 90.1-10bh, co, cr, dj, dl

Prototypes Affected: All six

Standard 90.1 Chapter 9 includes requirements for maximum LPD in watts per square foot (W/ft^2). Two prescriptive methods are allowed and tables of maximum LPD values are provided. The primary compliance path uses Table 9.5.1 which includes LPDs that are applied to an entire building area (Building Area Method). An alternative path uses Table 9.6.1, which allows assignment of maximum LPDs to specific space types (Space-by-Space Method). Various addenda to 90.1-2010 changed the LPD values that appear in 90.1-2013. Some LPDs increased while the majority decreased. The determination quantitative analysis report (Halverson et al. 2014) describes the impact of each addendum in greater detail.

Part of the basis for the interior lighting power cost development was a set of lighting models that was used by the 90.1 LSC to develop the maximum allowed LPD values for each space. The models incorporate interior lighting design elements including:

- Illuminating Engineering Society (IES) recommended light levels in footcandles (fc)
- Light source efficacy, lumens/watt (lm/W)
- Lamp, fixture, and room surface light loss factors
- Fixture coefficient of utilization (CU) related to expected room geometry

With few exceptions, the changes in LPD for 90.1-2013 are the result of changes to IES recommended light levels. A few changes in existing technology efficacy and choice of technologies also result in LPD changes, but the main driver for the majority of changes is the recommended light levels from IES. Assuming the same fixture and lamp type, lower recommended light levels would result in fewer fixtures, and higher light levels would result in more fixtures. Feedback from the 90.1 LSC suggested that there were no significant technology improvements (e.g., light emitting diodes or advances in fluorescent technology) in 90.1-2013, and so, the changes in LPD are interpreted as simply a decrease in the number of fixtures when 90.1-2013 requires a lower LPD. Thus, the lowering of LPDs, which is often a result of a move towards more efficient and more expensive fixtures, in this case actually results in a decrease in cost. When the LPD is increased as a result in an increase in recommended IES lighting levels, no cost increase is included, as 90.1-2013 does not require the building designer to increase the lighting to this level, the standard just allows the increase. Areas where LPDs increased due to IES changed recommendations include food preparation and the library in the Primary School prototype and the guest room in the Small Hotel prototype.

In developing the LPD limits, 90.1 LSC design experts determined an appropriate mix of fixture types and lighting sources and the portion of the recommended light level(s) provided by each combination. The mix of lighting technology for each space type was defined for both 90.1-2010 and 90.1-2013. Finally, the combined lamp efficacy, loss factors, and (CU) values for the various fixtures and sources were used to calculate the wattage needed to provide the recommended level of lighting.

Each space type or building area type was assigned up to four lighting systems, each of which provided an assigned percentage of the overall total illumination for that space. These percentages determined the quantity per square foot of each fixture and luminaire type and the respective lighting power in watts.

Material and labor costs were estimated for each fixture type and lamp type. These costs were applied to the lighting design information to calculate a cost/ft^2 for each space type or building area type. In the few cases where the LSC incorporated a significant shift in lighting design philosophy from 2010 to 2013 resulting in a change to lighting technology unrelated to a change in LPD, one of the designs was selected and adjustments were made in the quantity of fixtures installed while maintaining similar fixture types

Fixture (including ballast and lamp) costs were determined using Grainger's online catalog (Grainger 2014). Other online catalogs were used for fixture/lamp costs when Grainger did not carry the product (Amazon 2014; BuyLightFixtures 2014; Globalindustrial 2014; Goodmart 2014; Keystonedepot 2014; Westsidewholesale 2014). *RS Means 2014* was used for labor costs and for a few lighting equipment items not available in the other sources (RS Means 2014b). Besides cost, lamp life and complete connected luminaire wattage per fixture were recorded. Fixture cost per Watt ($/W) was calculated by dividing the total cost by the fixture wattage.

The formula used to calculate the cost per fixture types is:

Cost per ft^2 per fixture type = (total illumination, lumens × percentage of lumens provided by fixture type × fixture $/W) / efficacy of the lighting system in lm/W.

The total cost per space type, $/$ft^2$, was determined by combining the costs per fixture per ft^2 in proportion to the percentage of total illumination provided by each fixture described above. The cost per space type, $/$ft^2$, was multiplied by the area of each space type represented in each prototype to determine the total interior lighting power cost for each prototype.

Replacement life for each lamp and ballast was determined by dividing the lamp or ballast life by the annual full load equivalent hours from the corresponding energy model schedule for the assigned space type (modeling schedules were described in Thornton et al. (2011) for 90.1-2010 models and in Halverson et al. (2014) for 90.1-2013 models). Replacement costs were separated into the different replacement lives, for example, a space type may have included lamp replacement costs every three years and every five years for two different types of lamps.

4.2.2.2 Automatic Control of Interior Lighting

Location in 90.1-2013:	Sections 9.4.1.1
Addenda:	90.1-10by and bc
Prototypes Affected:	all six prototypes

Addendum 90.1-10by introduced a number of changes to Standard 90.1, including a complete overhaul of the way control requirements are expressed in Chapter 9. It introduced a new type of control – automatic partial off – that is required to automatically turn off half the lights in the space. It also added a number of new spaces to the list required to be controlled automatically. Addendum 90.1-10bc expanded the automatic control of bathroom lighting in hotel guestrooms to the entire guestroom, while also requiring automatic control of switched receptacles in the guestroom. The affected space types are as follows:

1. Partial automatic turn off: corridor lobby (other than hotels and elevator lobbies), stairwell, and library stacks.
2. Full automatic turn off: stairwell, hotel guestroom.

Manual on/auto off occupancy sensors are required in the library stacks. For other spaces, the conventional auto on/auto off sensors were used.

The cost estimate began by determining how many and what type of sensors are required in the affected space types. Because spaces in the models vary in size and there are many spaces, developing a specific design for each modeled space was not practical. Instead, representative spaces and occupancy control types (such as for classrooms) were developed. For each representative space, the type of sensor was determined. Each type of sensor was estimated to serve up to a defined area. The area of the representative space was based either on the coverage area of the sensor selected for the space type or the area of the space type in the prototype. Table 4.5 shows the types of occupancy sensors considered.

Cost estimates for each type of occupancy sensor including equipment costs were found in the Grainger catalog online (Grainger 2014), and labor costs in the *RS Means 2014* (RS Means 2014b).

Table 4.5. Occupancy Sensor Control Types

Control Type	Sensor Equipment Type
Auto on/off	Wall mount infrared
Auto on/off	Wall mount ultrasonic
Auto on/off	Wall mount infrared and ultrasonic
Auto on/off	Ceiling mount infrared
Auto on/off	Ceiling mount ultrasonic
Auto on/off	Ceiling mount infrared and ultrasonic
Auto on/off	Ceiling mount infrared and ultrasonic
Manual on/off	Wall mount infrared
Manual on/off	Wall mount infrared
Manual on/off	Wall mount ultrasonic
Manual on/off	Wall mount infrared and ultrasonic
Manual on/off	Ceiling mount infrared
Manual on/off	Ceiling mount infrared

Prototype zones are assigned a mix of space types. For each space type, the area of the space type was divided by the representative space area. This resulted in the number of controlled spaces. Cost per controlled space was multiplied by the number of controlled spaces. Costs were applied to 90.1-2013 prototypes for space types that are required to include automatic controls.

For receptacle controls wiring cost was added for two switched receptacles per guestroom. Receptacles are switched using the same occupancy sensor used for lighting control. An auxiliary power pack may not be needed because both the lighting load and the switched receptacle load are small enough to be handled directly by the occupancy sensor and controller.

Functional testing was introduced in 90.1-2010 to verify that occupancy sensors operate effectively and within the time limits specified by the Standard. These costs were added for the new spaces requiring automatic control. Commissioning costs were estimated based on review of three documents. Energy Efficiency Factsheet (WSU 2005) estimates that building commissioning is between 2 to 4% of the construction cost of the system. Fimek states that lighting control start-up and commissioning is 6 to 7%, but it does not specify to what the percentage is applied (Fimek 2011). This is interpreted to be 7% of the cost of lighting controls including labor. Peterson provides a variety of estimates (Peterson and Haasl 1994):

- Northeast utility uses \$0.20 to 0.67/ft^2
- Northwest utility uses 6% of total measure cost
- Commissioning agents use 1 to 4% of total measure cost or \$0.01 to 0.10/ft^2

Based on these documents, the range of commissioning costs for lighting controls is 1 to 7% of the total lighting controls costs including labor, with an average of 4%. Applying the 4% value to the lighting controls costs for the prototypes resulted in an added cost of \$0.01/ft^2. This falls within the range of potential costs identified for commissioning in the review, and 4% of the total controls costs was added to provide for commissioning of the controls.

4.2.2.3 Daylighting Controls

Location in 90.1-2013: Section 9.4.1.1 and Table 9.6.1

Addendum: 90.1-10ay

Prototypes Affected: Large Office, Primary School, Small Hotel, and Small Office

Addendum 90.1-10ay expanded the daylighting control requirements introduced in 90.1-2010 by requiring independent control of lights in the secondary sidelighted area, as well as requiring the controls to turn the general lighting completely off when sufficient daylight is available. The threshold for requiring controls was also changed from an area threshold of 250 ft^2 to a controlled power threshold of 150 W. This change results in some smaller private offices being included for daylight control in the 2013 models. These changes appear in Section 9.4.1.1 and Table 9.6.1 in 90.1-2013.

Table 4.6 shows the total sidelighted area controlled in each prototype, as well as the number of fixtures controlled, number of sensors required and the number of power packs required for secondary sidelighted areas. In the office prototypes, the increase in controlled area comes from the addition of small private offices and the secondary sidelighted area. In the Small Hotel prototype, additional spaces are required to be controlled due to the lower threshold in 90.1-2013. In the Primary School prototype, the increase in controlled area is due the control of the secondary sidelighted area. There were new control requirements for toplighting in 90.1-2013 but they are not applicable to the analyzed prototypes.

Table 4.6. Application of Daylighting Controls by Prototype and Space

Prototype/ Type of Control	Spaces affected	Daylighted area (ft^2)	Quantity of fixtures	Quantity of sensors and controlled light banks	Quantity of power packs for secondary sidelighted area
Sidelighting Controls					
Small Office	Perimeter open and enclosed offices and conference rooms	1,054	25	4	4
Large Office	Perimeter open and enclosed offices and conference rooms	69,793	1,685	40	40
Primary School	Multiple classrooms, lobby, offices gym, cafeteria and library	28,679	722	73	73
Small Hotel	Lounge, meeting room, office, laundry room	5,076	65	4	4

Costs for material, labor and commissioning were developed by PNNL from cost data produced by a daylighting consultant. The cost estimate was based on a switchable wired photosensor control system.

In the Small Office and Large Office prototypes, one photosensor was included per perimeter zone (or per orientation) and per floor. In the Primary School and Small Hotel prototypes, one photosensor is included per space. The same photosensor is used to control both the primary and secondary sidelighted areas, using a controller that can switch the two spaces independently. One power pack is required per primary sidelighted area and one per secondary sidelighted area.

Costs are also incurred for connecting control wiring to each fixture. Five minutes installation per fixture was estimated. The number of fixtures in the daylighted areas was determined. The starting point for these calculations was the fixtures per ft^2 values developed for the 90.1 analysis as described in Section 4.2.2.1 of this report. The daylighted areas were multiplied by the quantity of fixtures per ft^2 as determined for the interior lighting power allowance cost calculations.

Replacement and commissioning costs are included for both 90.1-2010 and 90.1-2013. Functional testing costs were estimated based on information provided by the daylighting consultant.

- Replacement costs involve only the cost of the photosensor and power pack; the lighting fixture types were based on fixture selection without daylighting.
- For new construction, ten minutes of commissioning were estimated for each fixture. The control wiring was not replaced during the study period of the 90.1 cost-effectiveness study.
- Functional testing, including calibration of photosensors, is a small cost that is included with two hours of installation per photosensor.

4.2.3 Building Envelope and Power

This section includes the cost items from the Standard 90.1 envelope and power chapters. Addendum 90.1-2010bb introduced extensive changes to the opaque insulation and fenestration requirements. These changes affect all six prototypes. While there are addenda to 90.1-2010 that affect the envelope requirements (e.g., addendum 90.1-2010bw fenestration orientation), there are not any, other than addendum 90.1-2010bb, that affect the six prototype buildings selected for this analysis.

90.1-2013 Chapter 8, Power, applies to all building power distribution systems. Addendum 90.1-2007bs introduces automatic shut off of receptacles in certain spaces. Addendum 90.1-2010bf expands this requirement to include more spaces as well as a shortened time to shut off.

4.2.3.1 Opaque Insulation and Fenestration

Location in 90.1-2013:	Section 5.5 (multiple locations)
Addendum:	90.1-10bb
Prototypes Affected:	All selected prototypes

Addendum 90.1-10bb introduced more stringent requirements for opaque insulation and fenestration U-factor in all climate zones for most of the assemblies prescribed in Standard 90.1. It also introduced a new requirement for the visible transmittance of vertical fenestration. The impact of addendum 90.1-10bb on the prototype models is described in the determination quantitative analysis report (Halverson et al. 2014). To determine the incremental cost of the changes introduced to the prototype models by addendum 90.1-10bb, cost estimates compiled by a cost estimating consultant were used.

The Envelope Subcommittee of ASHRAE SSPC 90.1 compiled a list of assemblies for which they desired cost estimates. These assemblies included those required by addendum 90.1-10bb along with more and less stringent assemblies. PNNL collected costs for these assemblies by contracting with a consultant who specialize in construction cost estimation. The cost estimates provided by the consultant were sufficient to calculate all the incremental costs incurred from the requirements of addendum 90.1-10bb. In the estimates, material costs are specified per square foot of the component area. Labor costs and total costs including overhead and profit are also provided. For opaque assemblies, when additional insulation is required, the cost of the entire assembly is calculated. Assemblies do not change between 90.1-2010 and 90.1-2013; only the amount of insulation required (e.g., R-13 batt to R-19 batt) is changed to meet the new requirement. The cost of the above-grade and below-grade walls, roofs, and slab-on-grade floors is calculated in this way. The selected prototypes do not include exposed floors.

It is more difficult to develop cost estimates for fenestration improvements than for opaque envelope improvements, mainly because the requirements can be met by a number of different fenestration assemblies. For example, a lower U-factor for metal-frame fixed windows could be achieved through improved glazing, an improved gas layer, or an improved frame. The way a lower U-factor is met has significant impact on the cost. The cost consultant’s estimates have costs for a limited number of glazing and gas layer combinations (a glazing unit) and costs for a few frame types. Costs are also provided for a few combinations of frame types (e.g., metal fixed without thermal break and metal fixed with thermal break) and a single type of glazing (e.g., low-e, 1 in. double glazing with ½ in. air space). The cost estimates from the consultant were evaluated as a group to contrast the incremental cost of going from one frame type to another while keeping the same glazing unit. This incremental frame cost was used to develop the cost of fenestration assemblies that were not covered in the consultant’s estimates. The cost of a new fenestration assembly was calculated as follows:

1. The cost of the glazing unit was subtracted from each of the complete assembly costs. The remaining cost would be that of a frame without a glazing unit.
2. The cost of individual glazing units was added to the frame cost in step 1 to determine the cost of a new fenestration assembly.

To model fenestration requirements in the prototypes, the U-factor for the four frame types in each climate zone was weighted by the respective fraction typically found in each of the prototype buildings (Thornton et al. 2011). This produced a weighted fenestration U-factor used for modeling. The solar heat gain coefficient (SHGC) prescribed by Standard 90.1 is the same for all frame types. Costs were developed for each frame type, prototype and Standard edition, and then combined per the weighting factors. The following steps describe the process used to determine the fenestration cost for the 90.1-2010 and 90.1-2013 models.

1. The U-factor, SHGC and VT (90.1-2013 only) for each prototype and Standard edition were determined.
2. Data from Tables 4 and 10 in Chapter 15 (Fenestration) in the ASHRAE Handbook of Fundamentals 2013 (ASHRAE 2013) were used to determine the fenestration assembly that just met the Standard requirements. It was found that all the U-factor requirements could be met using insulated double glazing units.

3. Using the fenestration glazing and frame assembly determined in step 2, the cost was determined using the consultant estimates or the new fenestration assembly costs developed from the consultant estimates as previously described.

Using the calculated cost/ft^2 of individual opaque and fenestration assemblies for each prototype in every climate zone, the total cost was then calculated by multiplying the cost/ft^2 by the area of each component (walls, roofs, windows, etc.) for the prototype.

4.2.3.2 Plug Receptacle Control

Location in 90.1-2013:	Section 8.4.2
Addendum:	90.1-10bf
Prototypes Affected:	Small Office, Large Office, Standalone Retail and Primary School

90.1-2010 Section 8.4.2 introduced requirements for automatic shut off of half the 15 and 20 amp, 120 volt receptacles located in certain spaces. Addendum 90.1-10bf expands those requirements by adding conference rooms, print/copy rooms, break rooms, and classrooms other than computer classrooms to the list of spaces requiring control and by reducing the occupancy sensor shut-off time to 20 minutes from 30 minutes.

The cost estimate was based on occupancy sensor control of the affected receptacles. Receptacle loads in the space types that had new control requirements specified in addendum 90.1-10bf were included. The areas where 90.1-2010 previously required control were not included in the cost estimate. The number of controlled receptacles was determined based on 33 Watts per receptacle serving 50% of the power used by equipment in the affected areas. Each control relay serves 8 controlled receptacles with an associated 8 uncontrolled receptacles in the same area.

In the space types that had new control requirements specified in addendum 90.1-10bf, costs for 90.1-2010 included wiring and installation of conventional receptacles without controls. Costs for 90.1-2013 include additional wiring for controlled receptacles, power pack controllers and occupancy sensors. Smaller zones already include occupancy sensor control for lighting, so in smaller zones the upgrade cost was for a bare contact in the occupancy sensor instead of a separate occupancy sensor and reduced wiring, resulting in a cost that was half of the larger area control configurations.

4.3 Cost Estimate Results

The cost estimates result in incremental costs for new construction and replacement material, labor, construction equipment plus overhead and profit, as well as maintenance and commissioning. Appendix B includes incremental cost summaries for first cost, maintenance cost, replacement costs for years 1 to 29, and residual value of items with useful lives extending beyond the 30-year analysis period. Residual values are discussed in Section 5.1.l of this report, and are used in the Life-Cycle Cost Analysis in Section 5.1.1.

The cost estimate spreadsheet (PNNL 2014) includes a worksheet with details of the summaries in Appendix B, and a similar worksheet extending the analysis period to 40 years. The cost in a given year in these tables is a negative value if there was a replacement cost for 90.1-2010 that was greater than the replacement cost for 90.1-2013. The useful lives of corresponding items such as lamps and ballasts may not be the same for the 90.1-2010 and 90.1-2013 cases, so replacement cost values can be positive or negative throughout the 30-year analysis period.

Table 4.7 includes total incremental first costs for each prototype and climate combination in units of total cost and cost per ft^2. Table 4.8 includes estimated total building costs per ft^2 from *RS Means 2014* for each prototype, and a rough indicator of the percentage increase due to the incremental costs, (based on the RS Means costs being representative of buildings that meet 90.1-2010). As described in Section 4.1 these costs were not adjusted for climate location. In some cases, there was an incremental reduction in first cost in moving to 90.1-2013. This is due to reductions in HVAC equipment capacity, as well as for the interior lighting costs in some cases.

Table 4.7. Incremental Costs

Prototype	Value	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
Small Office	First Cost	-$2,601	-$906	-$1,358	$12,472	$9,072
	$/ft^2	-$0.47	-$0.16	-$0.25	$2.27	$1.65
Large Office	First Cost	$352,647	-$1,065,759	-$1,476,190	$98,124	-$1,014,770
	$/ft^2	$0.71	-$2.14	-$2.96	$0.20	-$2.04
Standalone Retail	First Cost	-$36,190	-$35,180	-$34,522	-$9,985	-$9,712
	$/ft^2	-$1.47	-$1.42	-$1.40	-$0.40	-$0.39
Primary School	First Cost	$88,857	$119,646	$9,620	$167,916	$179,872
	$/ft^2	$1.20	$1.62	$0.13	$2.27	$2.43
Small Hotel	First Cost	$20,483	$18,527	$18,675	$32,441	$39,120
	$/ft^2	$0.47	$0.43	$0.43	$0.75	$0.91
Mid-rise Apartment	First Cost	$5,711	$23,214	$23,358	$12,891	$19,577
	$/ft2	$0.17	$0.69	$0.69	$0.38	$0.58

Table 4.8. Comparison of Total Building Cost and Incremental Cost (per ft^2 and percentage)

Prototype	Building First Cost $/ft^2	Incremental Cost for 90.1-2013 2A Houston $/ft^2	3A Memphis $/ft^2	3B El Paso $/ft^2	4A Baltimore $/ft^2	5A Chicago $/ft^2
Small Office	$132	-$0.47	-$0.16	-$0.25	$2.27	$1.65
		-0.36%	-0.12%	-0.19%	1.72%	1.25%
Large Office	$166	$0.71	-$2.14	-$2.96	$0.20	-$2.04
		0.43%	-1.29%	-1.78%	0.12%	-1.23%
Standalone Retail	$91	($1.47)	($1.42)	($1.40)	($0.40)	($0.39)
		-1.61%	-1.57%	-1.54%	-0.44%	-0.43%
Primary School	$138	$1.20	$1.62	$0.13	$2.27	$2.43
		0.87%	1.17%	0.09%	1.64%	1.76%
Small Hotel	$111	$0.47	$0.43	$0.43	$0.75	$0.91
		0.43%	0.39%	0.39%	0.68%	0.82%
Mid-rise Apartment	$117	$0.17	$0.69	$0.69	$0.38	$0.58
		0.14%	0.59%	0.59%	0.33%	0.50%

5.0 Cost-effectiveness Analysis

The purpose of this analysis is to determine the overall cost-effectiveness of Standard 90.1-2013 compared to the 90.1-2010 edition. Cost-effectiveness was analyzed using the incremental cost information presented in Chapter 4 and the energy cost information presented in this Chapter. Three economic metrics are presented:

- Net present value life-cycle cost savings
- The SSPC 90.1 scalar ratio
- Simple payback

Annual energy costs, a necessary part of the cost-effectiveness analysis, are presented in Section 5.2, with additional detail provided in Appendix C.

5.1 Cost-effectiveness Analysis Methodology

The methodology for cost-effectiveness assessments has been established[1] for analysis of prior editions of Standard 90.1 (Hart and Liu 2015). This report presents a cost-effectiveness assessment using an LCCA and the SSPC 90.1 Scalar Method for the combined changes in Standard 90.1-2010 to 2013 for each of the 30 combinations of prototype and climate evaluated. The commonly used metric of simple payback is also included.

5.1.1 Life-Cycle Cost Analysis

The LCCA perspective compared the present value of incremental costs, replacement costs, maintenance and energy savings for each prototype building and climate location. The degree of borrowing and the impact of taxes vary considerably for different building projects, creating many possible cost scenarios. These varying costs were not included in the LCCA, but were included with the 90.1 Scalar Method in Section 5.1.3.

The LCCA approach is based on the LCCA method used by the Federal Energy Management Program (FEMP), a method required for federal projects and used by other organizations in both the public and private sectors (NIST 1995). The LCCA method consists of identifying costs (and revenues, if any) and the year in which they occur, and determining their value in present dollars (known as the net present value). This method uses fundamental engineering economics relationships about the time value of money. For example the value of money in hand today is normally worth more than money tomorrow, which is why we pay interest on a loan, and earn interest on savings. Future costs were discounted to the present based on a discount rate. The discount rate may reflect what interest rate can be earned on other conventional investments with similar risk, or in some cases, the interest rate at which money can be borrowed for projects with the same level of risk.

The following calculation method can be used to account for the present value of costs or revenues:

[1] See methodology at: http://www.energycodes.gov/development/commercial/methodology.

$$\text{Present Value} = \text{Future Value} / (1+ i)^n$$

"i" is the discount rate (or interest rate in some analyses)

"n" is the number of years in the future the cost occurs

The present value of any cost that occurs at the beginning of year one of an analysis period is equal to that initial cost. For this analysis, initial construction costs occur at the beginning of year one, and all subsequent costs occur at the end of the future year identified.

The LCCA is a present value life-cycle cost analysis based on the Federal Energy Management Program (FEMP) LCCA method (NIST 1995). The present value of the incremental costs for new construction, replacement, maintenance, and energy of the 2013 edition of Standard 90.1 are analyzed and compared to similar results for the 2010 edition. If the present value cost of the 2013 edition is less than the present value cost of the 2010 edition there is positive net present value savings and Standard 90.1-2013 is cost-effective.

The LCCA depends on the number of years into the future that costs and revenues are considered, known as the *study period*. The FEMP method uses 25 years; this analysis used 30 years. This is the same study period used for the cost-effectiveness analysis of the residential energy code, conducted by DOE and PNNL (DOE 2012) and is the same period used in the previous cost-effectiveness comparison between 90.1-2007 and 90.1-2010 (Thornton et al. 2013). The 30-year study period is also widely used for LCCA in government and industry. The study period is also a balance between capturing the impact of future replacement costs, inflation, and energy escalation; with the increasing uncertainty of these costs the further into the future they are considered.

Several factors go into choosing the length of the study period and the residual value of equipment beyond the period of analysis. Sometimes the useful life of equipment or materials extends beyond the study period. In this case, the longest useful life defined is 40 years for all envelope cost items, such as wall assemblies, as recommended by the 90.1 SSPC Envelope Subcommittee. Forty years is longer than the typical 25- or 30-year study period for LCCA. A residual value of the unused life of a cost item is calculated at the last year of the study period for components with longer lives than the study period, or for items whose replacement life does not fit neatly into the study period, (e.g., a chiller with a 23-year useful life). The residual value is not a salvage value, but rather a measure of the available additional years of service not yet used. The FEMP LCCA method includes a simplified approach for determining the residual value. The residual value is the proportion of the initial cost equal to the remaining years of service divided by the initial cost. For example, the residual value of a wall assembly in year 30 is (40-30)/40 or 25% of the initial cost. The present value of the residual values applied in year 30 is included in the total present value.

The LCCA requires assumptions about what the value of money today is relative to money in the future, and about how values of the cost items will change over time, such as the cost of energy and HVAC equipment. These values are determined by the analyst depending on the purpose of the analysis. In the case of the FEMP LCCA method, the National Institute of Standards and Technology (NIST) periodically publishes an update of economic factors. The values published by NIST in June 2013 (Rushing et al. 2013) were used in this analysis.[1]

The DOE nominal discount rate is based on long-term Treasury bond rates averaged over the 12 months prior to publication of the NIST report. The nominal rate is converted to a real rate to correspond with the constant-dollar analysis approach for this analysis. The method for calculating the real discount rate from the nominal discount rate uses the projected rate of general inflation published in the most recent *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the NIST 2013 annual supplement without citation; Rushing et al. 2013). The mandated procedure would result in a discount rate for 2013 lower than the 3.0% floor prescribed in federal regulations (10 CFR 436). Thus the 3.0% floor is used as the real discount rate for FEMP analyses in 2011. The implied long-term average rate of inflation was calculated as -0.5 % (Rushing et al. 2013). Table 5.1 summarizes the analysis assumptions used.

Table 5.1. Life Cycle Cost Analysis Parameters

Economic Parameter	Commercial State Cost-Effectiveness Scenario 1 without Loans or Taxes	
	Value	Source
Nominal Discount Rate[1 4]	2.5%	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2013*, NIST annual update – (Rushing et al. 2013).
Real Discount Rate[2 4]	3.0%	
Inflation Rate[3 4]	-0.5%	
Electricity and Gas Price	$0.1032/kWh, $0.99/therm	SSPC-90.1 for 90.1-2013 scalar
Energy Price Escalation	Uniform present value factors	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2013*, NIST annual update – (Rushing et al. 2013).
	Electricity 20.37 Natural Gas 24.32	The NIST uniform present value factors are multiplied by the first year annual energy cost to determine the present value of 30 years of energy costs and are based on a series of different annual real escalation rates for 30 years.

[1] Nominal discount rate is like a quoted interest rate and takes into account expectations about the impact of inflation on future values. Higher nominal rates imply higher expectations of inflation.
[2] Real discount rate excludes inflation so that future amounts can be defined in today's dollars in the calculations. This is not a quoted interest rate. If inflation is zero, real and nominal discount rates are the same. Inflation is captured in the process of using constant dollar costs and the modified discount rate.
[3] General inflation is the background level of price increases for all costs other than energy. This is indirectly applied to replacement and maintenance costs through the real discount rate.
[4] Note that only the real discount rate is needed for the Scenario 1 LCCA calculation. The implied nominal discount rate and inflation rate are shown for comparison to other methods.

[1] The 2013 annual supplement was used, because at the time of analysis in mid-October 2014, the 2014 supplement had not yet been published.

5.1.2 Simple Payback

Simple payback is a more basic and common metric often used to access the reasonableness of an energy efficiency investment. It is based on the number of years required for the sum of the annual return on an investment to equal the original investment. In this case, simple payback is the total incremental first cost (described in Chapter 4) divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. This method does not take into account any costs or savings after the year in which payback is reached, does not consider the time value of money, and does not take into account any replacement costs, even those that occur prior to the year simple payback is reached. The method also does not have a defined threshold for determining whether an alternative's payback is cost-effective. Decision makers generally set their own threshold for a maximum allowed payback. The simple payback perspective is reported for information purposes only in this analysis, not as a basis for concluding that 90.1-2013 is cost-effective.

5.1.3 SSPC 90.1 Scalar Method

The SSPC 90.1 does not consider cost-effectiveness when evaluating the entire set of changes for an update to the whole Standard 90.1. However, cost-effectiveness is often considered when evaluating a specific addendum to Standard 90.1. The Scalar Method was developed by SSPC 90.1 to evaluate the cost-effectiveness of proposed changes (McBride 1995). The Scalar Method is an alternative life-cycle cost approach for individual energy efficiency changes with a defined useful life, taking into account first costs, annual energy cost savings, annual maintenance, taxes, inflation, energy escalation, and financing impacts. The Scalar Method allows a discounted payback threshold (scalar ratio limit) to be calculated based on the measure life. As this method is designed to be used with a single measure with one value for useful life, it does not account for replacement costs. A measure is considered cost-effective if the simple payback (scalar ratio) is less than the scalar limit.

Table 5.2 shows the economic parameters used for the 90.1-2013 analysis for this study. These parameters were adopted by the SSPC 90.1.

Table 5.2. Scalar Ratio Method Economic Parameters and Scalar Ratio Limit

Input Economic Variables – Linked	Heating	Cooling
Economic Life - Years	40	40
Down Payment - $	0.00	0.00
Energy Escalation Rate - %*	3.76	3.76
Nominal Discount Rate - %	7.0	7.0
Loan Interest Rate - %	6.25	6.25
Federal Tax Rate - %	34.0	34.0
State Tax Rate - %	6.5	6.5
Heating – Natural Gas Price, $/therm	0.990	
Cooling - Electricity Price $/kWh		0.1032
Scalar Ratio Limit	**21.85**	**21.85**

* The energy escalation rate used in the scalar calculation for 90.1-2013 includes inflation, so it is a nominal rather than a real escalation rate.

PNNL extended the Scalar Method to allow for the evaluation of multiple measures with different useful lives. This extension is necessary to evaluate a complete code edition, while the 90.1 scalar method was developed to evaluate single measures with individual lives. This extended method takes into account the replacement of different components in the total package of 90.1-2013 changes, allowing the net present value of the replacement costs to be calculated over 40 years. The SSPC 90.1 Envelope Subcommittee uses a 40-year replacement life for envelope components and all other cost component useful lives in the cost estimate are less than that. For example, an item with a 20-year life would be replaced once during the study period. The residual value of any items with useful lives that do not fit evenly within the 40-year period is calculated using the method described in Section 5.1.1. Using this approach, the simple payback is calculated as the sum of the first costs and present value of the replacement costs, divided by the difference of the energy cost savings and incremental maintenance cost. The result is compared to the scalar ratio limit for the 40-year period, 21.85, as shown in Table 5.2. The packages of changes for each combination of prototype and climate location were considered cost-effective if the corresponding scalar ratio was less than the scalar ratio limit. The parameters shown in Table 5.2 were based on consensus of the SSPC 90.1.

5.2 Energy Cost Savings

Annual energy costs are a necessary part of the cost-effectiveness analysis. Annual energy costs were lower for all of the selected 90.1-2013 models compared to the corresponding 90.1-2010 models. The energy costs for each edition of Standard 90.1 were determined previously under the development of Standard 90.1-2013, as described below.

In support of DOE's determination of energy savings of 90.1-2013, PNNL assessed the relative energy use for commercial buildings designed to meet requirements found in 90.1-2013 compared to the requirements found in 90.1-2010. The overall energy saving analysis of Standard 90.1 utilized a suite of 16 prototype EnergyPlus building models in 15 climate locations representing all eight U.S. climate zones. Detailed methodology and overall energy saving results from Standard 90.1-2013 are documented in the PNNL technical report titled *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis* (Halverson et al. 2014). The prototype models used in the analysis are available for download (DOE 2014b).

The current savings analysis builds on the determination analysis by including savings from equipment efficiency upgrades that are specifically excluded[1] from the determination analysis. Table 5.3 shows the resulting annual energy cost savings, (total and cost/ft^2). Appendix C includes the energy simulation results and additional details of these costs.

Energy rates used to calculate the energy costs from the modeled energy usage were \$0.990/therm for fossil fuel[2] and \$0.1032/kWh for electricity. These rates were used for the 90.1-2013 energy analysis, and derived from the US DOE Energy Information Administration data. These were the values approved by

[1] The determination only includes savings originating uniquely in the ASHRAE 90.1 standard and excludes savings from federally mandated appliance efficiency improvements. These savings are included here, as this analysis considers the cost effectiveness of Standard 90.1 in its entirety.

[2] The fossil fuel rate is a blended heating rate and includes proportional (relative to national heating fuel use) costs for natural gas, propane, heating oil, and electric heat. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas equipment, but in practice, natural gas equipment may be operated on propane, or boilers that are modeled as natural gas may use oil in some regions.

the SSPC 90.1 for cost-effectiveness for the evaluation of individual addenda during the development of 90.1-2013.

Table 5.3. Annual Energy Cost Savings, 90.1-2013 Compared to 90.1-2010

Prototype		2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
Small Office	Total	$827	$625	$379	$567	$535
	$/ft²	$0.15	$0.11	$0.07	$0.10	$0.10
Large Office	Total	$50,023	$27,105	$34,657	$17,461	$14,079
	$/ft²	$0.10	$0.05	$0.07	$0.04	$0.03
Standalone Retail	Total	$4,246	$4,183	$2,911	$4,551	$5,116
	$/ft²	$0.17	$0.17	$0.12	$0.18	$0.21
Primary School	Total	$16,072	$12,571	$16,848	$11,705	$11,520
	$/ft²	$0.22	$0.17	$0.23	$0.16	$0.16
Small Hotel	Total	$5,459	$4,649	$4,777	$4,588	$4,602
	$/ft²	$0.13	$0.11	$0.11	$0.11	$0.11
Mid-rise Apartment	Total	$3,119	$2,061	$2,119	$1,868	$2,083
	$/ft²	$0.09	$0.06	$0.06	$0.06	$0.06

Climate Zone and Location spans the five location columns.

5.3 Cost-effectiveness Analysis Results

Table 5.4 shows the results of the analysis from all three methods: LCCA, simple payback, and scalar ratio. This analysis demonstrates that 90.1-2013 is cost-effective for all the analyzed prototypes in each climate location for all three methods relative to 90.1-2010. As described previously, simple payback is a simpler and less robust method than the other two, is provided for information purposes only and is not truly a measure of cost-effectiveness. DOE's assessment of cost-effectiveness is based on LCCA. For the two life cycle cost metrics shown in Table 5.4, cost-effectiveness is determined as follows:

- The life cycle cost net savings is greater than zero. The life cycle cost net savings is the present value savings of a building built under 90.1-2013 compared to 90.1-2010, less the incremental cost difference, less the present value of the replacement and residual cost difference.
- The scalar ratio is less than the scalar limit for the analysis. The scalar ratio is calculated using the 90.1 methodology and is similar to a discounted payback.

Table 5.4. Cost-effectiveness Analysis Results

Prototype		Climate Zone and Location				
		2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
Life Cycle Cost Net Savings						
Small Office	Total	$21,600	$15,200	$10,800	$2,900	$5,000
	$/ft^2	$3.93	$2.76	$1.96	$0.53	$0.91
Large Office	Total	$740,000	$1,650,000	$2,540,000	$300,000	$1,340,000
	$/ft^2	$1.48	$3.31	$5.09	$0.60	$2.69
Standalone Retail	Total	$84,000	$81,400	$53,800	$67,000	$79,000
	$/ft^2	$3.40	$3.30	$2.18	$2.71	$3.20
Primary School	Total	$246,000	$116,000	$398,000	$70,000	$54,000
	$/ft^2	$3.33	$1.57	$5.38	$0.95	$0.73
Small Hotel	Total	$96,410	$76,000	$78,000	$62,600	$57,000
	$/ft^2	$2.23	$1.76	$1.81	$1.45	$1.32
Mid-rise Apartment	Total	$59,600	$22,600	$23,800	$29,200	$28,500
	$/ft^2	$1.77	$0.67	$0.71	$0.87	$0.84
Simple Payback (years)						
Small Office		Immediate	Immediate	Immediate	22.0	17.0
Large Office		6.8	Immediate	Immediate	5.1	Immediate
Standalone Retail		Immediate	Immediate	Immediate	Immediate	Immediate
Primary School		5.5	9.5	0.6	14.3	15.6
Small Hotel		3.9	4.1	4.0	7.2	8.7
Mid-rise Apartment		1.9	11.7	11.4	7.2	9.7
Scalar Ratio, Limit = 21.85[1]						
Small Office		(4.9)	(2.8)	(6.3)	20.0	15.1
Large Office		5.6	(44.7)	(53.7)	3.0	(86.8)
Standalone Retail		(1.9)	(1.6)	(2.0)	4.2	3.8
Primary School		5.1	11.1	(1.2)	15.3	16.7
Small Hotel		3.8	4.5	4.4	7.5	8.9
Mid-rise Apartment		2.2	11.3	11.1	7.0	9.5

[1.] Scalar ratio limit for an analysis period of 40 years.

Note: a negative scalar ratio indicates that the cost is negative. This occurs, for example, when there are net decreases in costs either from reductions in HVAC capacity or reductions in installed lighting due to lower LPDs.

6.0 References

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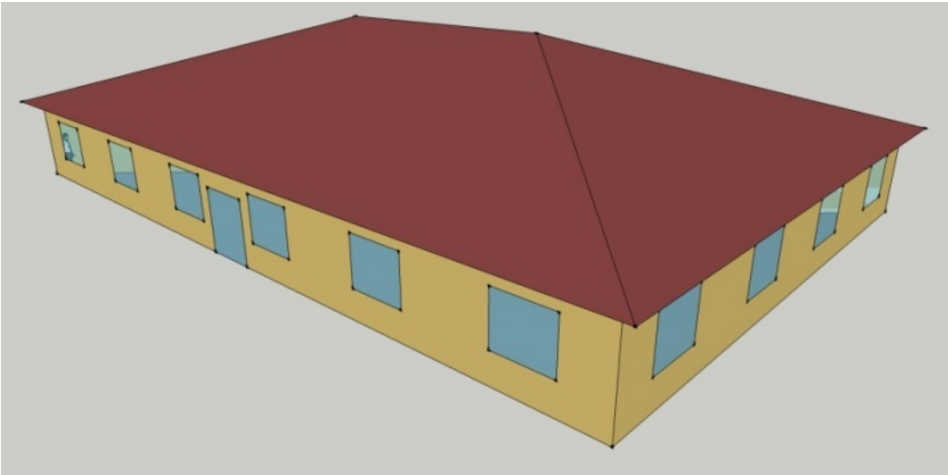
Appendix A

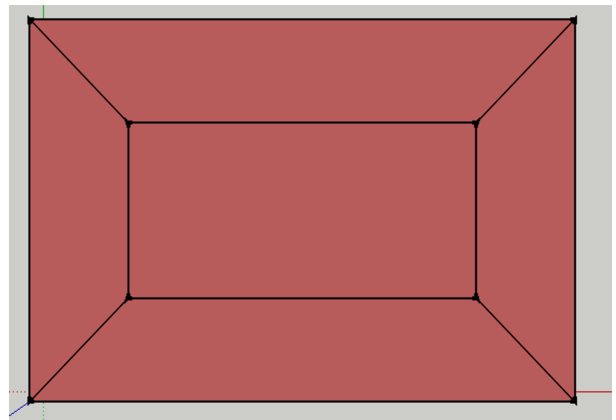
Energy Modeling Prototype Building Descriptions

This appendix includes information from the prototype profiles (also referred to as “scorecards”) that can be found at the website http://www.energycodes.gov/commercial-prototype-building-models. More detailed information, including EnergyPlus input files for the prototypes, can also be found at the website.

A.1

A.1 Small Office Modeling Description

	Item	Descriptions			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 17Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine)	Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine)	Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper. See Reference.
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**OFFICE**			
	Building Prototype	**Small Office**			
Form					
	Total Floor Area (sq. feet)	5500 (90.8 ft x 60.5ft)			
	Building shape				

	Item	Descriptions	Data Source
	Aspect Ratio	1.5	
	Number of Floors	1	
	Window Fraction (Window-to-Wall Ratio)	24.4% for South and 19.8% for the other three orientations (Window Dimensions: 6.0 ft x 5.0 ft punch windows for all façades)	2003 CBECS Data and PNNL's CBECS Study 2007.
	Window Locations	evenly distributed along four façades	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning	Perimeter zone depth: 16.4 ft. Four perimeter zones, one core zone and an attic zone. Percentages of floor area: Perimeter 70%, Core 30% 	
	Floor to floor height (feet)	10	
	Floor to ceiling height (feet)	10	
	Glazing sill height (feet)	3 (top of the window is 8 ft high with 5 ft high glass)	
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2X4 16in OC) 1in. Stucco + 5/8 in. gypsum board + wall Insulation+ 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Exterior wall layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Walls, Above-Grade, Wood-Framed	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Tilts and orientations	vertical	
	Roof		
	Construction	Attic Roof with Wood Joist: Roof insulation + 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Attic	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	Hipped roof: 10.76 ft attic ridge height, 2 ft overhang-soffit	
	Window		
	Dimensions	punch window, each 5 ft high by 6 ft wide	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Vertical Glazing	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance	Hypothetical window with the exact U-factor and SHGC shown above	
	Operable area	0	Ducker Fenestration Market Data provided by the 90.1 envelope subcommittee
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	8" concrete slab poured directly on to the earth	
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Slab-on-Grade Floors, unheated	ASHRAE 90.1
	Thermal properties for basement walls	NA	
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft²)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	PNNL-18898: Infiltration Modeling Guidelines for Commercial Building Energy Analysis.
HVAC			
	System Type		
	Heating type	Air-source heat pump with gas furnace as back up	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Air-source heat pump	
	Distribution and terminal units	Single zone, constant air volume air distribution, one unit per occupied thermal zone	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	Varies by climate location and design cooling capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Packaged Heat Pumps	ASHRAE 90.1
	Heating	Varies by climate location and design heating capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Packaged Heat Pumps and Warm Air Furnaces	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	85°F Cooling/60°F Heating	
	Supply air temperature	Maximum 104°F, Minimum 55°F	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	Varies by climate location and cooling capacity Control type: differential dry bulb	ASHRAE 90.1

	Item	Descriptions	Data Source
	Ventilation	ASHRAE Ventilation Standard 62.1	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Energy Recovery	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Supply Fan		
	Fan Hourly Operation Schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Total Efficiency (%)	Depending on the fan motor size	ASHRAE 90.1 requirements for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Varies depending on the fan supply air CFM	
	Pump		
	Pump Type	NA	
	Rated Pump Head	NA	
	Pump Power	autosized	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Efficiency	NA	
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Electric	
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Tank Volume (gal)	40	
	Water temperature setpoint	120F	
	Water consumption	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Building Area Method	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Daylighting Controls	ASHRAE 90.1 Requirements	
	Occupancy Sensors	ASHRAE 90.1 Requirements	
	Plug load		
	Average power density (W/ft^2)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)

	Item	Descriptions	Data Source
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Quantity	NA	
	Motor type	NA	Reference: DOE Commercial Reference Building Models of the National Building Stock
	Peak Motor Power(W/elevator)	NA	
	Heat Gain to Building	NA	
	Peak Fan/lights Power(W/elevator)	NA	90.1 Mechanical Subcommittee, Elevator Working Group
	Motor and fan/lights Schedule	NA	DOE Commercial Reference Building TSD and models (V1.3_5.0) and Addendum DF to 90.1-2007
	Exterior Lighting		
	Peak Power (W)	1,634	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

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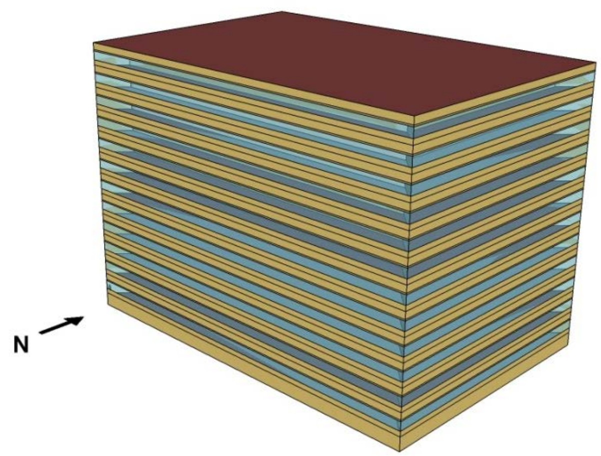
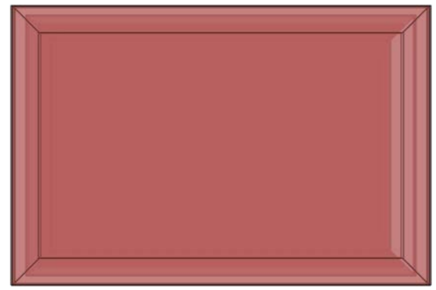
Gowri K, DW Winiarski, and RE Jarnagin. 2009. Infiltration modeling guidelines for commercial building energy analysis. PNNL-18898, Pacific Northwest National Laboratory, Richland, WA. http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18898.pdf

PNNL. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/development/commercial/90.1_models.

A.2 Large Office Modeling Description

	Item	Descriptions	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	
	Location (Representing All 17 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine) Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine) Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**OFFICE**	
	Building Prototype	**LARGE OFFICE**	
Form			
	Total Floor Area (sq. feet)	498,600 (240 ft x 160 ft)	*Time Saver Standards;* Large Office studies (ConEd, EPRI, MEOS, NEU1(1-4), NEU2, PNL) cited in Huang et al. 1991
	Building shape		
	Aspect Ratio	1.5	
	Number of Floors	12 (plus basement)	

	Item	Descriptions	Data Source
	Window Fraction (Window-to-Wall Ratio)	40% of above-grade gross walls 37.5% of gross walls (including the below-grade walls)	
	Window Locations	even distribution among all four sides	PNNL's CBECS Study
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning		*Time Saver Standards;* Large Office studies (ConEd, EPRI, MEOS, NEU1(1-4), NEU2, PNL) cited in Huang et al. 1992
		Perimeter zone depth: 15 ft. Each floor has four perimeter zones, one core zone and one IT closet zone. Percentages of floor area: Perimeter 29%, Core 70%, IT Closet 1% The basement has a datacenter zone occupying 28% of the basement floor area.	
	Floor to floor height (feet)	13	
	Floor to ceiling height (feet)	9	
	Glazing sill height (feet)	3	
Architecture			
	Exterior walls		
	Construction	Mass (pre-cast concrete panel): 8 in. Heavy-Weight Concrete + Wall Insulation + 0.5 in. gypsum board	Construction type: PNNL's CBECS Study
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Walls, Above-Grade, Steel-Framed	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Construction type: PNNL's CBECS Study Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Insulation entirely above deck	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance	Hypothetical window with the exact U-factor and SHGC shown above	
	Operable area	0%	Ducker Fenestration Market Data provided by the envelope subcommittee
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Basement (unconditioned)	
	Construction	8" concrete wall; 6" concrete slab, 140 lbs. heavy-weight aggregate	
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Floors, Mass	ASHRAE 90.1
	Thermal properties for basement walls	No insulation	
	Dimensions	based on floor area and aspect ratio	
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft²)	
	Air Barrier System		

	Item	Descriptions	Data Source
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	PNNL's Infiltration Study
HVAC			
	System Type		
	Heating type	Gas boiler	PNNL's CBECS Study
	Cooling type	Water-source DX cooling coil with fluid cooler for datacenter and IT closets and two water-cooled centrifugal chillers for the rest of the building	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Distribution and terminal units	VAV terminal box with damper and hot-water reheating coil except non-datacenter portion of the basement and IT closets that are served by CAV units. Zone control type: minimum damper positions are determined using the multizone calculation method.	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	Varies by climate locations based on cooling capacity	ASHRAE 90.1
	Heating	Varies by climate locations based on heating capacity	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	90.1 Simulation Working Group
	Thermostat Setback	85°F Cooling/60°F Heating	
	Supply air temperature	Maximum 110°F, Minimum 52°F	
	Chilled water supply temperatures	44°F	
	Hot water supply temperatures	180°F	
	Economizers	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Ventilation		
	Demand Control Ventilation	No	ASHRAE 90.1
	Energy Recovery	No	ASHRAE 90.1
	Supply Fan		
	Fan schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Total Efficiency (%)	60% to 62% depending on the fan motor size	ASHRAE 90.1
	Supply Fan Pressure Drop	Varies depending on the fan supply air CFM	
	Pump		
	Pump Type	Primary chilled water (CHW) pumps: constant speed; secondary CHW pump: variable speed; IT closet (water loop heat pump) pump: constant speed; cooling tower pump: variable speed: service hot water (SWH): constant speed; hot water (HW) pump: variable speed	

	Item	Descriptions	Data Source
	Rated Pump Head	CHW: 56 ft HW and CW: 60 ft	ASHRAE 90.1
	Pump Power	autosized	
	Cooling Tower		
	Cooling Tower Type	open cooling tower with two-speed fans; two-speed fluid-cooler for data center and IT closets	ASHRAE 90.1
	Cooling Tower Power	autosized	
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Natural Gas	
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	
	Tank Volume (gal)	300	
	Water temperature setpoint	140°F	
	Water consumption	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Building-Area Method	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Daylighting Controls	No	
	Occupancy Sensors	No	
	Plug load		
	Average power density (W/ft^2)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	ASHRAE Ventilation Standard 62.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Quantity	12	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0).
	Motor type	traction	
	Peak Motor Power (W/elevator)	20370	
	Heat Gain to Building	Exterior	

	Item	Descriptions	Data Source
	Peak Fan/lights Power (W/elevator)	161.9	90.1 Mechanical Subcommittee, Elevator Working Group
	Motor and fan/lights Schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	DOE Commercial Reference Building TSD (unpublished) and models (V1.3_5.0) and Appendix DF 2007
Exterior Lighting			
	Peak Power (W)	60,216	ASHRAE 90.1-2004; PNNL study; 90.1 Lighting Subcommittee inputs
	Schedule	Astronomical Clock	ASHRAE 90.1

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PNNL's CBECS Study. 2006. *Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment.* Dave Winiarski, Wei Jiang and Mark Halverson. Pacific Northwest National Laboratory. December 2006.

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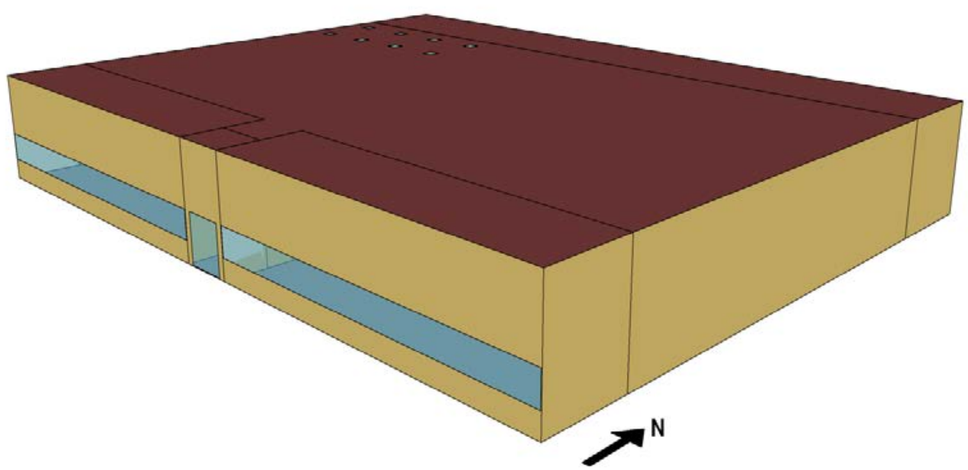
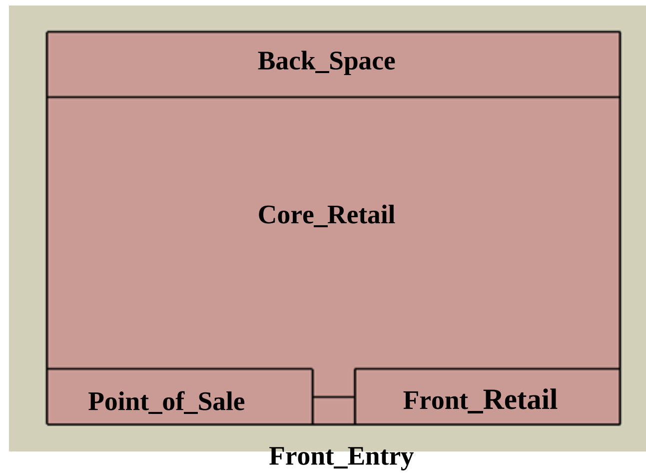
A.3 Standalone Retail Modeling Description

	Item	Descriptions	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine) Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine) Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper. See Reference.
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**RETAIL**	
	Building Prototype	**Standalone Retail**	
Form			
	Total Floor Area (sq. feet)	24695 (178 ft x 139 ft)	
	Building shape		
	Aspect Ratio	1.28	

	Item	Descriptions	Data Source
	Number of Floors	1	
	Window Fraction (Window-to-Wall Ratio)	7.1% (Window Dimensions: 82.136 ft x 5 ft, 9.843 ft x 8.563 ft and 82.136 ft x 5 on the street facing facade)	2003 CBECS Data and PNNL's CBECS Study 2007.
	Window Locations	Windows only on the street facing façade (25.4% WWR)	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning	Five thermal zones (See scorecard at www.energycodes.gov/commercial-prototype-building-models) 	
	Floor to floor height (feet)	N/A	
	Floor to ceiling height (feet)	20	
	Glazing sill height (feet)	5 (top of the window is 8.73 ft high with 3.74 ft high glass)	
Architecture			
	Exterior walls		
	Construction	Concrete Block Wall: 8 in. CMU+Wall Insulation+0.5 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Exterior wall layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Walls, Above-Grade, Mass	ASHRAE 90.1

	Item	Descriptions	Data Source
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	Vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Insulation entirely above deck	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Vertical Glazing	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance		Ducker Fenestration Market Data provided by the 90.1 envelope subcommittee
	Operable area	2%	Ducker Fenestration Market Data provided by the envelope subcommittee
	Skylight		
	Dimensions	Core Retail, Rectangular skylight 4 ft x 4 ft = 16 ft^2 per skylight Number of skylights and total skylight area vary according to ASHRAE 90.1 Requirements	ASHRAE 90.1
	Glass-Type and frame	Hypothetical glass and frame meeting ASHRAE 90.1 Requirements below	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Skylight with Curb, Glass	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	6" concrete slab poured directly on to the earth with carpet	

	Item	Descriptions	Data Source
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Slab-on-Grade Floors, unheated	ASHRAE 90.1
	Thermal properties for basement walls	NA	
	Dimensions	based on floor area and aspect ratio	
	Interior Partitions		
	Construction	0.5 in gypsum board + 0.5 in gypsum board	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft^2)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	Reference: PNNL-18898: Infiltration Modeling Guidelines for Commercial Building Energy Analysis.
HVAC			
	System Type		
	Heating type	Gas furnace inside the packaged air conditioning unit for back_space, core_retail, point_of_sale, and front_retail. Standalone gas furnace for front_entry.	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Packaged air conditioning unit for back_space, core_retail, point_of_sale, and front_retail; No cooling for front_entry.	
	Distribution and terminal units	Constant air volume air distribution 4 single-zone roof top units serving four thermal zones (back_space, core_retail, point_of_sale, and front_retail)	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	Varies by climate location and design cooling capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Air Conditioners and Condensing Units	ASHRAE 90.1
	Heating	Varies by climate location and design heating capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Warm Air Furnaces	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	85°F Cooling/60°F Heating	

	Item	Descriptions	Data Source
	Supply air temperature	Maximum 104°F, Minimum 55°F	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	Varies by climate location and cooling capacity Control type: differential dry bulb	ASHRAE 90.1
	Ventilation	ASHRAE Ventilation Standard 62.1	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Energy Recovery	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Supply Fan		
	Fan schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Mechanical Efficiency (%)	Varies depending on the fan motor size	ASHRAE 90.1 requirements for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Varies depending on the fan supply air CFM	
	Pump		
	Pump Type	N/A	
	Rated Pump Heat	No	
	Pump Power	N/A	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Efficiency	NA	
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Natural Gas	
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Tank Volume (gal)	40	
	Water temperature setpoint	140°F	
	Water consumption	BLDG_SWH_SCH See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Building Area Method	
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

	Item	Descriptions	Data Source
	Daylighting Controls	ASHRAE 90.1 Requirements	
	Occupancy Sensors	ASHRAE 90.1 Requirements	
	Plug load		
	Average power density (W/ft^2)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Peak Power	NA	
	Schedule	NA	
	Exterior Lighting		
	Peak Power	7,322 watts	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

References

Briggs, R.S., R.G. Lucas, and Z.T. Taylor. 2003. Climate Classification for Building Energy Codes and Standards: Part 2—Zone Definitions, Maps, and Comparisons. ASHRAE Transactions 109(2).

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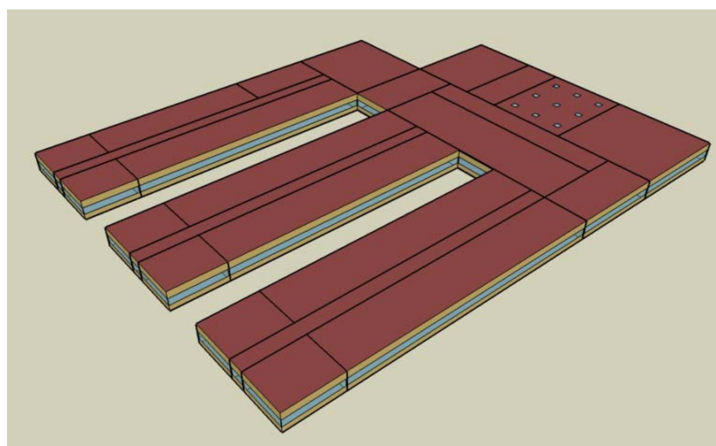
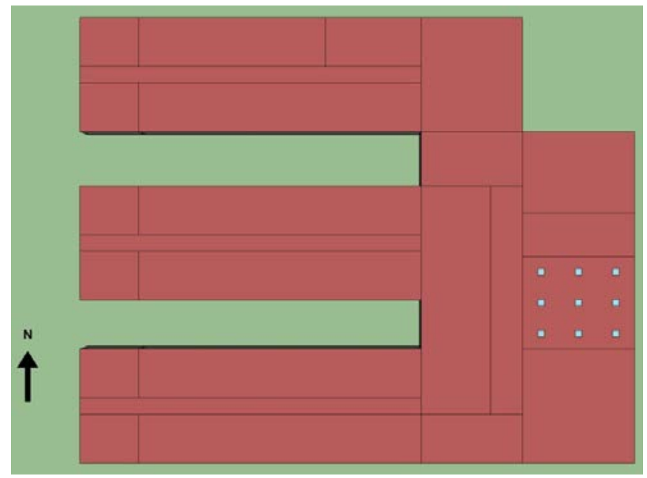
A.4 Primary School Modeling Description

	Item	Descriptions	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine) Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine) Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**EDUCATION**	
	Building Prototype	**Primary School**	
Form			
	Total Floor Area (sq. feet)	73, 960 (340 ft x 270 ft)	
	Building shape		
	Aspect Ratio	1.3	
	Number of Floors	1	

	Item	Descriptions	Data Source
	Window Fraction (Window-to-Wall Ratio)	35% for all facades Ribbon window across all facades	
	Window Locations	Continuous Band	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning	Classrooms zoned by exposure. Corner classrooms separated out from single exposure classrooms. Double loaded corridors zoned separately. Administrative area, gymnasium, mechanical, media center, lobby, kitchen, and cafeteria are single zones. See scorecard at www.energycodes.gov/commercial-prototype-building-models 	
	Floor to floor height (feet)	13	
	Floor to ceiling height (feet)	13	
	Glazing sill height (feet)	3.6 (top of the window is 8.1 ft high with 4.5 ft high glass)	
Architecture			
	Exterior walls		
	Construction	Steel-framed Walls (2x4, 16" OC) 0.75" stucco + 0.625" gypsum board + Cavity insulation + 0.625" gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Exterior wall layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Walls, Above-Grade, Steel-Framed	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof Roof membrane + Roof insulation + Metal decking	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Insulation entirely above deck	ASHRAE 90.1
	Area (ft2)	73,960	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with weighted U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Vertical Glazing, 30.1-40%	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance		
	Operable area	35%	PNNL 's Glazing Market Data for ASHRAE spreadsheet
	Skylight		
	Dimensions	Gymnasium/Multipurpose Room (4 ft x 4 ft) x 9 skylights = 144 ft² total Skylight Area 3.75% of gym roof area	AEDG K-12 Guide
	Glass-Type and frame	Hypothetical glass and frame meeting ASHRAE 90.1 Requirements below	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Skylight with curb, Glass, 2.1-5%	ASHRAE 90.1
	SHGC		
	Visible transmittance		
	Foundation		
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	6" concrete slab poured directly on to the earth + carpet	
	Thermal properties for ground level floor: F-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Slab-on-Grade Floors, unheated	ASHRAE 90.1
	Thermal properties for basement walls:	NA	
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft²)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/ft² of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	Reference: PNNL-18898: Infiltration Modeling Guidelines for Commercial Building Energy Analysis.
HVAC			
	System Type		
	Heating type	1. Gas furnace inside packaged air conditioning unit 2. Hot water from a gas boiler for heating	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Packaged air conditioning unit	
	Distribution and terminal units	1. CAV systems: direct air from the packaged air conditioning unit 2. VAV systems: VAV terminal box with damper and hot water reheating coil Zone Control Type: minimum supply air at 30% of the zone design peak supply air	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	Varies by climate location and design cooling capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Air Conditioners and Condensing Units	ASHRAE 90.1
	Heating	Varies by climate location and design heating capacity ASHRAE 90.1 Requirements Minimum equipment efficiency for Warm Air Furnaces Minimum equipment efficiency for Gas and Oil-fired Boilers	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	80°F Cooling/60°F Heating	
	Supply air temperature	Minimum 50°F and maximum 122°F	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	180°F	

	Item	Descriptions	Data Source
	Economizers	Varies by climate location and cooling capacity Control type: differential dry bulb	ASHRAE 90.1
	Outdoor Air Ventilation	ASHRAE Ventilation Standard 62.1	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Energy Recovery	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Supply Fan		
	Fan schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Mechanical Efficiency	Varies depending on the fan motor size and type of fan	ASHRAE 90.1 requirements for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Varies depending on the fan supply air CFM	
	Pump		
	Pump Type	Variable speed	
	Rated Pump Head	60 ft	
	Pump Power	autosized	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Power	NA	
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Natural Gas (main); Electric (dishwasher booster)	
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Tank Volume (gal)	200 (main); 6 (dishwasher booster)	
	Water temperature setpoint	140°F (main); 180°F (dishwasher booster)	
	Water consumption (peak gpm)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Internal Loads & Schedules			
	Lighting		
	Lighting power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Space-By-Space Method See scorecard at www.energycodes.gov/commercial-prototype-building-models	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Daylighting Controls	ASHRAE 90.1 Requirements	
	Occupancy Sensors	ASHRAE 90.1 Requirements	
	Plug load		
	Average power density (W/ft^2)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

	Item	Descriptions	Data Source
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Peak Power	NA	
	Schedule	NA	
	Exterior Lighting		
	Peak Power (W)	ASHRAE 90.1 Lighting Power Densities For Building Exteriors	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

References

Briggs, R.S., R.G. Lucas, and Z.T. Taylor. 2003. Climate Classification for Building Energy Codes and Standards: Part 2—Zone Definitions, Maps, and Comparisons. ASHRAE Transactions 109(2).

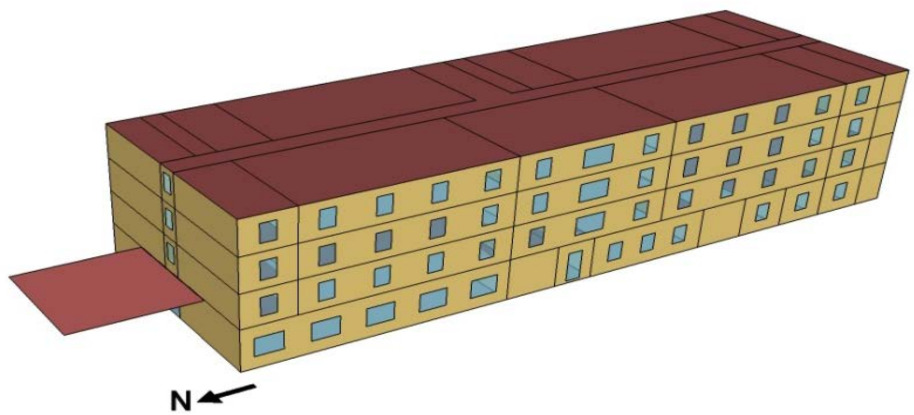
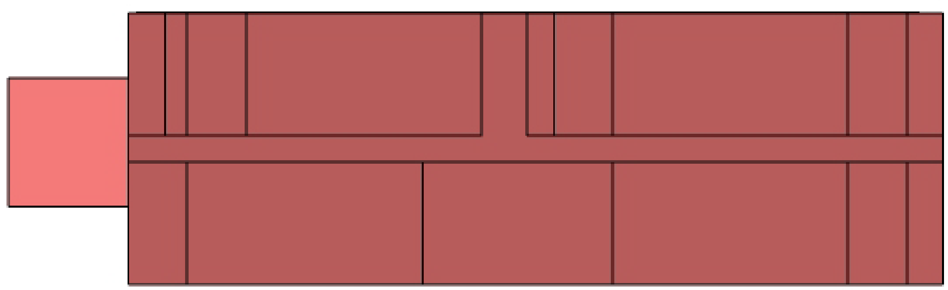
PNNL's CBECS Study. 2007. *Analysis of Building Envelope Construction in 2003 CBECS Buildings.* Dave Winiarski, Mark Halverson, and Wei Jiang. Pacific Northwest National Laboratory. March 2007.

PNNL's CBECS Study. 2006. *Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment.* Dave Winiarski, Wei Jiang and Mark Halverson. Pacific Northwest National Laboratory. December 2006.

“Study of the U.S. Market For Windows, Doors, and Skylights”, American Architectural Manufacturers Association, Window & Door Manufacturers Association, 2006.

A.5 Small Hotel Modeling Description

	Item	Input	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine) Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine) Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**Lodging**	
	Building Prototype	**Small Hotel**	
Form			
	Total Floor Area (sq. feet)	43200 (180 ft x 60 ft)	Hampton Inn Prototype from Hilton Hotels Corporation, Version 5.1, September 2004 (URL: http://www.hamptonfranchise.com), referred as Hilton prototype; F.W.Dodge Database

	Item	Input	Data Source
	Building shape		Hilton prototype and CBECS 2003
	Aspect Ratio	3	Hilton prototype
	Number of Floors	4	
	Window Fraction (Window-to-Wall Ratio)	South: 3.1%, East: 11.4%, North: 4.0%, West: 15.2% Average Total: 10.9%	Hilton prototype
	Window Locations	One per guest room (4' x 5')	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning		Hilton prototype

	Item	Input	Data Source
		Ground Floor: 19 zones including guest rooms, lobby, office space, meeting room, laundry room, employee lounge, restrooms, exercise room, mechanical room, corridor, stairs, storage; *2nd-4th Floor*: 16 zones per floor, including guest rooms, corridor, stairs and storage; Guest rooms accounts for 63% of total floor area.	
	Floor to floor height (feet)	Ground floor: 11 ft Upper floors: 9 ft	
	Floor to ceiling height (feet)	same as above	
	Glazing sill height (feet)	3 ft in ground floor, 2 ft. in upper floors	
Architecture			
	Exterior walls		
	Construction	Steel-Frame Walls (2x4 16 in. OC) 1 in. Stucco + 5/8 in. gypsum board + wall Insulation + 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Walls, Above-Grade, Steel-Framed	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane + Roof insulation + metal decking	AEDG Highway Lodging Committee Recommendation
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Insulation entirely above deck	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential for ground floor and residential for upper floors; Vertical Glazing, 10.1%-20.0%	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance	Hypothetical window with the exact U-factor and SHGC shown above	
	Operable area	0.00%	
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		

	Item	Input	Data Source
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	6" concrete slab poured directly on to the earth	
	Thermal properties for slab-on-grade floor F-factor (Btu / h * ft2 * °F) and/or R-value (h * ft2 * °F / Btu)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Thermal properties for basement walls	NA	
	Dimensions	based on floor area and aspect ratio	
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft²)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area, adjusted by wind (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	Reference: PNNL-18898. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis.*
HVAC			
	System Type		
	Heating type	Guest rooms: PTAC with electric resistance heating Public spaces (office, laundry, lobby, and meeting room): gas furnace inside the packaged air conditioning units Storage and stairs: electric cabinet heaters	2003 CBECS, NC3, Ducker report
	Cooling type	Guest rooms and corridors: PTAC and make-up air unit for outdoor air ventilation Public space: Split system with DX cooling Storage and stairs: No cooling	
	Distribution and terminal units	Constant air volume systems	
	HVAC Sizing		
	Air Conditioning	PTAC: 9,000 Btu/hr Split system and packaged MAU system: autosized to design day	PTAC: Ducker report
	Heating	autosized to design day	
	HVAC Efficiency		

	Item	Input	Data Source
	Air Conditioning	PTAC: EER = 10.58 Split system and packaged MAU system: varies by climate locations based on cooling capacity	ASHRAE 90.1
	Heating	PTAC and electric cabinet heater: Et = 100% Gas furnace: varies by climate locations based on heating capacity	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	70°F Cooling/Heating for rented guest rooms 74°F Cooling/66°F Heating for vacant guest rooms 75°F Cooling/70°F Heating for air conditioned public spaces (lobby, meeting room etc.) 45°F heating for stairs and storage rooms	AEDG Highway Lodging Committee Recommendation
	Thermostat Setback	74°F Cooling/66°F Heating for rented guest rooms	
	Supply air temperature	No seasonal supply air temperature reset.	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	no economizer	ASHRAE 90.1
	Ventilation		ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	No	ASHRAE 90.1
	Energy Recovery Ventilation	No	ASHRAE 90.1
	Supply Fan		
	Fan schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Mechanical Efficiency (%)	Varies by fan motor size	AEDG-SR Technical Support Document (Liu 2006)
	Supply Fan Pressure Drop	PTAC: 1.33 in. w.c. Cabinet Heater: 0.2 in w.c. Split DX units and MAU: 90.1 fan power limitation (depends on design flow rate)	PTAC Manufacture's Catalogs Split System: Wassmer and Brandemuehl, 2006,
	Pump		
	Pump Type	Constant speed (recirculating pump for Main Water Heater)	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Rated Pump Head	10ft	
	Pump Power	autosized	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Power	NA	
	Service Water Heating		
	SWH type	Two Storage Tanks: one for laundry and the other for guest rooms	
	Fuel type	Natural Gas	
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	ASHRAE 90.1

	Item	Input	Data Source
	Tank Volume (gal)	300 (main); 200 (laundry)	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Water temperature setpoint	140°F for guest rooms and 180°F for laundry	
	Water consumption	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Guest room: ASHRAE Handbook of Applications 2007, Chapter 49, Table 7 Laundry: AEDG Highway Lodging Committee Recommendation
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Building Space-by-Space Method	ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Daylighting Controls	No	
	Occupancy Sensors	No	
	Plug load		
	Average power density (W/ft^2)	See scorecard at www.energycodes.gov/commercial-prototype-building-models	AEDG Highway Lodging Committee Recommendation
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Guest Room: AEDG Highway Lodging Committee Recommendation All other spaces: ASHRAE 62.1-1999
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Quantity	2	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0).
	Motor type	hydraulic	
	Peak Motor Power (W/elevator)	16055	
	Heat Gain to Building	Interior	
	Peak Fan/lights Power (W/elevator)	161.9	90.1 Mechanical Subcommittee, Elevator Working Group

	Item	Input	Data Source
	Exterior Lighting	See scorecard at www.energycodes.gov/commercial-prototype-building-models	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0) and Appendix DF 2007
	Peak Power, kW	13.03	Derived based on ASHRAE 90.1-2004 and inputs from 90.1 Lighting Subcommittee
	Schedule	Astronomical Clock	

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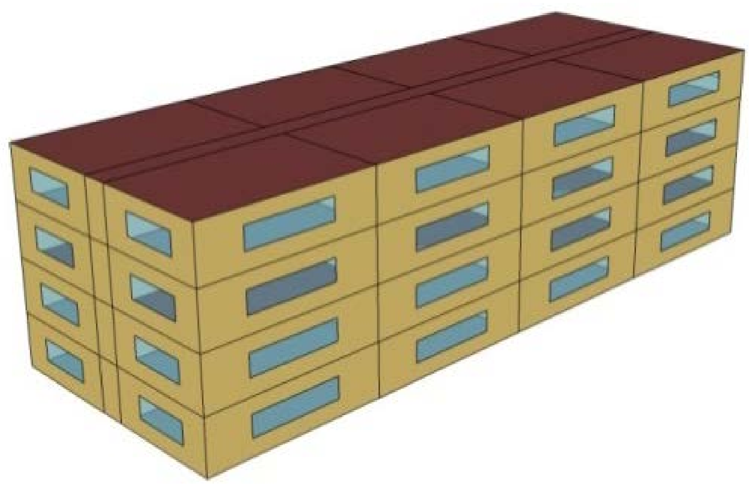
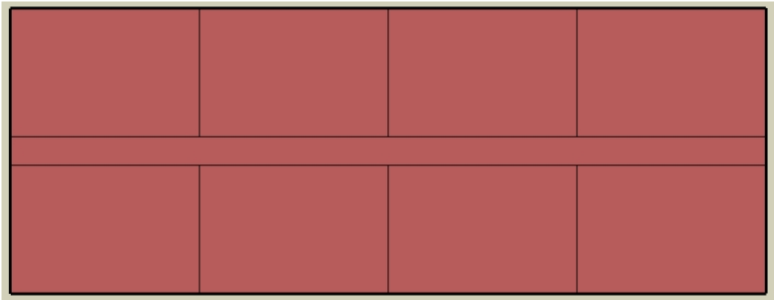
Wassmer and Brandemuehl, 2006, Effect of Data Availability on Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations

A.6 Mid-Rise Apartment Modeling Description

	Item	Descriptions	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 1B: Riyadh, Saudi Arabia (very hot, dry) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm, marine) Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry) Zone 5C: Vancouver, BC (cold, marine) Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)	Selection of representative climates based on Briggs' paper. See Reference.
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**Multifamily**	
	Building Prototype	**Mid-rise Apartment**	
Form			
	Total Floor Area (sq. feet)	33,700 (152 ft x 55.5 ft)	Reference: PNNL-16770: *Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York*
	Building shape		
	Aspect Ratio	2.74	

	Item	Descriptions	Data Source
	Number of Floors	4	90.1 Envelop Subcommittee
	Window Fraction (Window-to-Wall Ratio)	South: 20%, East: 20%, North: 20%, West: 20% Average Total: 20%	Reference: Based on feedback from the National Multi-family Housing Council (NMHC)
	Window Locations	See image	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning	 Each floor has 8 apartments except ground floor (7 apartments and 1 lobby with equivalent apartment area) Total 8 apartments per floor with corridor in center. Zone depth is 25 ft for each apartment from side walls and each apt is 25' x 38' (950 ft²).	Reference: PNNL-16770: *Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York*
	Floor to floor height (ft)	10	
	Floor to ceiling height (ft)	10 (No drop-in ceiling plenum is modeled)	
	Glazing sill height (ft)	3 ft (14 ft wide x 4 ft high)	
Architecture			
	Exterior walls		
	Construction	Steel-Frame Walls (2X4 16IN OC) 0.4 in. Stucco+5/8 in. gypsum board + wall Insulation+5/8 in.	Reference: PNNL-16770: *Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York*. Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft² * °F) and/or R-value (h * ft² * °F / Btu)	ASHRAE 90.1 Requirements Residential; Walls, above grade, Steel Frame	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	

	Item	Descriptions	Data Source
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Reference: PNNL-16770: Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Residential; Roofs, Insulation entirely above deck	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	SHGC (all)		
	Visible transmittance		
	Operable area	100%	
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	8" concrete slab poured directly on to the earth	
	Slab-on-grade floor insulation level (F-factor)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	

	Item	Descriptions	Data Source
	Internal Mass	8 lbs/ft^2 of floor area	Reference: Building America Research Benchmark
	Air Barrier System		
	Infiltration (ACH)	0.2016 CFM/ft^2 of gross exterior wall area at all times (at 10 mph wind speed)	Reference: PNNL-18898. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis.*
HVAC			
	System Type		
	Heating type	Gas Furnace	90.1 Mechanical Subcommittee
	Cooling type	Split system DX (1 per apt)	
	Distribution and terminal units	Constant volume	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Air Conditioners and Condensing Units	ASHRAE 90.1
	Heating	ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Warm Air Furnaces	ASHRAE 90.1
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	No setback for apartments	
	Supply air temperature	Maximum 110°F, Minimum 52°F	
	Economizers	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Ventilation	ASHRAE Ventilation Standard 62.1	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Energy Recovery	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Supply Fan		
	Fan schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
	Supply Fan Total Efficiency (%)	Depending on the fan motor size	ASHRAE 90.1 requirements for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Depending on the fan supply air CFM	
	Service Water Heating		
	SWH type	Individual Residential Water Heater with Storage Tank	

	Item	Descriptions	Data Source
	Fuel type	Electricity	Reference: RECS 2005
	Thermal efficiency (%)	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Tank Volume (gal)	50	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Water temperature setpoint	140 F	
	Water consumption	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Reference: Building America Research Benchmark
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	Apartment units: 0.36 W/ft² (daily peak for hard-wired lighting) and 0.09 W/ft² (daily peak for plug-in lighting) - See under Lighting Load for the detailed calculations. Corridor: 0.5 W/ft²	Apartment: Building America Research Benchmark Corridor: ASHRAE 90.1
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Reference: Building America Research Benchmark
	Daylighting Controls	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Occupancy Sensors	ASHRAE 90.1 Requirements	ASHRAE 90.1
	Plug load		
	Average power density (W/ft^2)	0.62 W/ft² daily peak per apartment, including all the home appliances See under Plug Load for the detailed calculations	Reference: Building America Research Benchmark
	Schedule	See Appendix C	
	Occupancy		
	Average people	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Reference: Building America Research Benchmark
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Misc.			
	Elevator		
	Quantity	1	Reference: DOE Commercial Reference Building Models of the National Building Stock
	Motor type	hydraulic	
	Peak Motor Power (watts/elevator)	16,055	
	Heat Gain to Building	Interior	
	Peak Fan/lights Power (watts/elevator)	161.9	90.1 Mechanical Subcommittee, Elevator Working Group
	Motor and fan/lights Schedules	See scorecard at www.energycodes.gov/commercial-prototype-building-models	Reference: DOE Commercial Reference Building Models of the National Building Stock
	Exterior Lighting		
	Peak Power (W)	4,642	ASHRAE 90.1

	Item	Descriptions	Data Source
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models	

References

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Appendix B

Incremental Cost Estimate Summary

This appendix includes summary cost data used in the cost effectiveness analysis. Cost tables for each building prototype show cost data grouped by HVAC, Lighting, Envelope and Power, and Total. Cost data includes the incremental cost of implementing 90.1-2013 compared to 90.1-2010. Incremental costs include New Construction or initial cost, annual maintenance cost, replacement costs for years 1 through 29, and residual costs in year 30.

B.1 Small Office Cost Summary

Small Office	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	-$1,185	$510	$58	-$374	$8	-$2,473	-$2,473	-$2,473	-$2,473	-$2,473
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
2	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
3	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
4	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
5	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
6	$0	$0	$0	$0	$0	-$178	-$178	-$178	-$178	-$178
7	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
8	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
9	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
10	$0	$0	$0	$0	$0	-$318	-$318	-$318	-$318	-$318
11	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
12	$0	$0	$0	$0	$0	-$416	-$416	-$416	-$416	-$416
13	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
14	$0	$0	$0	$0	$0	-$1,636	-$1,636	-$1,636	-$1,636	-$1,636
15	-$1,596	-$705	-$977	-$1,155	-$968	$4,058	$4,058	$4,058	$4,058	$4,058
16	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
17	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
18	$0	$0	$0	$0	$0	-$178	-$178	-$178	-$178	-$178
19	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
20	$0	$0	$0	$0	$0	-$557	-$557	-$557	-$557	-$557
21	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
22	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
23	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
24	$0	$0	$0	$0	$0	-$416	-$416	-$416	-$416	-$416
25	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
26	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
27	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
28	$0	$0	$0	$0	$0	-$1,875	-$1,875	-$1,875	-$1,875	-$1,875
29	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
30	$0	$0	$0	$0	$0	$1,513	$1,513	$1,513	$1,513	$1,513

Small Office	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$1,058	$1,058	$1,058	$15,318	$11,538	-$2,600.6	-$906	-$1,358	$12,472	$9,072
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
2	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
3	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
4	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
5	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
6	$0	$0	$0	$0	$0	-$178	-$178	-$178	-$178	-$178
7	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
8	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
9	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
10	$0	$0	$0	$0	$0	-$318	-$318	-$318	-$318	-$318
11	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
12	$0	$0	$0	$0	$0	-$416	-$416	-$416	-$416	-$416
13	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
14	$0	$0	$0	$0	$0	-$1,636	-$1,636	-$1,636	-$1,636	-$1,636
15	$0	$0	$0	$0	$0	$2,462	$3,353	$3,081	$2,903	$3,091
16	$0	$0	$0	$0	$0	-$249	-$249	-$249	-$249	-$249
17	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
18	$0	$0	$0	$0	$0	-$178	-$178	-$178	-$178	-$178
19	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
20	$510	$510	$510	$510	$510	-$47	-$47	-$47	-$47	-$47
21	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
22	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
23	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
24	$0	$0	$0	$0	$0	-$416	-$416	-$416	-$416	-$416
25	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
26	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
27	$0	$0	$0	$0	$0	-$155	-$155	-$155	-$155	-$155
28	$0	$0	$0	$0	$0	-$1,875	-$1,875	-$1,875	-$1,875	-$1,875
29	$0	$0	$0	$0	$0	-$10	-$10	-$10	-$10	-$10
30	-$933	-$944	-$944	-$5,452	-$4,312	$581	$569	$569	-$3,938	-$2,799

B.2 Large Office Cost Summary

Large Office	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$667,588	-$750,818	-$1,161,248	$329,744	-$717,326	-$354,847	-$354,847	-$354,847	-$354,847	-$354,847
Maintenance	$1,786	$1,786	$0	$1,786	$1,786	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
2	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
3	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
4	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
5	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
6	$0	$0	$0	$0	$0	-$29,710	-$29,710	-$29,710	-$29,710	-$29,710
7	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
8	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
9	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
10	$0	$0	$0	$0	$0	-$26,507	-$26,507	-$26,507	-$26,507	-$26,507
11	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
12	$0	$0	$0	$0	$0	-$39,517	-$39,517	-$39,517	-$39,517	-$39,517
13	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
14	$0	$0	$0	$0	$0	-$182,999	-$182,999	-$182,999	-$182,999	-$182,999
15	$392,981	$397,076	-$12,191	$411,694	$410,467	$26,363	$26,363	$26,363	$26,363	$26,363
16	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
17	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
18	$0	$0	$0	$0	$0	-$29,710	-$29,710	-$29,710	-$29,710	-$29,710
19	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
20	$10,818	$13,800	$23,802	$21,521	$21,689	-$36,314	-$36,314	-$36,314	-$36,314	-$36,314
21	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
22	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
23	$1,444	$6,285	$9,396	$4,846	$4,894	-$224	-$224	-$224	-$224	-$224
24	$0	$0	$0	$0	$0	-$39,517	-$39,517	-$39,517	-$39,517	-$39,517
25	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
26	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
27	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
28	$0	$0	$0	$0	$0	-$192,806	-$192,806	-$192,806	-$192,806	-$192,806
29	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
30	-$6,149	-$11,677	-$18,779	-$14,006	-$14,095	$161,568	$161,568	$161,568	$161,568	$161,568

Large Office	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$39,906	$39,906	$39,906	$123,227	$57,404	$352,647	-$1,065,759	-$1,476,190	$98,124	-$1,014,770
Maintenance	$0	$0	$0	$0	$0	$1,786	$1,786	$0	$1,786	$1,786
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
2	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
3	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
4	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
5	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
6	$0	$0	$0	$0	$0	-$29,710	-$29,710	-$29,710	-$29,710	-$29,710
7	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
8	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
9	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
10	$0	$0	$0	$0	$0	-$26,507	-$26,507	-$26,507	-$26,507	-$26,507
11	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
12	$0	$0	$0	$0	$0	-$39,517	-$39,517	-$39,517	-$39,517	-$39,517
13	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
14	$0	$0	$0	$0	$0	-$182,999	-$182,999	-$182,999	-$182,999	-$182,999
15	$0	$0	$0	$0	$0	$419,344	$423,439	$14,173	$438,058	$436,830
16	$0	$0	$0	$0	$0	-$10,030	-$10,030	-$10,030	-$10,030	-$10,030
17	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
18	$0	$0	$0	$0	$0	-$29,710	-$29,710	-$29,710	-$29,710	-$29,710
19	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
20	$5,439	$5,439	$5,439	$5,439	$5,439	-$20,056	-$17,074	-$7,073	-$9,353	-$9,185
21	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
22	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
23	$0	$0	$0	$0	$0	$1,220	$6,062	$9,173	$4,623	$4,670
24	$0	$0	$0	$0	$0	-$39,517	-$39,517	-$39,517	-$39,517	-$39,517
25	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
26	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
27	$0	$0	$0	$0	$0	-$28,759	-$28,759	-$28,759	-$28,759	-$28,759
28	$0	$0	$0	$0	$0	-$192,806	-$192,806	-$192,806	-$192,806	-$192,806
29	$0	$0	$0	$0	$0	-$224	-$224	-$224	-$224	-$224
30	-$36,525	-$37,456	-$37,456	-$67,632	-$45,364	$118,895	$112,435	$105,333	$79,930	$102,109

B.3 Standalone Retail Cost Summary

Standalone Retail	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$1,686	$1,497	$2,155	$2,408	$2,681	-$65,035	-$65,035	-$65,035	-$65,035	-$65,035
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$8,203	-$8,203	-$8,203	-$8,203	-$8,203
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$2,957	-$2,957	-$2,957	-$2,957	-$2,957
15	$4,350	$5,596	$6,008	$6,542	$6,965	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$4,514	$4,514	$4,514	$4,514	$4,514
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$9,760	$9,760	$9,760	$9,760	$9,760
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$3,824	-$3,824	-$3,824	-$3,824	-$3,824

Standalone Retail	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$27,158	$28,358	$28,358	$52,642	$52,642	-$36,190	-$35,180	-$34,522	-$9,985	-$9,712
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$8,203	-$8,203	-$8,203	-$8,203	-$8,203
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$2,957	-$2,957	-$2,957	-$2,957	-$2,957
15	$0	$0	$0	$0	$0	$4,350	$5,596	$6,008	$6,542	$6,965
16	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$510	$510	$510	$510	$510	$5,024	$5,024	$5,024	$5,024	$5,024
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$12,717	$12,717	$12,717	$12,717	$12,717
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$9,760	$9,760	$9,760	$9,760	$9,760
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$11,985	-$12,330	-$12,330	-$19,693	-$19,703	-$15,809	-$16,154	-$16,154	-$23,517	-$23,527

B.4 Primary School Cost Summary

Primary School	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	-$75,274	-$23,258	-$133,113	-$47,700	-$43,026	$12,267	$12,267	$12,267	$12,267	$12,267
Maintenance	$81	$84	-$801	$63	$46	-$27	-$27	-$27	-$27	-$27
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$55,113	-$19,111	-$125,544	-$34,912	-$30,224	$50,960	$50,960	$50,960	$50,960	$50,960
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	-$546	-$290	-$429	-$551	-$716	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$356	$69	$225	$361	$547	$0	$0	$0	$0	$0

Primary School	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$151,864	$130,637	$130,637	$203,349	$210,631	$88,857	$119,646	$9,620	$167,916	$179,872
Maintenance	$0	$0	$0	$0	$0	$54	$57	-$829	$36	$19
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$4,153	$31,849	-$74,884	$16,048	$20,737
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$32,635	$32,635	$32,635	$32,635	$32,635	$32,089	$32,345	$32,206	$32,084	$31,919
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$56,080	-$48,726	-$48,726	-$71,328	-$73,298	-$55,724	-$48,657	-$48,501	-$70,967	-$72,751

B.5 Small Hotel Cost Summary

Small Hotel	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$1,181	$5,098	$5,246	$5,154	$5,100	$2,863	$2,863	$2,863	$2,863	$2,863
Maintenance	-$144	-$1	-$1	-$1	-$1	-$91	-$91	-$91	-$91	-$91
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$604	-$604	-$604	-$604	-$604
15	$902	$4,317	$4,563	$4,254	$4,236	$2,792	$2,792	$2,792	$2,792	$2,792
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$604	-$604	-$604	-$604	-$604
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	$517	$517	$517	$517	$517

Small Hotel	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$16,439	$10,565	$10,565	$24,423	$31,157	$20,483	$18,527	$18,675	$32,441	$39,120
Maintenance	$0	$0	$0	$0	$0	-$235	-$92	-$92	-$92	-$92
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$604	-$604	-$604	-$604	-$604
15	$0	$0	$0	$0	$0	$3,694	$7,109	$7,356	$7,046	$7,028
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$850	$850	$850	$850	$850	$850	$850	$850	$850	$850
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$604	-$604	-$604	-$604	-$604
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$8,337	-$6,341	-$6,341	-$10,779	-$12,587	-$7,820	-$5,823	-$5,823	-$10,262	-$12,069

B.6 Mid-rise Apartment Cost Summary

Mid-rise Apartment	HVAC					Lighting				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	-$586	$1,926	$2,070	$1,631	$1,769	$0	$0	$0	$0	$0
Maintenance	$0	$0	$0	$0	$0	-$71	-$71	-$71	-$71	-$71
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$2,794	$1,982	$2,170	$1,595	$1,777	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Mid-rise Apartment	Envelope, Power and Other					Total				
	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago	2A Houston	3A Memphis	3B El Paso	4A Baltimore	5A Chicago
New Construction	$6,296	$21,288	$21,288	$11,261	$17,807	$5,711	$23,214	$23,358	$12,891	$19,577
Maintenance	$0	$0	$0	$0	$0	-$71	-$71	-$71	-$71	-$71
Replacement (Year)						$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	$2,794	$1,982	$2,170	$1,595	$1,777
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$5,079	-$10,325	-$10,325	-$6,910	-$8,659	-$5,079	-$10,325	-$10,325	-$6,910	-$8,659

Appendix C

Energy Cost and Use

This appendix includes summary energy use, cost, and savings data used in the cost effectiveness analysis.

Energy cost savings tables show the total building energy cost in $ per square foot for each prototype in each climate zone analyzed. Annual energy cost for each edition of Standard 90.1 is shown with the cost savings and percentage savings.

Energy use savings tables show the total building site energy use cost in kWh, therms, and kBtu per square foot per year for each prototype in each climate zone analyzed. Annual energy use for each edition of Standard 90.1 is shown with the use savings and percentage savings.

Energy end use tables show the end use breakdown of annual electric and gas use per square foot for each prototype in each climate zone analyzed. Results are shown for 90.1-2010 and 90.1-2013.

C.1 Energy Cost and Savings Summary with Plug and Process Loads, 90.1-2010 and 90.1-2013

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office												
Electricity	$1.053	$0.903	$0.150	14.2%	$1.001	$0.887	$0.114	11.4%	$0.954	$0.885	$0.069	7.2%
Gas	$0.000	$0.000	$0.000	-	$0.002	$0.002	$0.000	0.0%	$0.000	$0.001	$0.000	-
Totals	$1.053	$0.903	$0.150	14.2%	$1.003	$0.889	$0.114	11.4%	$0.954	$0.885	$0.069	7.2%
Large Office												
Electricity	$2.158	$2.055	$0.102	4.7%	$2.062	$1.989	$0.073	3.5%	$2.107	$2.036	$0.071	3.4%
Gas	$0.018	$0.020	-$0.002	-11.1%	$0.033	$0.051	-$0.019	-57.6%	$0.016	$0.017	-$0.001	-6.3%
Totals	$2.176	$2.076	$0.100	4.6%	$2.094	$2.040	$0.054	2.6%	$2.123	$2.053	$0.070	3.3%
Stand-Alone Retail												
Electricity	$1.408	$1.246	$0.162	11.5%	$1.324	$1.168	$0.156	11.8%	$1.321	$1.209	$0.112	8.5%
Gas	$0.055	$0.045	$0.010	18.2%	$0.077	$0.063	$0.014	18.2%	$0.067	$0.061	$0.006	9.0%
Totals	$1.462	$1.290	$0.172	11.8%	$1.401	$1.231	$0.169	12.1%	$1.388	$1.270	$0.118	8.5%
Primary School												
Electricity	$1.481	$1.266	$0.216	14.6%	$1.366	$1.193	$0.172	12.6%	$1.314	$1.080	$0.234	17.8%
Gas	$0.118	$0.117	$0.002	1.7%	$0.152	$0.155	-$0.002	-1.3%	$0.106	$0.112	-$0.006	-5.7%
Totals	$1.600	$1.382	$0.217	13.6%	$1.518	$1.348	$0.170	11.2%	$1.420	$1.193	$0.228	16.1%
Small Hotel												
Electricity	$1.259	$1.133	$0.126	10.0%	$1.215	$1.106	$0.108	8.9%	$1.168	$1.057	$0.111	9.5%
Gas	$0.203	$0.203	$0.000	0.0%	$0.218	$0.218	-$0.001	-0.5%	$0.209	$0.209	$0.000	0.0%
Totals	$1.462	$1.336	$0.126	8.6%	$1.432	$1.325	$0.108	7.5%	$1.377	$1.267	$0.111	8.1%
Mid-rise Apartment												
Electricity	$1.284	$1.193	$0.091	7.1%	$1.236	$1.170	$0.065	5.3%	$1.243	$1.179	$0.064	5.1%
Gas	$0.012	$0.011	$0.001	8.3%	$0.039	$0.043	-$0.004	-10.3%	$0.010	$0.011	-$0.002	-20.0%
Totals	$1.296	$1.203	$0.092	7.1%	$1.275	$1.214	$0.061	4.8%	$1.253	$1.190	$0.063	5.0%

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office								
Electricity	$0.957	$0.855	$0.102	10.7%	$0.956	$0.862	$0.094	9.8%
Gas	$0.004	$0.003	$0.001	25.0%	$0.013	$0.010	$0.003	23.1%
Totals	$0.961	$0.858	$0.103	10.7%	$0.969	$0.872	$0.097	10.0%
Large Office								
Electricity	$1.991	$1.944	$0.048	2.4%	$1.976	$1.935	$0.041	2.1%
Gas	$0.054	$0.067	-$0.013	-24.1%	$0.098	$0.111	-$0.013	-13.3%
Totals	$2.046	$2.011	$0.035	1.7%	$2.074	$2.046	$0.028	1.4%
Standalone Retail								
Electricity	$1.265	$1.107	$0.158	12.5%	$1.247	$1.077	$0.169	13.6%
Gas	$0.102	$0.075	$0.027	26.5%	$0.144	$0.106	$0.038	26.4%
Totals	$1.367	$1.182	$0.184	13.5%	$1.390	$1.183	$0.207	14.9%
Primary School								
Electricity	$1.297	$1.134	$0.163	12.6%	$1.261	$1.106	$0.155	12.3%
Gas	$0.173	$0.178	-$0.005	-2.9%	$0.207	$0.206	$0.001	0.5%
Totals	$1.470	$1.312	$0.158	10.7%	$1.468	$1.312	$0.156	10.6%
Small Hotel								
Electricity	$1.190	$1.083	$0.107	9.0%	$1.240	$1.133	$0.107	8.6%
Gas	$0.236	$0.237	-$0.001	-0.4%	$0.255	$0.255	$0.000	0.0%
Totals	$1.426	$1.320	$0.106	7.4%	$1.495	$1.389	$0.106	7.1%
Mid-rise Apartment								
Electricity	$1.227	$1.178	$0.049	4.0%	$1.224	$1.176	$0.048	3.9%
Gas	$0.063	$0.057	$0.006	9.5%	$0.121	$0.108	$0.014	11.6%
Totals	$1.290	$1.235	$0.055	4.3%	$1.345	$1.284	$0.062	4.6%

C.2 Energy use and Savings Summary with Plug and Process Loads, 90.1-2010 and 90.1-2013

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office												
Electricity, kWh/ft^2	10.205	8.747	1.457	14.3%	9.699	8.593	1.106	11.4%	9.241	8.571	0.670	7.3%
Gas, therm/ft^2	0.000	0.000	0.000	-	0.002	0.002	0.000	0.0%	0.000	0.001	0.000	-
Totals, kBtu/ft^2	34.859	29.888	4.971	14.3%	33.289	29.560	3.728	11.2%	31.575	29.309	2.267	7.2%
Large Office												
Electricity, kWh/ft^2	20.909	19.917	0.991	4.7%	19.979	19.269	0.710	3.6%	20.420	19.733	0.686	3.4%
Gas, therm/ft^2	0.019	0.021	-0.002	-10.5%	0.033	0.052	-0.019	-57.6%	0.016	0.017	-0.001	-6.3%
Totals, kBtu/ft^2	73.213	70.031	3.182	4.3%	71.477	70.964	0.512	0.7%	71.262	69.053	2.209	3.1%
Stand-Alone Retail												
Electricity, kWh/ft^2	13.641	12.072	1.569	11.5%	12.830	11.320	1.509	11.8%	12.805	11.716	1.088	8.5%
Gas, therm/ft^2	0.055	0.045	0.010	18.2%	0.078	0.064	0.014	17.9%	0.067	0.062	0.006	9.0%
Totals, kBtu/ft^2	52.070	45.701	6.370	12.2%	51.542	45.009	6.534	12.7%	50.445	46.167	4.278	8.5%
Primary School												
Electricity, kWh/ft^2	14.355	12.265	2.090	14.6%	13.235	11.565	1.670	12.6%	12.735	10.466	2.269	17.8%
Gas, therm/ft^2	0.119	0.118	0.002	1.7%	0.154	0.156	-0.002	-1.3%	0.107	0.114	-0.006	-5.6%
Totals, kBtu/ft^2	60.935	53.642	7.293	12.0%	60.550	55.095	5.455	9.0%	54.173	47.077	7.096	13.1%
Small Hotel												
Electricity, kWh/ft^2	12.200	10.978	1.222	10.0%	11.769	10.720	1.049	8.9%	11.319	10.245	1.075	9.5%
Gas, therm/ft^2	0.205	0.205	0.000	0.0%	0.220	0.221	-0.001	-0.5%	0.211	0.211	0.000	0.0%
Totals, kBtu/ft^2	62.133	57.937	4.196	6.8%	62.164	58.648	3.516	5.7%	59.746	56.114	3.632	6.1%
Mid-rise Apartment												
Electricity, kWh/ft^2	12.442	11.557	0.886	7.1%	11.975	11.340	0.634	5.3%	12.049	11.424	0.625	5.2%
Gas, therm/ft^2	0.012	0.011	0.001	8.3%	0.039	0.044	-0.004	-10.3%	0.010	0.011	-0.002	-20.0%
Totals, kBtu/ft^2	43.662	40.536	3.126	7.2%	44.792	43.068	1.723	3.8%	42.090	40.127	1.963	4.7%

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office								
Electricity, kWh/ft^2	9.277	8.288	0.989	10.7%	9.265	8.352	0.913	9.9%
Gas, therm/ft^2	0.004	0.003	0.001	25.0%	0.013	0.010	0.003	23.1%
Totals, kBtu/ft^2	32.034	28.550	3.484	10.9%	32.951	29.534	3.416	10.4%
Large Office								
Electricity, kWh/ft^2	19.295	18.833	0.462	2.4%	19.148	18.750	0.397	2.1%
Gas, therm/ft^2	0.055	0.068	-0.013	-23.6%	0.099	0.112	-0.013	-13.1%
Totals, kBtu/ft^2	71.337	71.039	0.298	0.4%	75.274	75.208	0.066	0.1%
Standalone Retail								
Electricity, kWh/ft^2	12.256	10.728	1.528	12.5%	12.080	10.440	1.641	13.6%
Gas, therm/ft^2	0.103	0.076	0.027	26.2%	0.145	0.107	0.038	26.2%
Totals, kBtu/ft^2	52.115	44.210	7.905	15.2%	55.738	46.310	9.429	16.9%
Primary School								
Electricity, kWh/ft^2	12.571	10.990	1.581	12.6%	12.221	10.717	1.504	12.3%
Gas, therm/ft^2	0.175	0.180	-0.005	-2.9%	0.209	0.208	0.001	0.5%
Totals, kBtu/ft^2	60.386	55.490	4.896	8.1%	62.608	57.420	5.188	8.3%
Small Hotel								
Electricity, kWh/ft^2	11.533	10.497	1.036	9.0%	12.018	10.982	1.037	8.6%
Gas, therm/ft^2	0.238	0.239	-0.001	-0.4%	0.257	0.258	0.000	0.0%
Totals, kBtu/ft^2	63.204	59.744	3.460	5.5%	66.750	63.261	3.489	5.2%
Mid-rise Apartment								
Electricity, kWh/ft^2	11.889	11.412	0.478	4.0%	11.861	11.397	0.464	3.9%
Gas, therm/ft^2	0.064	0.058	0.006	9.4%	0.123	0.109	0.014	11.4%
Totals, kBtu/ft^2	46.989	44.747	2.242	4.8%	52.735	49.757	2.978	5.6%

C.3 Energy by Usage Category, 90.1-2010 and 90.1-2013

Annual Energy Usage for Buildings in Climate Zone 2A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-rise Apartment	
	Electric kWh/ft^2·yr	Gas therms/ft^2·yr	Electric kWh/ft^2·yr	Gas therms/ft^2·yr	Electric kWh/ft^2·yr	Gas therms/ft^2·yr	Electric kWh/ft^2·yr	Gas therms/ft^2·yr	Electric kWh/ft^2·yr	Gas therms/ft^2·yr	Electric kWh/ft^2·yr	Gas therms/ft^2·yr
Base Code: 90.1-2007												
Heating, Humidification	0.084	0.000	0.004	0.010	0.000	0.021	0.000	0.060	0.192	0.003	0.000	0.012
Cooling	2.109	0.000	4.183	0.000	3.079	0.000	3.867	0.000	3.310	0.000	2.250	0.000
Fans, Pumps, Heat Recovery	1.262	0.000	1.787	0.000	2.680	0.000	1.876	0.000	1.815	0.000	1.787	0.000
Lighting, Interior & Exterior	3.356	0.000	2.534	0.000	5.692	0.000	3.264	0.000	3.083	0.000	1.438	0.000
Plugs, Refrigeration, Other	2.485	0.000	12.401	0.000	2.190	0.000	5.252	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.109	2.756	0.000
Total	10.205	0.000	20.909	0.019	13.641	0.055	14.355	0.119	12.200	0.205	12.442	0.012
ASHRAE 90.1-2010												
Heating, Humidification	0.082	0.000	0.004	0.012	0.000	0.011	0.000	0.059	0.195	0.003	0.000	0.011
Cooling	1.375	0.000	3.540	0.000	2.702	0.000	3.094	0.000	2.899	0.000	1.795	0.000
Fans, Pumps, Heat Recovery	0.994	0.000	1.708	0.000	2.401	0.000	1.581	0.000	1.789	0.000	1.558	0.000
Lighting, Interior & Exterior	2.947	0.000	2.277	0.000	4.782	0.000	2.864	0.000	2.510	0.000	1.242	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.628	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.109	2.754	0.000
Total	8.747	0.000	19.917	0.021	12.072	0.045	12.265	0.118	10.978	0.205	11.557	0.011
Total Savings	1.457	0.000	0.991	-0.002	1.569	0.010	2.090	0.002	1.222	0.000	0.886	0.001

Annual Energy Usage for Buildings in Climate Zone 3A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-rise Apartment	
	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr
Base Code: 90.1-2007												
Heating, Humidification	0.240	0.002	0.010	0.024	0.000	0.043	0.000	0.093	0.539	0.009	0.000	0.039
Cooling	1.575	0.000	3.410	0.000	2.344	0.000	2.835	0.000	2.559	0.000	1.687	0.000
Fans, Pumps, Heat Recovery	1.154	0.000	1.650	0.000	2.590	0.000	1.855	0.000	1.802	0.000	1.662	0.000
Lighting, Interior & Exterior	3.337	0.000	2.509	0.000	5.706	0.000	3.198	0.000	3.069	0.000	1.439	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.250	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.035	0.097	0.014	0.000	0.119	2.976	0.000
Total	9.699	0.002	19.979	0.033	12.830	0.078	13.235	0.154	11.769	0.220	11.975	0.039
ASHRAE 90.1-2010												
Heating, Humidification	0.265	0.002	0.010	0.043	0.000	0.029	0.000	0.096	0.613	0.009	0.000	0.044
Cooling	1.041	0.000	2.995	0.000	2.073	0.000	2.343	0.000	2.215	0.000	1.364	0.000
Fans, Pumps, Heat Recovery	0.988	0.000	1.592	0.000	2.245	0.000	1.615	0.000	1.791	0.000	1.552	0.000
Lighting, Interior & Exterior	2.951	0.000	2.284	0.000	4.817	0.000	2.884	0.000	2.515	0.000	1.242	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.626	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.035	0.097	0.014	0.000	0.119	2.975	0.000
Total	8.593	0.002	19.269	0.052	11.320	0.064	11.565	0.156	10.720	0.221	11.340	0.044
Total Savings	1.106	0.000	0.710	-0.019	1.509	0.014	1.670	-0.002	1.049	-0.001	0.634	-0.004

Annual Energy Usage for Buildings in Climate Zone 3B

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-rise Apartment	
	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$
Base Code: 90.1-2007												
Heating, Humidification	0.109	0.000	1.095	0.007	0.000	0.033	0.000	0.047	0.188	0.003	0.000	0.010
Cooling	1.183	0.000	2.658	0.000	2.170	0.000	2.364	0.000	2.391	0.000	1.578	0.000
Fans, Pumps, Heat Recovery	1.222	0.000	1.765	0.000	2.681	0.000	1.832	0.000	1.871	0.000	1.920	0.000
Lighting, Interior & Exterior	3.333	0.000	2.500	0.000	5.764	0.000	3.195	0.000	3.070	0.000	1.439	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.247	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.035	0.097	0.014	0.000	0.116	2.902	0.000
Total	9.241	0.000	20.420	0.016	12.805	0.067	12.735	0.107	11.319	0.211	12.049	0.010
ASHRAE 90.1-2010												
Heating, Humidification	0.120	0.001	1.006	0.008	0.000	0.027	0.000	0.054	0.222	0.003	0.000	0.011
Cooling	1.016	0.000	2.423	0.000	1.983	0.000	1.959	0.000	2.067	0.000	1.278	0.000
Fans, Pumps, Heat Recovery	1.145	0.000	1.640	0.000	2.658	0.000	0.928	0.000	1.854	0.000	1.795	0.000
Lighting, Interior & Exterior	2.941	0.000	2.278	0.000	4.889	0.000	2.861	0.000	2.517	0.000	1.242	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.621	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.035	0.097	0.014	0.000	0.116	2.901	0.000
Total	8.571	0.001	19.733	0.017	11.716	0.062	10.466	0.114	10.245	0.211	11.424	0.011
Total Savings	0.670	0.000	0.686	-0.001	1.088	0.006	2.269	-0.006	1.075	0.000	0.625	-0.002

Annual Energy Usage for Buildings in Climate Zone 4A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-rise Apartment	
	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$
Base Code: 90.1-2007												
Heating, Humidification	0.344	0.004	0.015	0.045	0.000	0.067	0.000	0.113	0.949	0.015	0.000	0.064
Cooling	1.115	0.000	2.814	0.000	1.694	0.000	2.160	0.000	1.928	0.000	1.244	0.000
Fans, Pumps, Heat Recovery	1.114	0.000	1.574	0.000	2.705	0.000	1.922	0.000	1.795	0.000	1.753	0.000
Lighting, Interior & Exterior	3.310	0.000	2.491	0.000	5.668	0.000	3.144	0.000	3.062	0.000	1.438	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.248	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.036	0.097	0.015	0.000	0.131	3.244	0.000
Total	9.277	0.004	19.295	0.055	12.256	0.103	12.571	0.175	11.533	0.238	11.889	0.064
ASHRAE 90.1-2010												
Heating, Humidification	0.274	0.003	0.018	0.057	0.000	0.040	0.000	0.118	1.008	0.016	0.000	0.058
Cooling	0.804	0.000	2.595	0.000	1.509	0.000	1.827	0.000	1.650	0.000	1.044	0.000
Fans, Pumps, Heat Recovery	0.957	0.000	1.555	0.000	2.176	0.000	1.668	0.000	1.780	0.000	1.677	0.000
Lighting, Interior & Exterior	2.905	0.000	2.277	0.000	4.857	0.000	2.774	0.000	2.474	0.000	1.242	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.624	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.036	0.097	0.015	0.000	0.131	3.242	0.000
Total	8.288	0.003	18.833	0.068	10.728	0.076	10.990	0.180	10.497	0.239	11.412	0.058
Total Savings	0.989	0.001	0.462	-0.013	1.528	0.027	1.581	-0.005	1.036	-0.001	0.478	0.006

Annual Energy Usage for Buildings in Climate Zone 5A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-rise Apartment	
	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$
Base Code: 90.1-2007												
Heating, Humidification	0.532	0.013	0.889	0.088	0.000	0.108	0.000	0.146	1.781	0.025	0.000	0.123
Cooling	0.913	0.000	1.824	0.000	1.356	0.000	1.813	0.000	1.576	0.000	0.999	0.000
Fans, Pumps, Heat Recovery	1.113	0.000	1.538	0.000	2.826	0.000	1.920	0.000	1.801	0.000	1.782	0.000
Lighting, Interior & Exterior	3.313	0.000	2.496	0.000	5.709	0.000	3.144	0.000	3.061	0.000	1.438	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.248	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.140	3.432	0.000
Total	9.265	0.013	19.148	0.099	12.080	0.145	12.221	0.209	12.018	0.257	11.861	0.123
ASHRAE 90.1-2010												
Heating, Humidification	0.436	0.010	0.897	0.101	0.000	0.070	0.000	0.146	1.796	0.026	0.000	0.109
Cooling	0.679	0.000	1.676	0.000	1.204	0.000	1.531	0.000	1.343	0.000	0.830	0.000
Fans, Pumps, Heat Recovery	0.980	0.000	1.508	0.000	2.171	0.000	1.686	0.000	1.784	0.000	1.689	0.000
Lighting, Interior & Exterior	2.908	0.000	2.281	0.000	4.878	0.000	2.780	0.000	2.473	0.000	1.241	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.623	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.140	3.429	0.000
Total	8.352	0.010	18.750	0.112	10.440	0.107	10.717	0.208	10.982	0.258	11.397	0.109
Total Savings	0.913	0.003	0.397	-0.013	1.641	0.038	1.504	0.001	1.037	0.000	0.464	0.014

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APPENDIX C

Measure	Changes in Proposed 2018 NC Energy Code from 2012 Energy Code	Estimated Impact on Costs
SECTION C402 BUILDING ENVELOPE REQUIREMENTS		
C402.1 General	No Change	None
TABLE C402.1.3: Thermal Insulation Values	No Change	None
C402.2 Specific building thermal envelope insulation requirements	No Change	None
C402.3 Roof solar reflectance and thermal emittance.	New	Minor impact; several exceptions
C402.4 Fenestration	No Change	None
C402.5 Air leakage—thermal envelope		
C402.5.1 Air barriers.	Exterior air barrier	Significant impact for some buildings; many are already in compliance
C402.5.2 Air leakage of fenestration.	No Change	None
C402.5.3 Rooms containing space conditioning fuel-burning appliances. [	No Change	None
C402.5.4 Doors and access openings to shafts, chutes, stairways and elevator lobbies.	No Change	None
C402.5.5 Air intakes, exhaust openings, stairways and shafts.	No Change	None
C402.5.6 Loading dock weatherseals.	No Change	None
C402.5.7 Vestibules.	No Change	None
C402.5.8 Recessed lighting.	No Change	None

SECTION C405 ELECTRICAL POWER AND LIGHTING SYSTEMS		
C405.1 General (Mandatory).	No Change	None
C405.2 Lighting controls		
C405.2.1 Occupant sensor controls.	Added requirements for copy/print rooms, lounges, restrooms, storage rooms (>100 sq ft), janitorial closets, mech rooms, warehouses)	Minor impact
C405.2.1.1 Occupant sensor control function.	New requirement	None
C405.2.1.2 Occupant sensor control function in warehouses.	New requirement	Insignificant impact on cost
C405.2.2 Time-switch controls.	Added requirement for shop and laboratory classrooms	Insignificant impact on cost
C405.2.2.1 Time-switch control function.	Very similar to previous	None
C405.2.2.2 Light-reduction controls.	Very similar to previous	None
C405.2.3 Daylight responsive controls	Deleted this section from the 2015 IECC	None
C405.2.4 Specific application controls	Very similar to previous	None
C405.2.5 Exterior lighting controls	Very similar to previous	None
C405.3 Exit signs	Very similar to previous	None
C405.4 Interior lighting power requirements		
C405.4.1 Total connected interior lighting power	Very similar to previous	
TABLE C405.4.2(1) INTERIOR LIGHTING POWER ALLOWANCES: BUILDING AREA METHOD	Many values have changed; some are lower and others are higher; the total wattage/ sq ft that decrease are balanced by the total wattage/ sq ft that increased	No significant change on a multi-building basis
TABLE C405.4.2(1) INTERIOR LIGHTING POWER ALLOWANCES: SPACE-BY-SPACE AREA METHOD		
C405.4.2.2 Space-by-Space Method.	Many changes/ some lower and some higher	No significant change on a multi-building basis
C405.4.2.2.1 Additional interior lighting power.	Very similar to previous	None
C405.5.1 Exterior building lighting power	New tables	Insignificant cost impact
C405.6 Electrical energy consumption	Very similar to previous	None
C405.7 Electrical transformers	New requirement	Insignificant cost impact
C405.8 Electrical motors	New requirement	Insignificant cost impact
C405.9 Verical and horizontal transportation systems and equipmet	New requiremnt	Insignificant cost impact
SECTION C406 ADDITIONAL EFFICIENCY PACKAGE OPTIONS		
C406.1 Requirements. Buildings shall comply with at least one of the following:		
1. More efficient HVAC performance in accordance with Section C406.2.	Very similar to previous	Insignificant cost impact
2. Reduced lighting power density system in accordance with Section C406.3.	Very similar to previous	Insignificant cost impact

3. Enhanced lighting controls in accordance with Section C406.4.	Very similar to previous	Insignificant cost impact
4. On-site supply of renewable energy in accordance with Section C406.5.	Very similar to previous	Insignificant cost impact
5. Provision of a dedicated outdoor air system for certain HVAC equipment in accordance with Section C406.6.	Very similar to previous	Insignificant cost impact
6. High-efficiency service water heating in accordance with Section C406.7.	Very similar to previous	Insignificant cost impact

SECTION C408 SYSTEM COMMISSIONING

C408.3 Lighting system functional testing	Similar to previous (505.2.6)	Insignificant cost impact

Definition of Impacts:
Insignificant impact = less than $0.05/ sq ft
Minor Impact = $0.05 to $0.25/ sq ft
Significant impact = $0.25 to 1 / sq ft
Major impact = greater than $1/ sq ft

Comparison of Building Area Method Lighting Densities:

	2012 NC Energy Code	Proposed 2018 NC Energy Code		2018 diff	2012 diff
BUILDING AREA TYPE		LPD (w/ft2)	2018 vs 2012		
Automotive facility [Note: New to table]	0.91	0.8	lower	0.11	
Convention center	1.05	1.01	lower	0.04	
Courthouse	1.07	1.01	lower	0.06	
Dining: bar lounge/leisure	1.01	1.01	no change		
Dining: cafeteria/fast food	0.93	0.9	lower	0.03	
Dining: family	0.94	0.95	higher		0.01
Dormitory	0.58	0.57	lower	0.01	
Exercise center	0.89	0.84	lower	0.05	
Fire station		0.67	higher		0.67
Gymnasium	0.7	0.94	higher		0.24
Health care clinic	1.06	0.9	lower	0.16	
Hospital	1.06	1.05	lower	0.01	
Hotel/Motel	1.01	0.87	lower	0.14	
Library	0.96	1.19	higher		0.23
Manufacturing facility	0.98	1.17	higher		0.19
Motel	1.05	0.87	lower	0.18	
Motion picture theater	0.86	0.76	lower	0.1	
Multifamily	0.53	0.51	lower	0.02	
Museum	1.05	1.02	lower	0.03	
Office	0.89	0.82	lower	0.07	
Parking garage	0.22	0.21	lower	0.01	
Penitentiary	0.94	0.81	lower	0.13	
Performing arts theater	1.35	1.39	higher		0.04
Police station	0.94	0.87	lower	0.07	
Post office	0.84	0.87	higher		0.03
Religious building	1.14	1	lower	0.14	
Retail	1.41	1.26	lower	0.15	
School/university	0.98	0.87	lower	0.11	
Sports arena	0.71	0.91	higher		0.2
Town hall	0.89	0.89	no change		
Transportation	0.76	0.7	lower	0.06	
Warehouse	0.56	0.66	higher		0.1
Workshop	1.59				
				1.68	1.71

Building Area Type[a]	(W/ft^2)	
Common Space Types		
Active Storage		0.63
Atrium - First Three Floors		0.63
Atrium - Each Additional Floor		0.16
Automotive Facility		0.91
Bank / Office, Bank Activity Area		1.38

Classroom / Lecture / Training		1.25
Conference / Meeting / Multipurpose		1.29
Corridor / Transition		0.65
Education Laboratory		1.28
Electrical / Mechanical		0.95
Food Preparation		0.99
Lobby		0.6
Locker Room		0.78
Medical / Industrial Research Laboratory		1.62
Parking Garage - Garage Area		0.21
Restroom		0.84
Stairway		0.69
Convention Center	1.05	
Exhibit Space		1.58
Audience / Seating Area		0.8
Court House	1.07	
Audience / Seating Area		0.8
Courtroom		1.91
Confinement Cells		1.1
Judges Chambers		1.17
Dressing / Locker / Fitting Room		0.78
Dining: Bar / Lounge / Leisure	1.01	
Lounge / Leisure Dining		1.4
Dining: Cafeteria / Fast Food	0.93	
Dining: Family	0.94	
Dining		0.99
Dormitory	0.58	
Living Quarters		0.32
Bedroom		0.5
Study Hall		1.3
Exercise Center	0.89	
Dressing / Locker / Fitting Room		0.78
Audience / Seating Area		0.3
Exercise Area / Gymnasium		0.72
Gymnasium	0.7	
Dressing / Locker / Fitting Room		0.78
Audience / Seating Area		0.4
Playing Area		1.35
Exercise Area		0.72
Healthcare Clinic / Hospital	1.06	
Corridors w/ patient waiting, exam		0.94
Exam / Treatment		1.66
Emergency		2.35
Public & Staff Lounge		0.79
Hospital / Medical Supplies		1.27
Hospital - Nursery		0.6
Nurse Station		0.87
Physical Therapy		0.91
Patient Room		0.62
Pharmacy		1.14
Hospital / Radiology		1.34
Operating Room		1.89
Recovery		1.15
Active Storage		0.63
Laundry – Washing		0.6
Hotel	1.01	
Dining Area		0.85
Guest quarters		1.11
Reception / Waiting		2.3
Lobby		1.05
Library	0.96	
Library - Audio Visual		0.6
Stacks		1.42
Card File & Cataloguing		0.72
Reading Area		0.93
Manufacturing Facility	0.98	
Low Bay (< 25 ft Floor to Ceiling)		1.19
High Bay (> 25 ft Floor to Ceiling)		1.34
Detailed Manufacturing		1.29
Equipment Room		0.95
Corridor / Transition		0.41
Motel	1.05	
Dining Area		1.05

Living Quarters		0.75
Reception / Waiting		1.9
Motion Picture Theater	0.86	
Audience / Seating Area		0.53
Lobby		1.13
Multi-Family	0.53	
Museum	1.05	
Active Storage		0.63
General Exhibition		1.05
Restoration		1.02
Office	0.89	
Enclosed		1.11
Open Plan		0.98
Parking Garage	0.22	
Penitentiary	0.94	
Performing Arts Theater	1.35	
Audience / Seating Area		2.3
Lobby		2.34
Dressing / Locker / Fitting Room		1.14
Police / Fire Station	0.94	
Fire Station Engine Room		0.56
Sleeping Quarters		0.25
Post Office / SF	0.84	
Sorting Area		0.94
Lobby		1
Religious Buildings	1.14	
Lobby / Fellowship Hall		0.64
Worship / Pulpit / Choir		1.95
Retail$_c$	1.41	
Department Store Sales Area		1.3
Dressing / Fitting Room		0.96
Fine Merchandise Sales Area		2.6
Mall Concourse		1.06
Mass Merchandising Sales Area		1.3
Personal Services Sales Area		1.3
Specialty Store Sales Area		1.6
Supermarket Sales Area		1.3
School / University	0.98	
Classroom		1.3
Audience		0.7
Dining Area		1
Office		1
Corridor		0.5
Storage		0.5
Laboratory		1.28
Sports Arena	0.71	
Ring Sports Arena		2.68
Court Sports Arena		1.8
Town Hall	0.89	
Transportation	0.76	
Dining Area		1.9
Baggage Area		0.76
Airport - Concourse		0.39
Terminal - Ticket Counter		1.12
Reception / Waiting		0.5
Warehouse	0.56	
Fine Material		0.95
Medium Bulky Material		0.63
Workshop	1.59	

Convention Center	1.05	
Court House	1.07	
Dining: Bar / Lounge / Leisure	1.01	
Dining: Cafeteria / Fast Food	0.93	
Dining: Family	0.94	
Dormitory	0.58	
Exercise Center	0.89	
Gymnasium	0.7	
Healthcare Clinic / Hospital	1.06	
Hotel	1.01	
Library	0.96	
Manufacturing Facility	0.98	

Motel	1.05	
Motion Picture Theater	0.86	
Multi-Family	0.53	
Museum	1.05	
Office	0.89	
Parking Garage	0.22	
Penitentiary	0.94	
Performing Arts Theater	1.35	
Police / Fire Station	0.94	
Post Office / SF	0.84	
Religious Buildings	1.14	
Retail$_c$	1.41	
School / University	0.98	
Sports Arena	0.71	
Town Hall	0.89	
Transportation	0.76	
Warehouse	0.56	
Workshop	1.59	
Active Storage		0.63
Atrium - First Three Floors		0.63
Atrium - Each Additional Floor		0.16
Automotive Facility		0.91
Bank / Office, Bank Activity Area		1.38
Classroom / Lecture / Training		1.25
Conference / Meeting / Multipurpose		1.29
Corridor / Transition		0.65
Education Laboratory		1.28
Electrical / Mechanical		0.95
Food Preparation		0.99
Lobby		0.6
Locker Room		0.78
Medical / Industrial Research Laboratory		1.62
Parking Garage - Garage Area		0.21
Restroom		0.84
Stairway		0.69
Exhibit Space		1.58
Audience / Seating Area		0.8
Audience / Seating Area		0.8
Courtroom		1.91
Confinement Cells		1.1
Judges Chambers		1.17
Dressing / Locker / Fitting Room		0.78
Lounge / Leisure Dining		1.4
Dining		0.99
Living Quarters		0.32
Bedroom		0.5
Study Hall		1.3
Dressing / Locker / Fitting Room		0.78
Audience / Seating Area		0.3
Exercise Area / Gymnasium		0.72
Dressing / Locker / Fitting Room		0.78
Audience / Seating Area		0.4
Playing Area		1.35
Exercise Area		0.72
Corridors w/ patient waiting, exam		0.94
Exam / Treatment		1.66
Emergency		2.35
Public & Staff Lounge		0.79
Hospital / Medical Supplies		1.27
Hospital - Nursery		0.6
Nurse Station		0.87
Physical Therapy		0.91
Patient Room		0.62
Pharmacy		1.14
Hospital / Radiology		1.34
Operating Room		1.89
Recovery		1.15
Active Storage		0.63
Laundry – Washing		0.6
Dining Area		0.85
Guest quarters		1.11
Reception / Waiting		2.3
Lobby		1.05

Library - Audio Visual		0.6
Stacks		1.42
Card File & Cataloguing		0.72
Reading Area		0.93
Low Bay (< 25 ft Floor to Ceiling)		1.19
High Bay (> 25 ft Floor to Ceiling)		1.34
Detailed Manufacturing		1.29
Equipment Room		0.95
Corridor / Transition		0.41
Dining Area		1.05
Living Quarters		0.75
Reception / Waiting		1.9
Audience / Seating Area		0.53
Lobby		1.13
Active Storage		0.63
General Exhibition		1.05
Restoration		1.02
Enclosed		1.11
Open Plan		0.98
Audience / Seating Area		2.3
Lobby		2.34
Dressing / Locker / Fitting Room		1.14
Fire Station Engine Room		0.56
Sleeping Quarters		0.25
Sorting Area		0.94
Lobby		1
Lobby / Fellowship Hall		0.64
Worship / Pulpit / Choir		1.95
Department Store Sales Area		1.3
Dressing / Fitting Room		0.96
Fine Merchandise Sales Area		2.6
Mall Concourse		1.06
Mass Merchandising Sales Area		1.3
Personal Services Sales Area		1.3
Specialty Store Sales Area		1.6
Supermarket Sales Area		1.3
Classroom		1.3
Audience		0.7
Dining Area		1
Office		1
Corridor		0.5
Storage		0.5
Laboratory		1.28
Ring Sports Arena		2.68
Court Sports Arena		1.8
Dining Area		1.9
Baggage Area		0.76
Airport - Concourse		0.39
Terminal - Ticket Counter		1.12
Reception / Waiting		0.5
Fine Material		0.95
Medium Bulky Material		0.63

Measure	Changes in Proposed 2018 NC Energy Code from 2012 Energy Code	Estimated Impact on Costs
C403 BUILDING MECHANICAL SYSTEMS		
C403.1 to C403.2 General Requirements	No Change	None
C403.2.3 HVAC Equipment Performance Requirements.	Federal Requirements; no impact from adopting new code	None
C403.2.4 HVAC System Controls.	No Change	None
C403.2.4.7 Economizer fault detection and diagnostics.	Not adopted. No Change	None
C403.2.6.1 Demand controlled ventilation.	Classrooms and some other additional spaces required	Minor impact
C403.2.6.2 Enclosed parking garage ventilation controls.	Not adopted. No Change	None
C403.2.7 Energy recovery ventilation systems.	No Change	None
C403.2.8 Kitchen exhaust system.	Not adopted. No Change	None
C403.2.9 Duct and plenum insulation and sealing.	Duct insulation goes from R-5 to R-6 and additional minor	Minor impact
C403.2.9.1 Duct construction.	No Change	None
C403.2.10 Piping insulation.	No Change	None
C403.2.11 Mechanical systems commissioning and completion requirements. (C408.2)	Added more comprehensive commissioning requirements	Significant impact
C403.2.12 Air system design and control.	Minor changes	Insignificant impact
C403.2.13 Heating outside a building.	No Change	None
C403.2.14 to C403.2.17. Sections dealing with refrigeration.	Not adopted. No Change	None
C403.3 Economizers.	No Change	None
C403.3.4 Water-side economizers.	No Change	None
C403.4.1. Fan control.	VAV fan controls are now required for fan systems => 5 hp, was 10 hp in 2012 NCECC	Minor impact
C403.4.1.3 Set points for direct digital control.	This requires reset of static pressure in VAV systems.	Insignificant impact
C403.4.2 Hydronic systems controls.	This section requires staging of boilers on systems of 300,000 btu/hr or greater; was 500,000 btu/hr	Minor impact
C403.4.2.3.2 Heat rejection.	No Change	None
C403.4.2.4 Part-load controls.	New code requires temperature reset and speed control on hydronic systems => 300,000 btu/hr; was 500,000 btu/hr	Minor impact
C403.4.2.5 Boiler Turndown.	New code requires certain boiler turndown ratios for systems > 1,000,000 btu/hr.	Insignificant impact
C403.4.2.6 Pump isolation.	No Change	None
C403.4.3 Heat rejection equipment.	There is a requirement for running multiple cell cooling towers at the same speed. There is also a new requirement for reducing water flows to cooling towers.	Minor impact
C403.4.4.4 Fractional hp fan motors.	Requires ECM motors for motors between 1/12 hp and 1 hp.	Minor impact
C403.4.4.5 Supply-air temperature reset controls.	No Change	None
C403.4.4.6 Multiple-zone VAV system ventilation optimization control.	Not adopted. No Change	None
C403.4.5 Heat recovery for service water heating. .	No Change	None
C403.4.6 Hot gas bypass limitation.	No Change	None
C403.5 Refrigeration systems.	Not adopted. No Change	None
C404 SERVICE WATER HEATING	No Change	None
C404.11 Service water-heating system commissioning and completion requirements (C408.2)	Requires commissioning	Significant impact

Definition of Impacts:
Insignificant impact = less than $0.05/ sq ft
Minor Impact = $0.05 to $0.25/ sq ft
Significant impact = $0.25 to 1 / sq ft
Major impact = greater than $1/ sq ft