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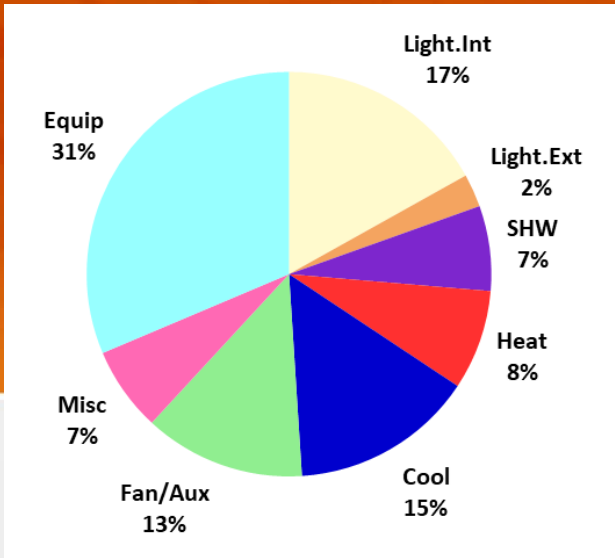

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End-Use Opportunity Analysis Based on Standard 90.1-2016

November 2019

C Nambiar
R Hart
Y Xie

U.S. DEPARTMENT OF ENERGY

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

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Executive Summary

This report summarizes technical analysis conducted by Pacific Northwest National Laboratory (PNNL), assessing expected end-use energy consumption in commercial buildings, based on recent editions of the model energy code for the commercial sector, ANSI/ASHRAE/IES[1] Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings.* The results, which are available in supplemental summary tables,[2] represent simulated energy use based on the U.S. Department of Energy (DOE) Commercial Prototype Building Models[3] across representative climate zones in the United States, as defined by Standard 90.1. PNNL examined the resulting simulation outputs to assess how energy is used across primary systems within prominent U.S. commercial building types. This work builds upon the previously published report; *End-Use Opportunity Analysis from Progress Indicator Results for ASHRAE Standard 90.1-2013* (Hart and Xie, 2014).

The purpose of this study was to understand how energy is being used in each building type at the end-use level and to identify areas for improvements in future code cycles. The analysis was performed with the simulation results of the 90.1-2016 Progress Indicator[4] study conducted by PNNL. This report is aimed at providing members of ASHRAE 90.1 Standing Standard Project Committee and other interested parties a better understanding of how the code affects the various systems and end uses within the commercial buildings whose energy efficiency is most prominently influenced by code, and where the greatest opportunities exist for remaining efficiency and affordability. In addition, this report is aimed at providing industry stakeholders guidance in identifying building types and end-uses with greatest potential for energy efficiency improvements through meeting energy codes and those that may require beyond code measures to meet aggressive energy use reduction targets.

This report is broken down into two major parts: the first part introduces the background and analysis method followed and the second part presents the breakdown of results in terms of energy cost. The main findings of this analysis work are summarized in Figure S.1, which shows end-use cost data by building type weighted by national construction by climate zone. The weighting represents the relative share of each building type in the predicted national construction floor area. Prototype results are grouped by similar type into eight building groups: Office (Off), Warehouse (Whse), Retail (Rtl), Hotel, Apartment (Apt), Education (Sch), Healthcare (Med), and Food Service (Rest). The widths of the building type (vertical) bars are scaled to represent each building group's share of impact on national building energy cost. The examined end uses include:

- interior lighting (Light.Int)
- exterior lighting (Light.Ext)
- service hot water (SHW)
- space heating, humidification and dehumidification (Heat)

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society

[2] PNNL. 2014. *2016EndUseTables.xlsx.* Pacific Northwest National Laboratory, Richland, WA. Available at https://www.energycodes.gov/sites/default/files/documents/2016EndUseTables.zip.

[3] Commercial Prototype Building Models, details available at: https://www.energycodes.gov/development/commercial/prototype_models

[4] Available at: https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf

- space cooling and heat rejection (Cool)
- heating, ventilation, and air conditioning fans and pumps (FanAux)
- miscellaneous loads including refrigeration, elevators and transformers (Misc); and
- equipment including cooking, information technology and other plug load equipment (Equip).

The area of each block represents the proportion of weighted national energy cost for each end use within the building group. The entire area of the plot represents the total national building energy cost of the Prototype Buildings based on Standard 90.1-2016. Equipment and Interior lighting are the two most dominant end uses with the most impact on national building energy cost, and Retail and Medical are the building groups that contribute more than the others.

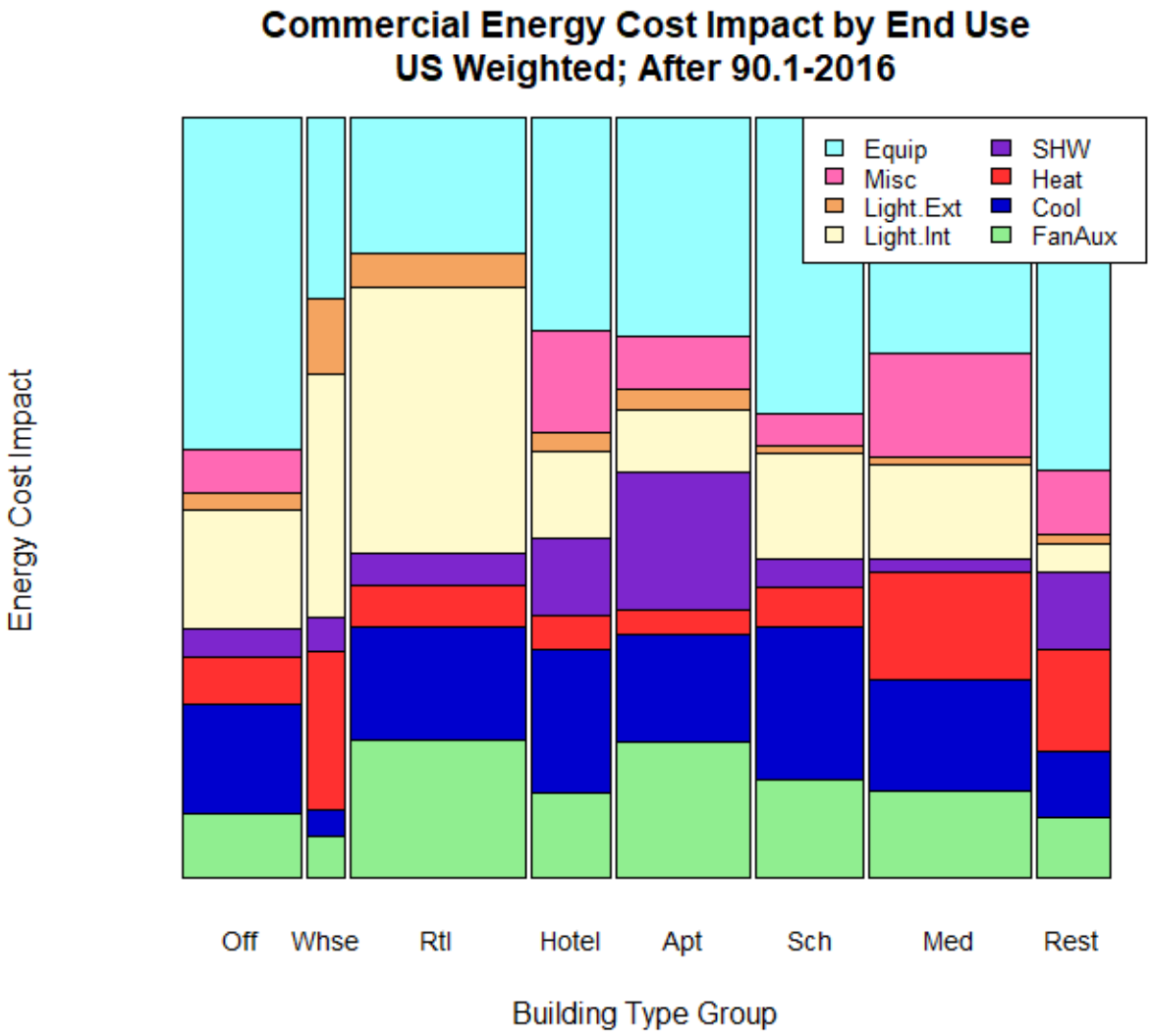


Figure S.1. Prototype energy cost impact by end use after 90.1-2016; U.S. weighted by building type and climate zone

Potential Savings Areas

To help future codes focus on measures with greatest savings potential we developed a scoring methodology called "Focus Potential Score." The score is intended to focus attention on the highest remaining end-use categories that have not achieved savings to date and is explained in more detail on Page 17. The "focus potential score" is based on three factors: Savings from 90.1-2004 to 90.1-2016, individual building energy cost index (ECI), and national weighted ECI. The three factors are weighted as shown in Table 4 below with higher priority given to end-uses that have not had large savings historically, and have high building ECI and high national weighted ECI.

In the heat map of focus potential scores (see Table 5), darker green indicates areas that may have high savings potential, and white indicates areas that have lower savings potential. Based on the heat map in Table S1, prime areas for investigation of further savings potential (in order) are

- Equipment
- Service hot water
- Interior lighting (especially retail)
- Space cooling
- Fans and auxiliaries

Table S1. Total end-use "Focus Potential Scores"

Building Type	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc.	Equip
Office	5.6	2.3	6.5	4.7	5.6	5.7	6.1	11.2
Warehouse	4.1	3.6	6.0	4.8	3.5	3.4		6.9
Retail	10.0	3.3	6.4	3.6	5.7	6.4		9.0
Hotel	5.6	4.1	7.6	3.1	7.2	6.4	8.0	9.9
Apartment	5.9	3.6	8.6	3.0	6.5	7.9	6.6	10.2
School	4.0	2.5	6.4	3.6	5.5	4.4	5.1	10.2
Medical	8.4	2.6	6.1	7.1	8.1	7.2	9.7	11.4
Restaurant	4.8	3.2	9.3	8.8	7.3	6.4	8.2	10.6
U.S. Weighted	6.3	3.1	6.8	4.2	5.7	5.8	4.2	9.6

Acknowledgments

Data used as the basis for this analysis was developed by the Building Energy Codes Program (BECP) team members at the Pacific Northwest National Laboratory (PNNL) to compare ANSI/ASHRAE/IES Standard 90.1-2016 to earlier editions of Standard 90.1. Their long-term work to develop and enhance the underlying building simulation prototype models made this report possible. PNNL BECP team members include Michael Rosenberg, Mark Halverson, Yulong Xie, Jian Zhang, Supriya Goel, Reid Hart, Yan Chen, Chitra Nambiar, Jeremy Lerond, and Michael Myer. The authors wish to acknowledge support of the ASHRAE Standing Standard Project Committee 90.1, which provided valuable feedback and insight that is paramount to developing and maintaining the prototype building models. The authors would also like to thank Jeremy Williams at the U.S. Department of Energy (DOE) for providing programmatic oversight and funding for the project.

Acronyms and Abbreviations

ANSI	American National Standards Institute
Apt	Apartment
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BECP	Building Energy Codes Program
Cook	cooking
Cool	cooling
CZ	climate zone
DOE	Department of Energy
ECI	energy cost index
EIA	Energy Information Administration
Equip	equipment
EUI	energy use index
Fan.Aux	fans, pumps and auxiliaries
Heat	heating
Ht.Rcvy	heat recovery
Ht.Rej	heat rejection
Humidify	humidification
HVAC	heating, ventilation, and air conditioning
IES	Illuminating Engineering Society
IT	information technology
Light.Ext	exterior lighting
Light.Int	interior lighting
Med	Healthcare
MHC	McGraw-Hill Construction
Misc.	miscellaneous
Off	office
PNNL	Pacific Northwest National Laboratory
Refrig	refrigeration
Rest	restaurant
Rtl	retail
Sch	school
SSPC	Standing Standard Project Committee
SHW	service hot water
Txfmr	transformer
WBCI	weighted building cost index
Whse	warehouse

Contents

Figures

Tables

Background and Method

End Uses Analyzed

Pacific Northwest National Laboratory (PNNL) conducts analysis to estimate the energy use of buildings constructed in accordance with each edition of ANSI/ASHRAE/IES[5] Standard 90.1 (Standard 90.1), *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2004, 2007, 2010, 2013, and 2016). The comparison of the savings of each edition to the prior edition is referred to as the "progress indicator." This report is based on analysis of the Standard 90.1-2016 (ASHRAE 2016) progress indicator.[6] The progress indicator analysis is based on Commercial Building prototype models simulated in EnergyPlus across representative climate zones in the United States as defined by Standard 90.1.[7] PNNL examined the detailed results to determine how the remaining energy was used. This report provides analysis results using the simple and detailed breakdowns as shown in Table 1.

Table 1. Simple and detailed end-use category descriptions

Simple Breakdown Abbreviation	Color Code	Detailed Breakdown Abbreviation	End-Use Description
Light.Int		Light.Int	Interior lighting
Light.Ext		Light.Ext	Exterior lighting
SHW		SHW	Service hot water
Heat		Heat	Space heating
		Humidify	Humidification and dehumidification
Cool		Cool	Mechanical cooling (including unitary heat rejection)
		Ht.Rej	Heat rejection, cooling towers (unitary is in cool)
Fan.Aux		Fans	Heating, ventilation, and air conditioning (HVAC) supply, return and exhaust fans
		Ht.Rcvy	Heat recovery fan and wheel energy
		Pumps	Hydronic pumping, including SHW recirculation
Misc		Refrig	Refrigeration equipment and kitchen refrigerators and freezers
		Elevator	Elevators
		Txfmr	In-building transformers
Equip		Cook	Cooking and laundry equipment
		IT	Computer room information technology (IT) and telephone equipment[8]
		Equip	Other plug loads and equipment

The graphs in this report are based on energy cost index (ECI) and mostly use the simple breakdown.

[5] American National Standards Institute/American Society of Heating, Refrigerating, and Air-Conditioning Engineers/Illuminating Engineering Society.
[6] Commercial Building Prototype Models available at: https://www.energycodes.gov/development/commercial/prototype_models
[7] Commercial Building Prototype Models available at: https://www.energycodes.gov/development/commercial/prototype_models
[8] While IT equipment is present to some extent in many building types, only the Large Office prototype models equipment in the specific computer room IT end-use subcategory. Computing equipment in other prototypes is captured under the Equipment subcategory.

This report builds upon the previously published work *End-Use Opportunity Analysis from Progress Indicator Results for ASHRAE Standard 90.1-2013* (Hart and Xie, 2014). That previous work includes energy and energy cost results for prototypes modeled in accordance with all versions of Standard 90.1 between 2004 and 2013. If a comparison is made between the results in the previous report and the current report, there will be minor differences. Those differences occur for several reasons including:

- use of different cities and weather files to represent each climate location
- updated energy costs based on more recent data from the U.S. Energy Information Administration
- improvements to the prototype building models to add additional details and to correct any errors uncovered.

Prototype Buildings for the Progress Indicator

To determine the savings impact from various editions of Standard 90.1, PNNL developed prototype commercial building models. They have been described in detail previously in *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011). As noted in that report, PNNL developed a suite of 16 prototype buildings covering the majority of commercial and mid-rise to high-rise residential new building construction. The prototypes used in the simulations are intended to represent a cross section of common commercial building types and cover the building types that comprise 80% of new commercial construction floor area. The 16 prototype building models were reviewed extensively by building industry experts on the ASHRAE Standing Standard Project Committee (SSPC) 90.1 during development and assessment of multiple editions of Standard 90.1. These prototype models, their detailed characteristics, and their development are described in detail on the Building Energy Codes Program (BECP) web site.[9] A detailed description of the prototypes may also be found in the completed savings analysis of Standard 90.1-2010: *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*, which can be found on the BECP web site.[10] The prototype models described in that report have since been modified as described in the document *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014), also available at the same web site.

The energy analysis of the 16 prototype buildings shown in Table 2 was completed with the EnergyPlus building simulation program (DOE 2019). The results from that analysis are examined in detail and results aggregated based on building type and end-use to produce this detailed end-use analysis report. Each prototype building model is defined as characteristic of a certain class of buildings, mostly corresponding to a classification scheme established in the 2003 DOE/Energy Information Administration Commercial Building Energy Consumption Survey (EIA 2003). Building configurations of the prototype models are shown in Figure 1.

[9] Prototype detail on BECP web site at www.energycodes.gov/development/commercial/90.1_models.
[10] BECP web site at www.energycodes.gov/achieving-30-goal-energy-and-cost-savings-analysis-ashrae-ASHRAE Standard-901-2010.

Table 2. Prototype building models

Building Type	Building Abbreviation	Prototype building	Prototype Abbreviation	Prototype Floor Area (ft^2)
Office	Off	Small Office	OffS	5,502
		Medium Office	OffM	53,628
		Large Office	OffL	498,588
Retail	Rtl	Stand-Alone Retail	RtlStA	24,692
		Strip Mall	RtlMall	22,500
Education	Sch	Primary School	SchPri	73,959
		Secondary School	SchSec	210,887
Lodging	Med	Outpatient Health Care	MedOP	40,946
		Hospital	MedHos	241,501
Hotel	Hotel	Small Hotel	HotSml	43,202
		Large Hotel	HotLrg	122,120
Warehouse	Whse	Non-Refrigerated Warehouse	Whse	52,045
Food Service	Rest	Quick-service Restaurant	RestQS	2,501
		Full-service Restaurant	RestFS	5,502
Apartment	Apt	Mid-Rise Apartment	AptMR	33,741
		High-Rise Apartment	AptHR	84,360

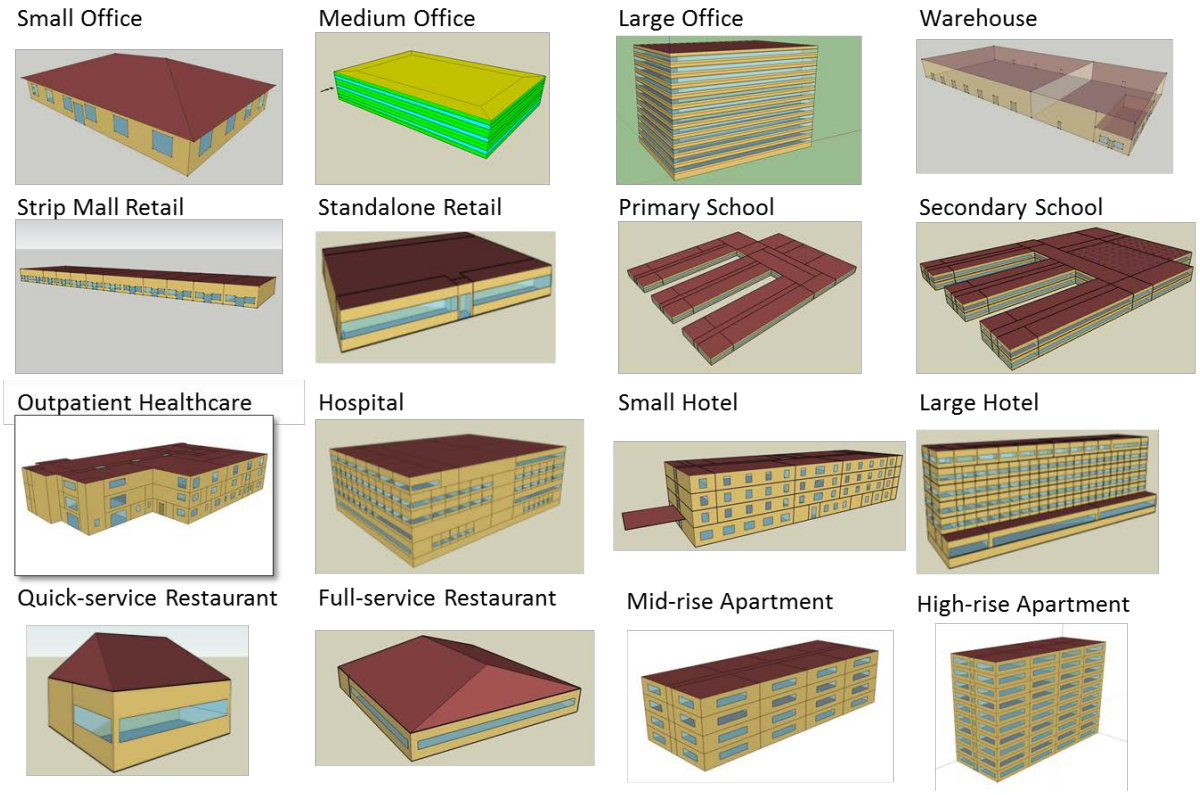


Figure 1. Prototypes analyzed for the end-use dataset

Detailed Tables and Lists

In addition to the graphs included in this report, a supplemental Excel workbook containing detailed results for each prototype at the detailed end-use level is available online (PNNL 2019). That workbook contains a worksheet for each prototype and a matrix of tables with summary national results and detailed results for each climate zone. In addition to ECI, site energy use index (EUI) results, source EUI results, and gas and electric end-use results are included. The workbook also contains the following tables:

- U.S. average summary results, based on construction weighting,
- results of the prototype buildings at 17 representative climate locations for Standard 90.1 in 2004, 2007, 2010, 2013 and 2016, and
- percentage savings from Standards 90.1-2004 to 90.1-2016.

The workbook also includes a worksheet (i.e., the “DetPri” tab) that provides all detailed ECIs by end use and prototype, sorted by remaining use after Standard 90.1-2016 and sorted by savings from Standard 90.1-2016 when compared to Standard 90.1-2004.

Cost Breakdown Results

The resulting data from the analysis is presented in one of several ways:

- Weighted by U.S. 2003 - 2007 new construction to give an idea of the impact on total U.S. commercial energy cost (Jarnagin and Bandyopadhyay, 2010). Such weightings are usually for the nation as a whole but may focus on energy cost for a particular climate zone. The weightings are based on factors shown in Table 8 on Page 22 of this report. The weightings have been reorganized based on climate zones. Where results are noted as weighted by building type, this data is used.
- Partial weighting is applied to subset building prototypes to arrive at the use and cost breakdown for a building type. For instance, to find the end-use costs for the Office type, the end-use costs for the large, medium, and small offices are weighted proportionally by the individual prototype construction weightings.
- Unweighted results represent the end-use cost experienced by a particular building type and provide a good idea of the ECI on a floor area basis.

Throughout, the cost is based on the energy prices adopted by SSPC 90.1 for their cost-effective analysis using the *Scalar Method*[11] of proposals for Standard 90.1-2016: $0.1013/kWh for electricity and $1.00/therm for fossil fuels.[12]

[11] Details of the Scalar Method can be found here: https://www.energycodes.gov/sites/default/files/documents/commercial_methodology.pdf

[12] The ASHRAE Scalar Method identifies a fossil fuel rate that is primarily applied to heating energy use. For this reason, 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.

U.S. End-Use Cost Breakdown, 90.1-2016

Figure 2 provides a breakdown of building energy costs after implementation of Standard 90.1-2016 across U.S. climate zones, weighted by U.S. new construction.

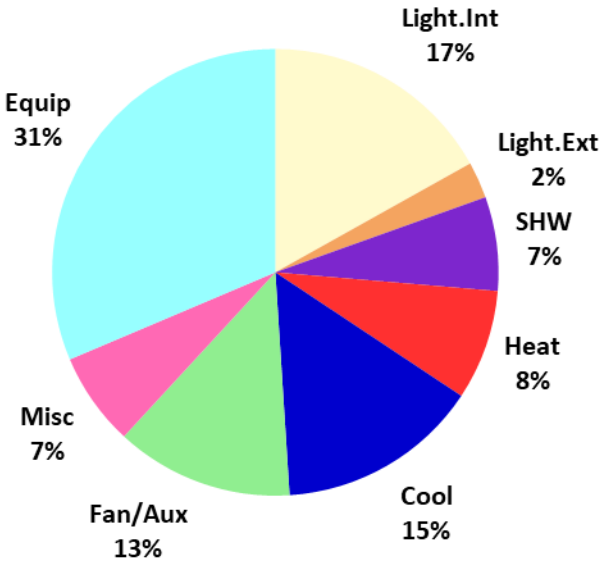


Figure 2. End-use cost for buildings in all U.S. climate zones

Figure 3 shows the same weighted national energy cost with a finer breakdown of end uses and an increase in significant digits for the percentages.

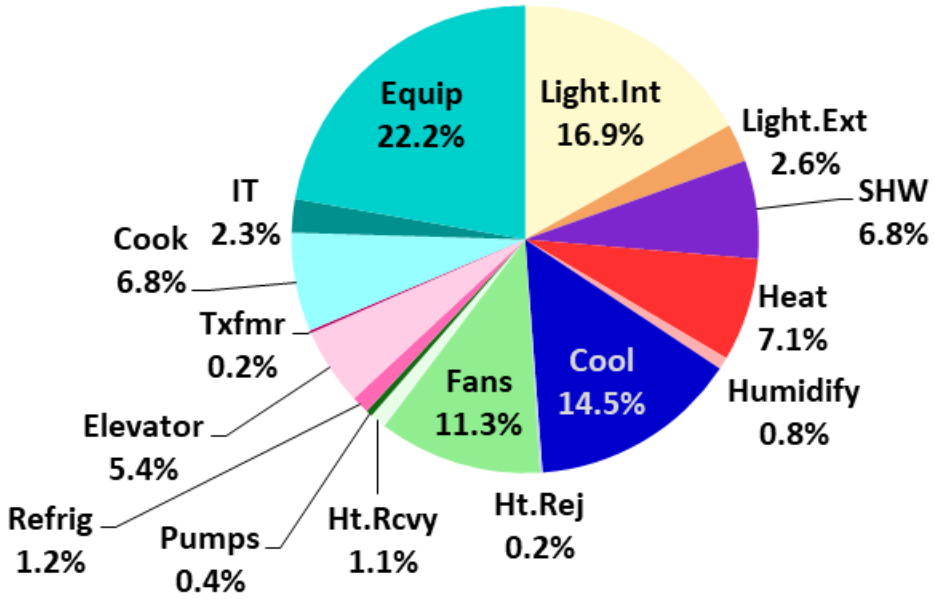


Figure 3. Detailed end-use cost for buildings in all U.S. climate zones

U.S. Weighted Cost by End Use, 2004 vs. 2016

Total U.S. weighted end-use building energy costs can be directly compared for Standards 90.1-2004 and 90.1-2016 (see Figure 4). Most categories show significant reduction; however, the cost reductions for equipment, miscellaneous, and service hot water were not significant, indicating minor progress on measures impacting these end-uses in subsequent editions of Standard 90.1 since 2004. Interior and exterior lighting, heating, cooling and fan/auxiliaries are the end uses with the most savings.

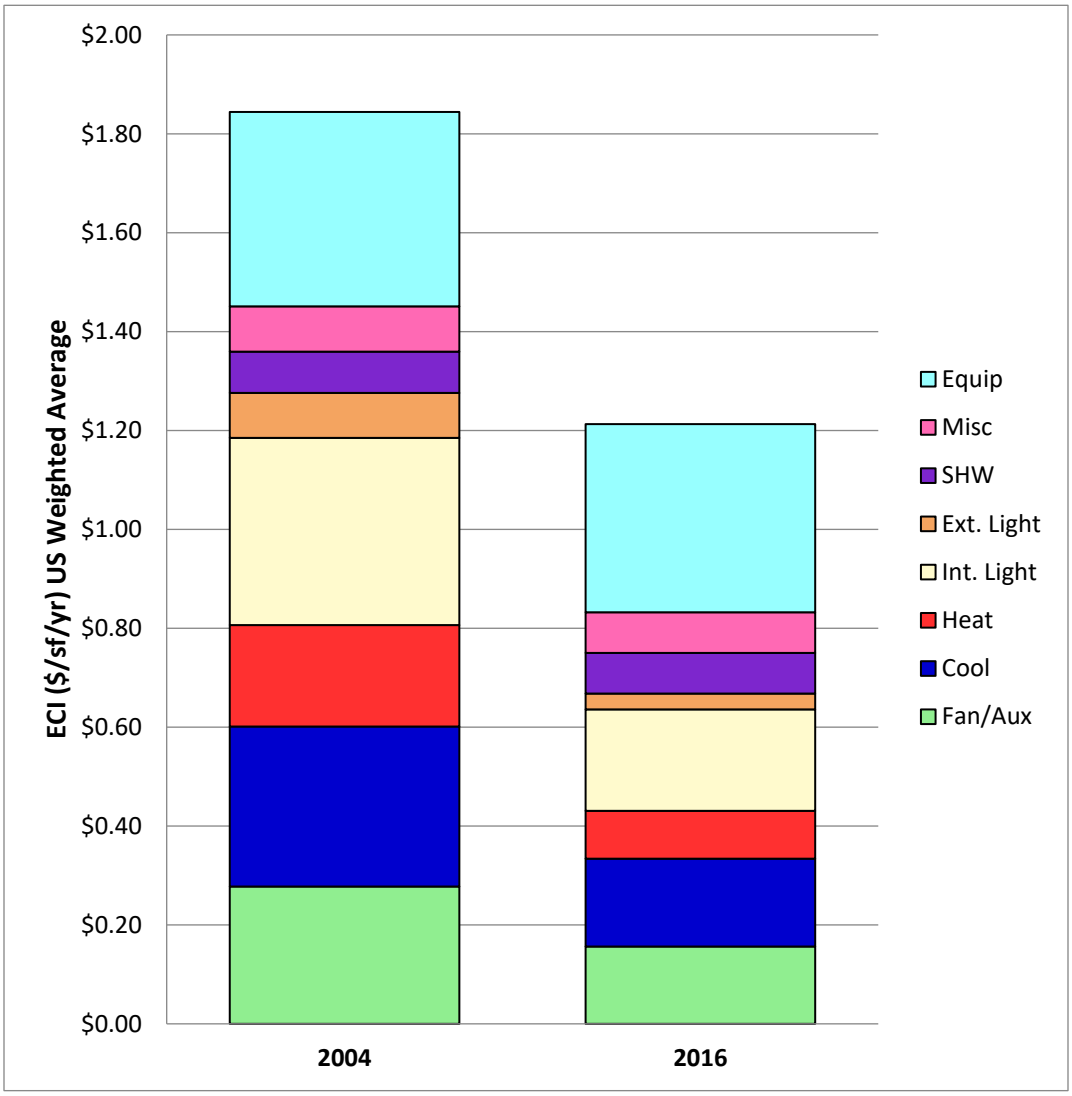


Figure 4. Standard 90.1 end-use cost improvement

U.S. Weighted Cost Impact by Building Type and End Use

An examination of end-use cost data by building type is presented in this section. Figure 5 illustrates building type and energy cost impact weighted by national construction by climate zone. Prototypes are grouped by similar type. The widths of the building type (vertical) bars are scaled to represent each building type's share of impact on national building energy cost. The entire area of the plot matches national building energy use based on Standard 90.1-2016. Using an estimated 8.5 billion square feet of new building floor area calculated by projection of the 8.2 billion square feet from 2003-2007 construction data reports (Jarnagin and Bandyopadhyay, 2010), the area of the plot represents a commercial new construction building energy cost of $10.3 billion per year. Retail lighting stands out as a dominant contributor to the national building energy cost.

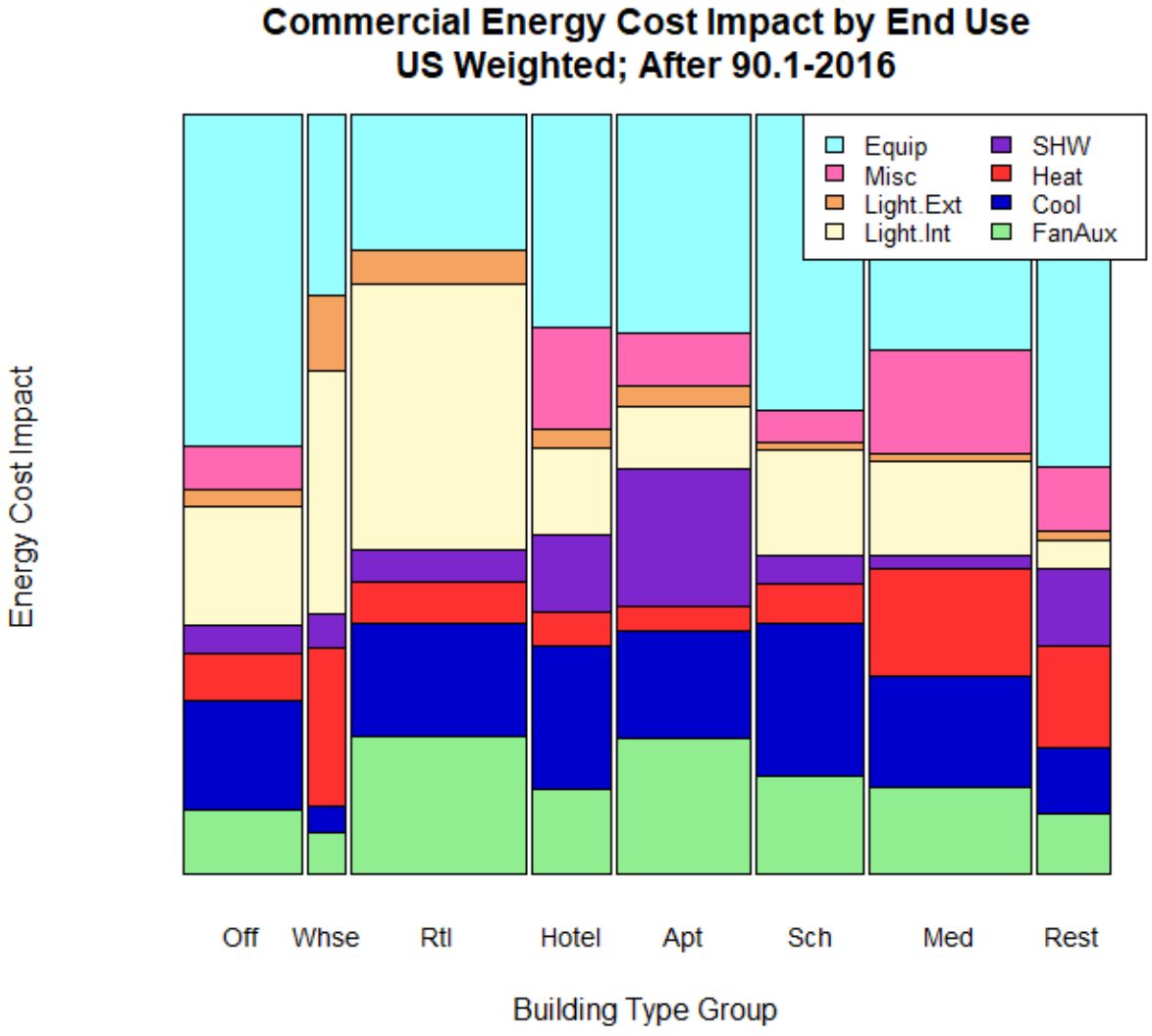


Figure 5. Commercial energy cost impact by end use U.S. weighted, after 90.1-2016

U.S. Weighted Cost Impact by Building Type and End Use, 2004 Base

Figure 6 shows the same nationally weighted results after Standard 90.1-2016 against a base of Standard 90.1-2004. Again, the widths of the building type (vertical) bars are scaled to represent each building type's share of impact on national building energy cost. The entire area of the plot matches national building energy cost based on Standard 90.1-2004, or $13.9 billion. The white savings blocks show the difference for 90.1-2016 compared to 90.1-2004, which amounts to $3.5 billion per year. So, we can see both the savings from the stable 2004 baseline and the remaining energy cost after 90.1-2016. Most savings can be seen in the School, Warehouse and Retail building groups and least in the Apartment and Restaurant groups.

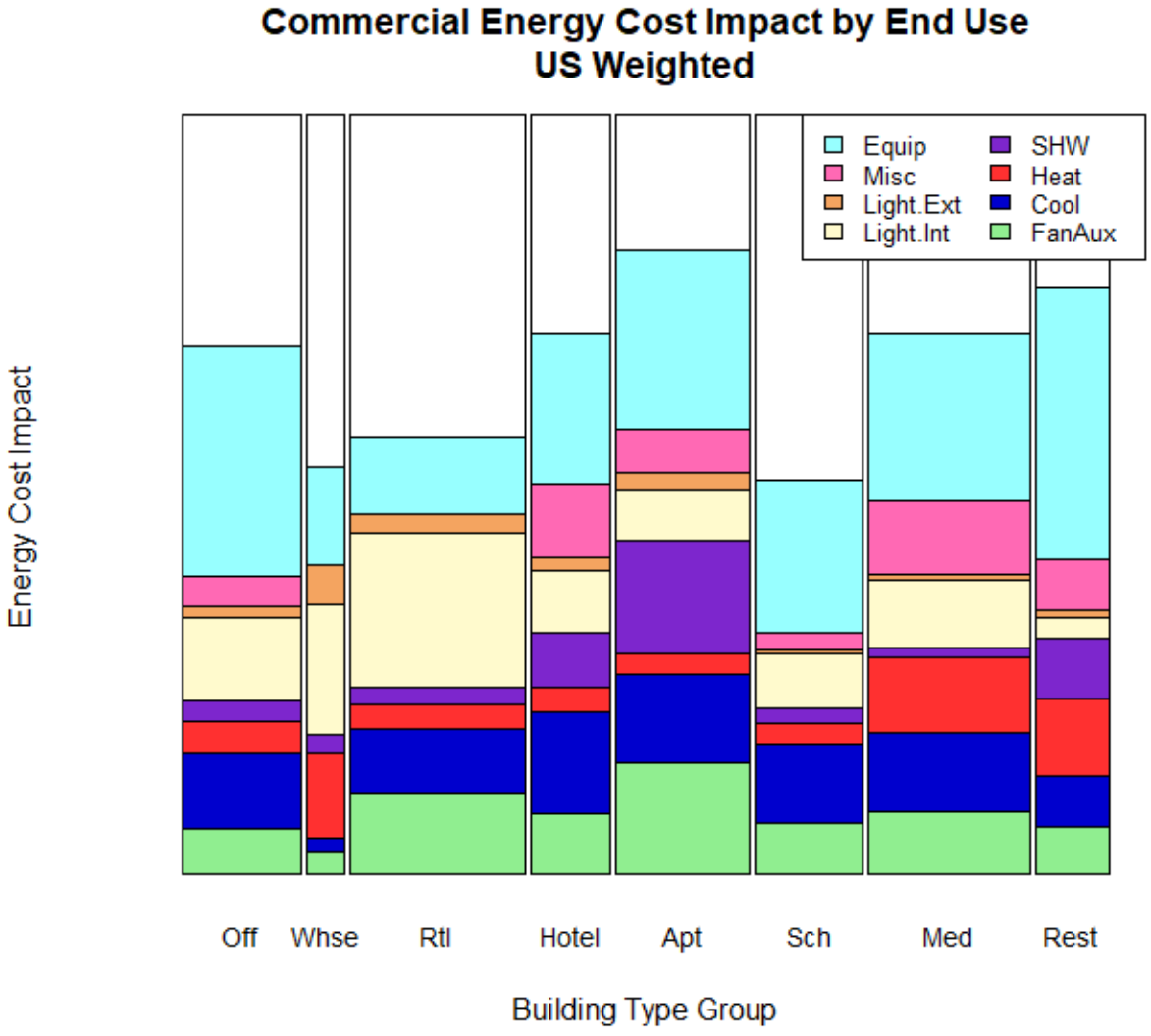


Figure 6. Commercial energy cost impact by end use U.S. weighted (90.1-2004). White area represents savings from 90.1-2004 to 2016

U.S. Weighted End-Use Prioritization

Figure 7 shows overall progress by detailed end use, measured as cost savings from Standard 90.1-2004 to Standard 90.1-2016. The information is prioritized for end uses by national weighted building energy impact or percentage of U.S. total building use after Standard 90.1-2016. The graph shows that equipment, interior lighting and cooling end-uses have the most impact on national weighted energy cost after Standard 90.1-2016 and that equipment end use has surpassed interior lighting as having the highest impact on total national building energy cost.

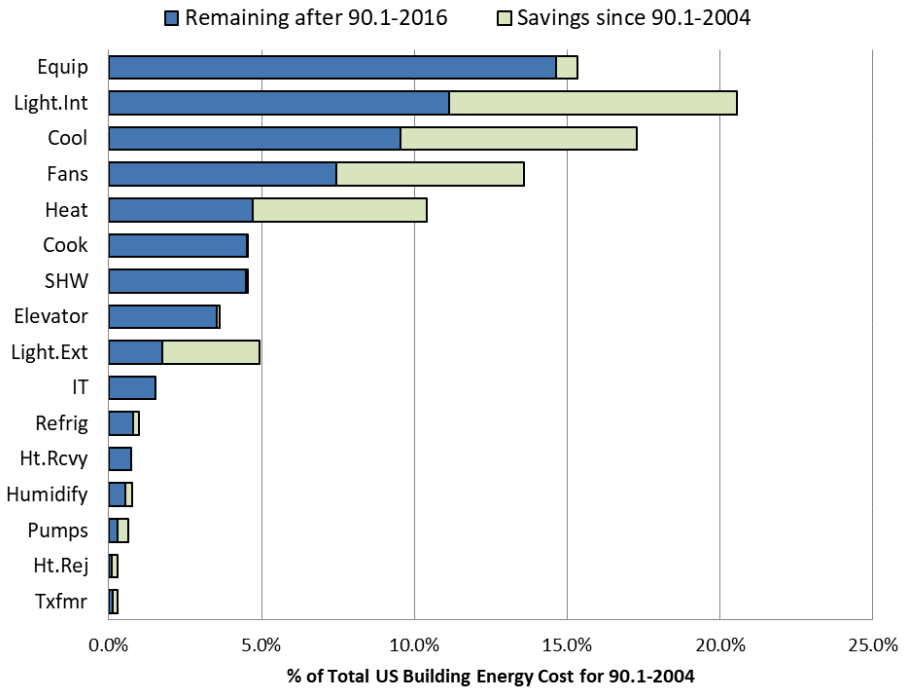


Figure 7. U.S. building energy cost by end use prioritized by post-2016 cost

Table 3 shows the breakdown by building type, with remaining energy cost after Standard 90.1-2016. Red indicates highest remaining cost impact, and white represents lowest remaining cost impact. Appendix A includes more detailed heat maps of costs and cost savings from Standard 90.1-2004 to Standard 90.1-2016.

Table 3. Impact percent of U.S. building energy cost remaining after 90.1-2016

	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc	Equip	Total
Office	2.1%	0.3%	0.5%	0.8%	1.9%	1.1%	0.8%	5.8%	13.3%
Warehouse	1.4%	0.4%	0.2%	0.9%	0.1%	0.2%	0.0%	1.0%	4.3%
Retail	6.9%	0.9%	0.8%	1.1%	2.9%	3.6%	0.0%	3.5%	19.8%
Hotel	1.0%	0.2%	0.9%	0.4%	1.7%	1.0%	1.2%	2.5%	9.0%
Apt	1.2%	0.4%	2.7%	0.5%	2.2%	2.7%	1.1%	4.3%	15.1%
School	1.7%	0.1%	0.5%	0.6%	2.4%	1.5%	0.5%	4.7%	12.1%
Medical	2.3%	0.2%	0.3%	2.6%	2.7%	2.1%	2.5%	5.7%	18.3%
Restaurant	0.3%	0.1%	0.8%	1.1%	0.7%	0.6%	0.7%	3.7%	8.1%
U.S. Weighted	16.9%	2.6%	6.8%	8.0%	14.7%	12.9%	6.8%	31.4%	**100%**

Segment Graphs

Segment Graphs, ECI Weighted for Climate

The segment graphs for each building type (see Figure 8) show the relative end uses based on individual building ECI ($/ft^2/yr). Because they are weighted by climate zone construction, they represent national averages. The radius of each segment is proportional to the end-use ECI for the building type shown, relative to the largest building end-use ECI in the data set. Table A.1 in Appendix A shows the ECIs for each building group and end use. In this segment graph, most building graphs are quite small, but we can see the very high equipment, heating, and service water heating intensity in the food service sector. In the following graphs the other buildings and uses are scaled to make them more readable. The raw data used to generate the segment graphs in this section can be found in Appendix A, Table A.1.

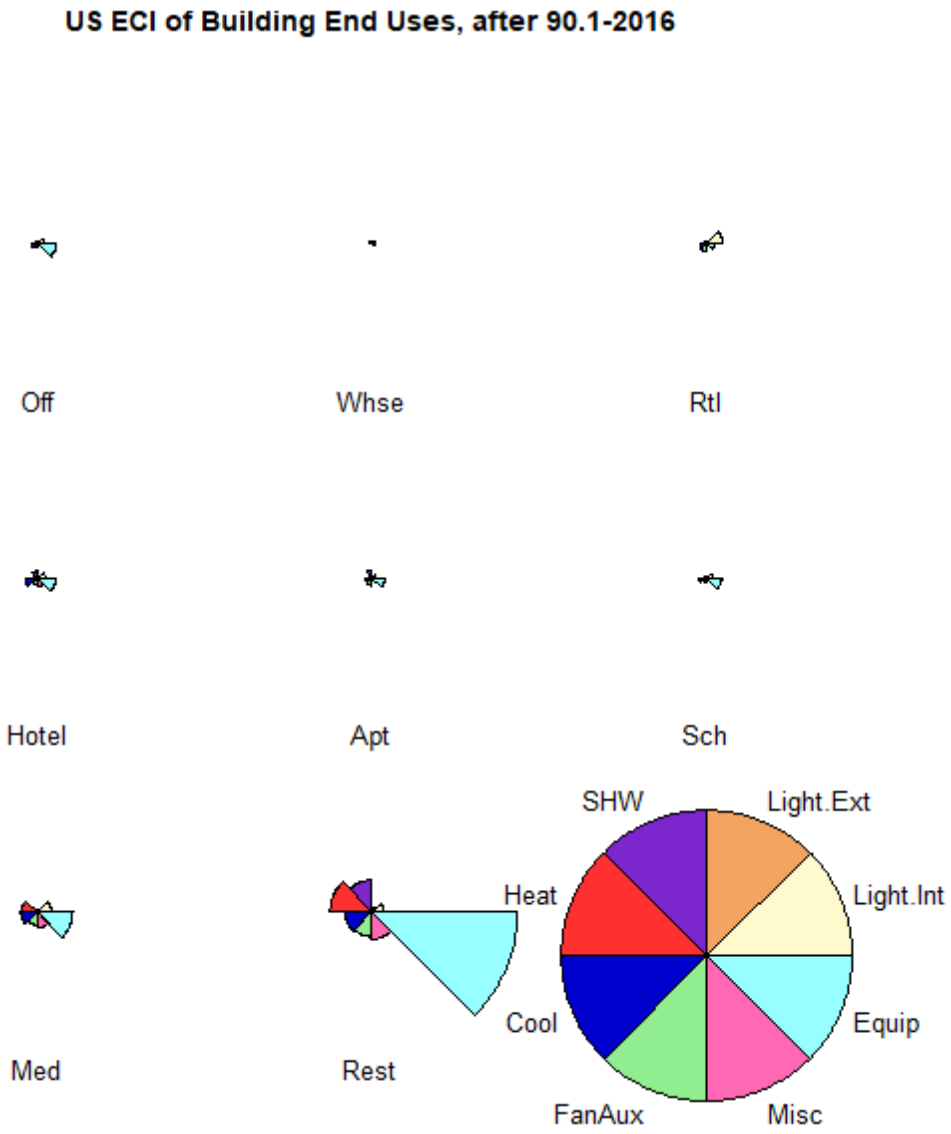


Figure 8. U.S. ECI of building end uses, after 90.1-2016

Segment Graphs, ECI by Climate with Scaled Restaurant Equipment

Figure 9 is based on the same data as Figure 8[13] and shows the Restaurant equipment (primarily cooking) at one-fourth the scale of the other segments. The radius of each segment is proportional to the end-use ECI for the building type shown, relative to the largest full-scale building end-use ECI in the data set (Restaurant heat).

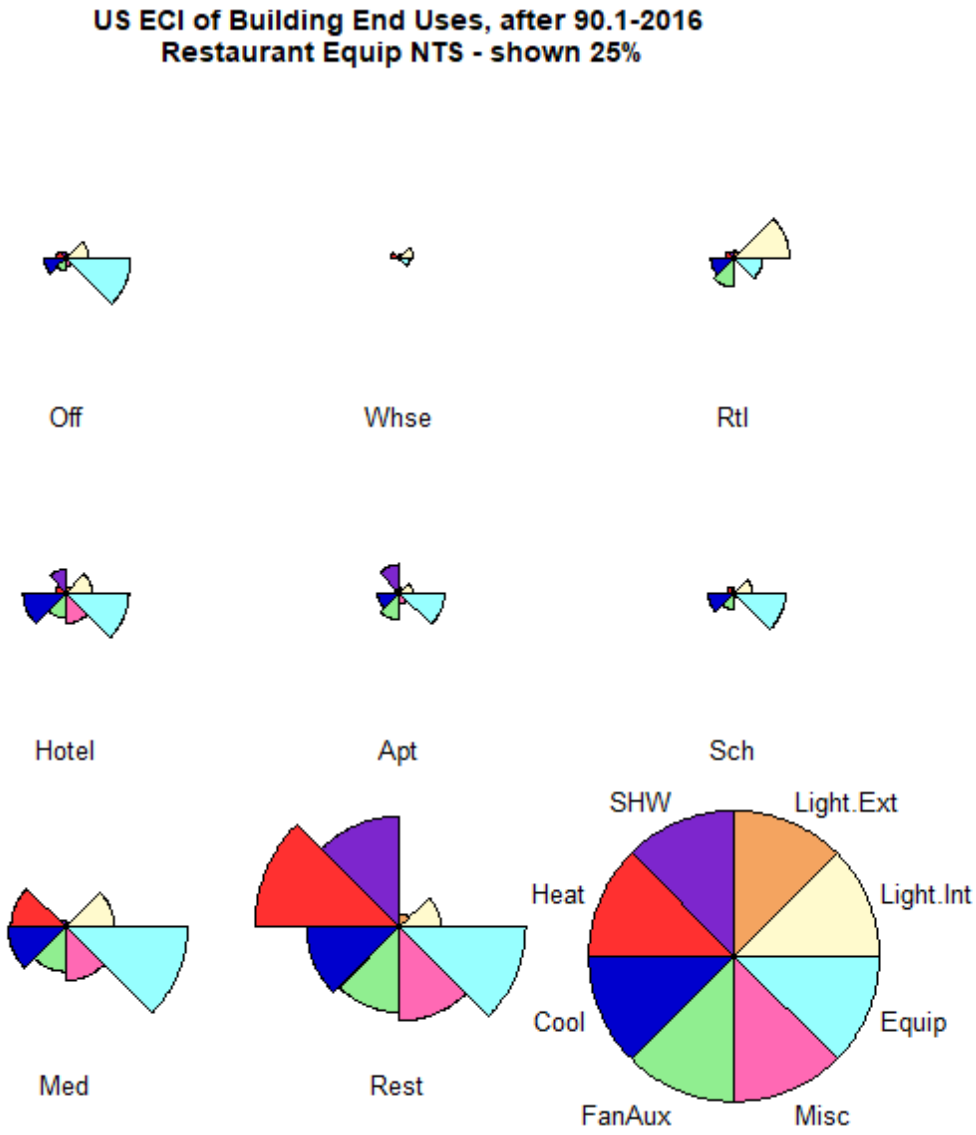


Figure 9. U.S. ECI of building end uses, after 90.1-2016 (Cooking not to scale). (Restaurant equipment is shown at 25% of actual scale.)

[13] See Appendix A – Table A. 1 for details.

Segment Graphs, ECI Weighted for U.S. Construction

When individual building ECI results are weighted by each building's share of new construction floor area (see Figure 10), the impact on total U.S. commercial building cost by type and end use becomes apparent. This result can be referred to as the weighted building cost index (WBCI). Retail interior lighting has the largest contributing end use. Equipment dominates in most other areas; however, service water heating captures a large segment of contributing end use for Apartments. This data is also presented in Table 3 in a tabular format.

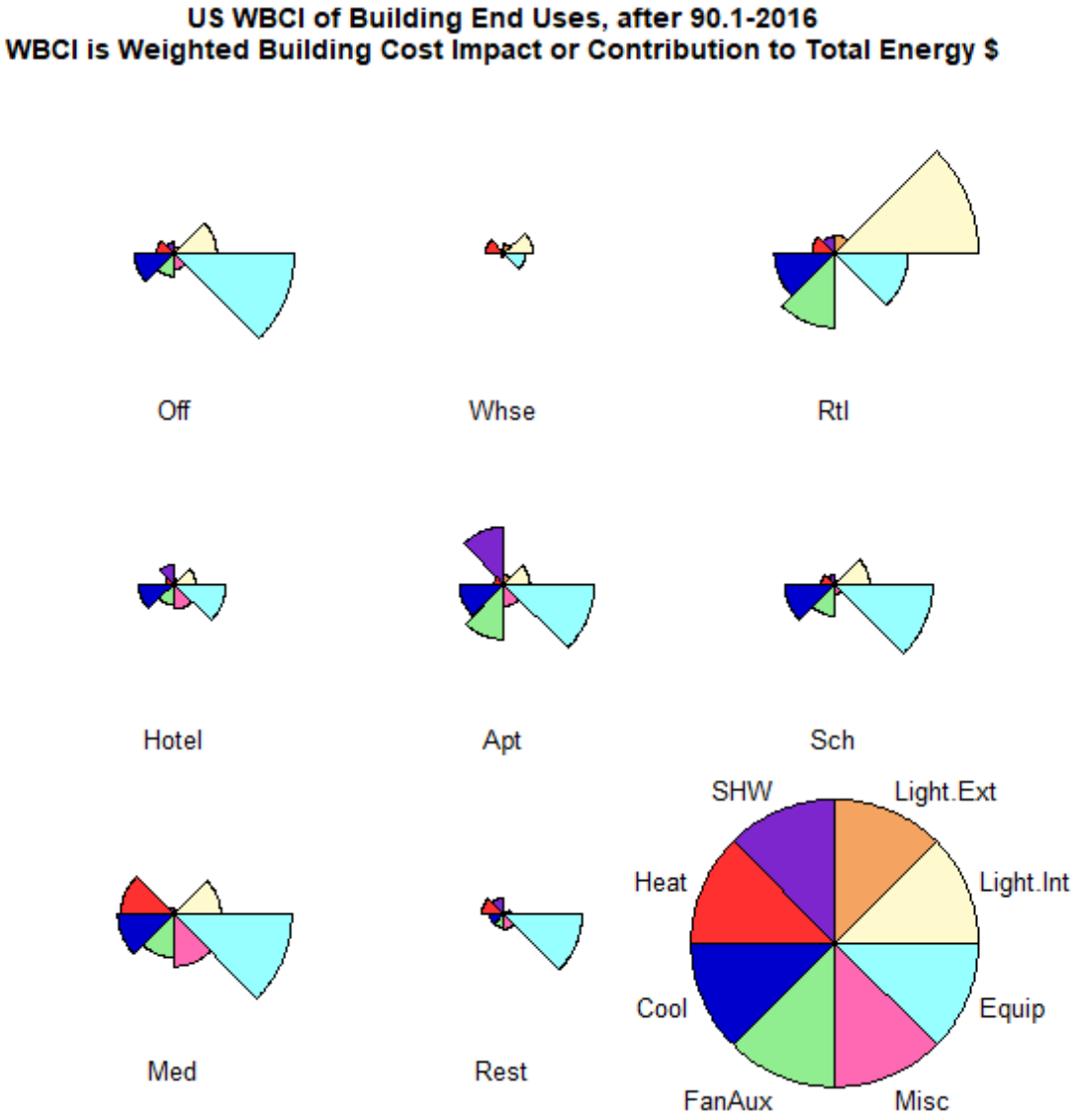


Figure 10. U.S. WBCI of building end uses, after 90.1-2016.
(WBCI = weighted building cost impact or contribution to total energy cost)

U.S. Weighted Sorted End Use ECI, with Building Splits

Figure 11 breaks down end uses based on overall weighted U.S. impact (from largest to smallest impact) and shows the breakdown in each bar by building. Separating equipment and miscellaneous (e.g., transformers, refrigeration, and elevators) helps identify which unregulated loads are impacted.

Though units are in dollars per square foot contribution to an average U.S. building (i.e., a weighted combination of all building types), it may be easier to think of this graph as showing a relative impact factor, since the results are partial. That is, the sum of all end uses shown would equal the weighted average U.S. building ECI based on total construction, or about $1.21 per square foot.

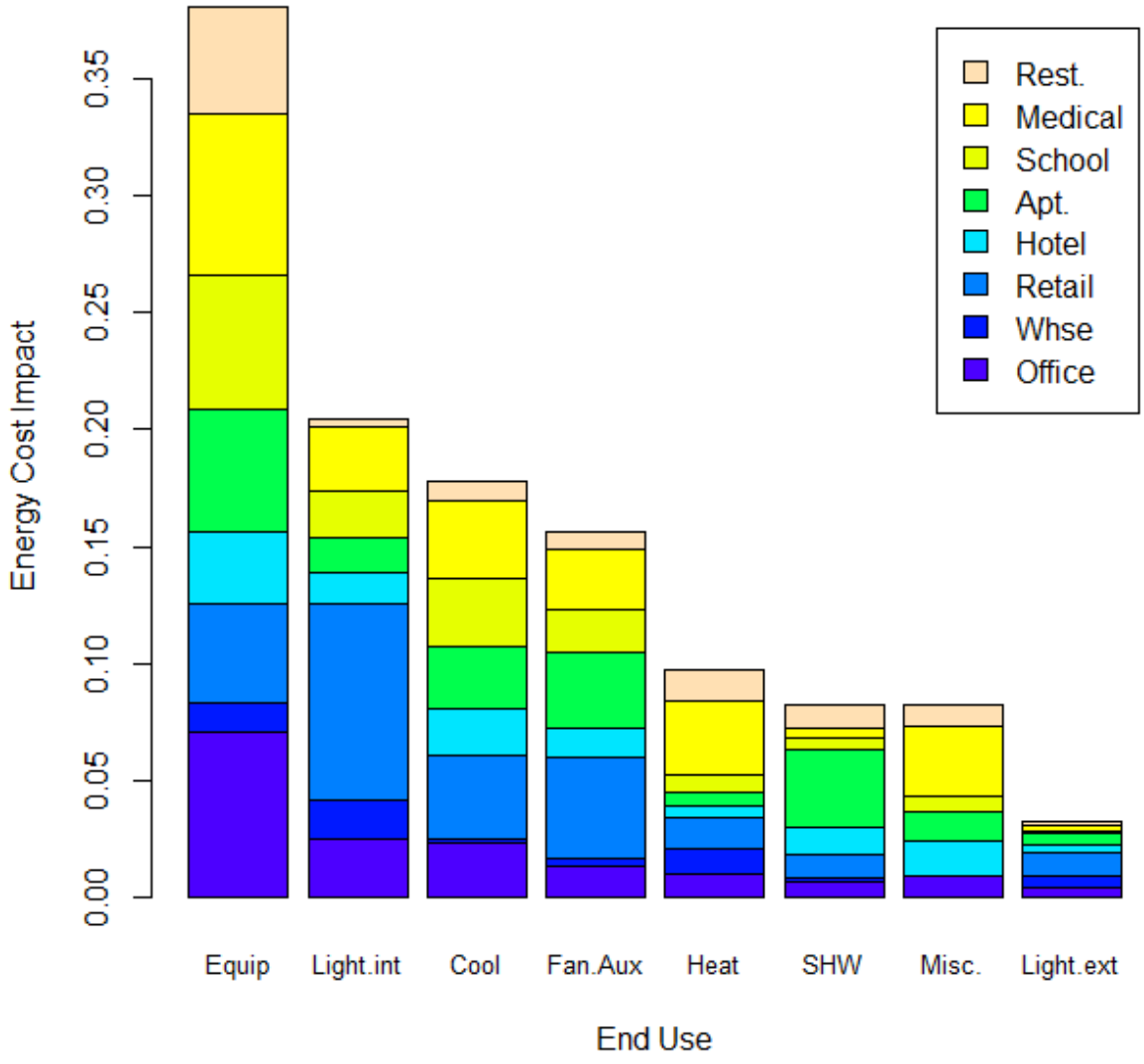


Figure 11. U.S. commercial energy cost impact by end use (weighted by new construction floor area)

Total U.S. Energy Cost by Building Type

Figure 12 shows the comparison of ECI by building type and energy cost savings of each building type compared to 90.1-2004. The blue blocks show the remaining ECI following the implementation of Standard 90.1-2016, and the grey blocks show the energy cost savings of Standard 90.1-2016 compared to Standard 90.1-2004 for each building group. Figure 12 indicates that ECI for food service (Rest) is highest, based primarily on the high-energy density of fast food restaurants. Healthcare (Med) is next, followed by Hotel, Retail (Rtl), and Office (Off). Figure 12 also shows that compared to 90.1-2004, most percent savings were achieved in the School (Sch), Warehouse (Whse) and Retail (Rtl) building types in 90.1-2016. Appendix B provides separate graphs for each end use to better illustrate the distribution of individual end-use costs by building type.

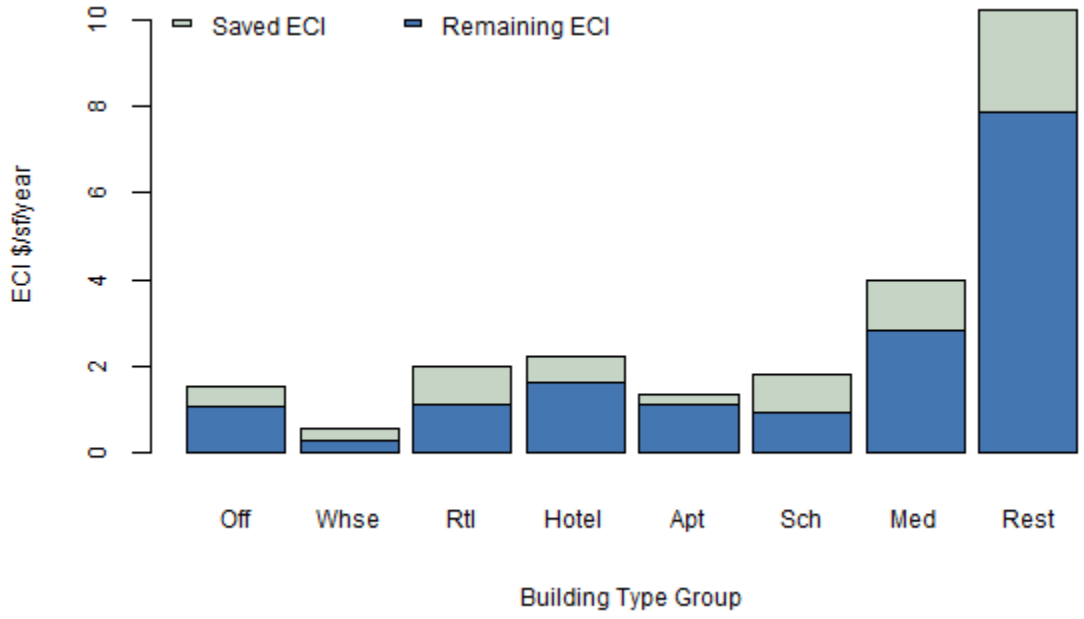


Figure 12. Total U.S. energy cost index; Standard 90.1-2016 vs. Standard 90.1-2004

Focus Potential Score

To help future codes focus on measures with greatest savings potential we developed a scoring methodology called “Focus Potential Score.” The score is intended to focus attention on the highest remaining end-use categories that have not achieved savings to date. The “focus potential scoring” method uses a numerical approach based on three factors: savings from 90.1-2004 to 90.1-2016, individual building ECI, and national weighted ECI. The three factors are weighted as shown in Table 4 below with higher priority given to end uses that have not had large savings historically, and have high building ECI and high national weighted ECI. The scores are simply numerical and do not include judgment about what is possible or an analysis of maximum technical potential. This approach helps identify end uses which are energy intensive, have significant savings potential but have not historically achieved large savings. For example, the equipment end-use scores high, even though, with the exception

of receptacle control requirements, it has been considered an "unregulated" load. The focus potential scoring method combines the three factors shown in Table 4

Table 4. "Focus potential scoring" method factors

Weight	Focus	Low score	High score
6	Savings from 90.1-2004 to 90.1-2016	Low (2) if high previous savings	High (6) if little previous savings
3	Individual building end-use cost (ECI)	Low (0) if building ECI low	High (3) if building ECI high
3	National weighted end-use cost (ECI)	Low (0) if national ECI low	High (3) if national ECI high

In the heat map of focus potential scoring results (see Table 5), darker green indicates areas that may have high savings potential, and white indicates areas that have lower savings potential. "Focus Potential Scores" are rolled up at the simple end-use level and for building groups rather than the detailed level as many of the detailed uses are so small, they would score zero. Because restaurant and equipment end uses are outliers, their partial scores are capped at the maximum. The "Focus Potential Scores" are shown in Table 5 and charted in Figure 13 at the end-use level overall for all building types. Based on the heat map, prime areas for investigation of further savings potential are equipment, service hot water, and interior lighting (especially retail). Following those priorities are cooling and fans/auxiliaries.

Table 5. Total end-use "Focus Potential Scores"

Building Type	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc.	Equip
Office	5.6	2.3	6.5	4.7	5.6	5.7	6.1	11.2
Warehouse	4.1	3.6	6.0	4.8	3.5	3.4		6.9
Retail	10.0	3.3	6.4	3.6	5.7	6.4		9.0
Hotel	5.6	4.1	7.6	3.1	7.2	6.4	8.0	9.9
Apartment	5.9	3.6	8.6	3.0	6.5	7.9	6.6	10.2
School	4.0	2.5	6.4	3.6	5.5	4.4	5.1	10.2
Medical	8.4	2.6	6.1	7.1	8.1	7.2	9.7	11.4
Restaurant	4.8	3.2	9.3	8.8	7.3	6.4	8.2	10.6
U.S. Weighted	6.3	3.1	6.8	4.2	5.7	5.8	4.2	9.6

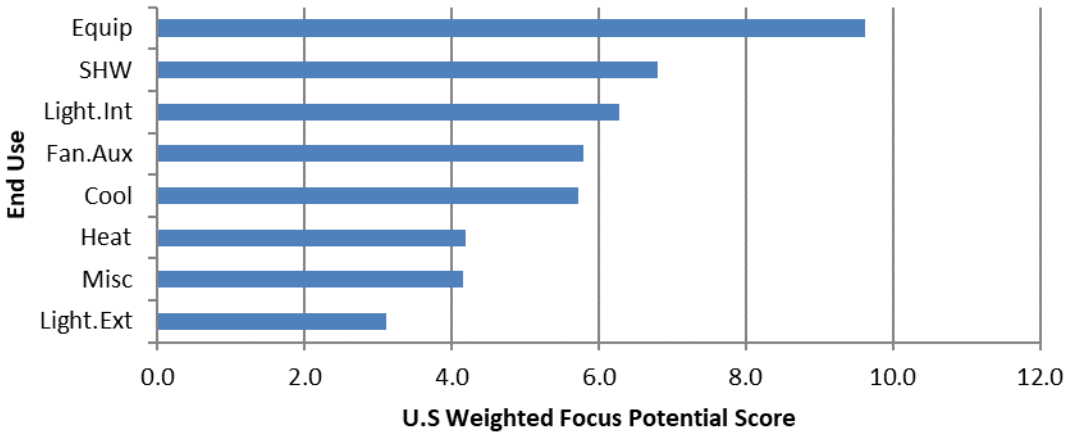


Figure 13. Total end-use "Focus Potential Scores," prioritized

HVAC by Climate Zone

The heating and cooling ECIs by climate zone (weighted by building type construction within each climate zone) are shown in Figure 14. Climate zones are grouped by moisture regime, and climate zone 1B is excluded because it has no U.S. construction. Heat rejection is included with cooling; humidification is included with heating.

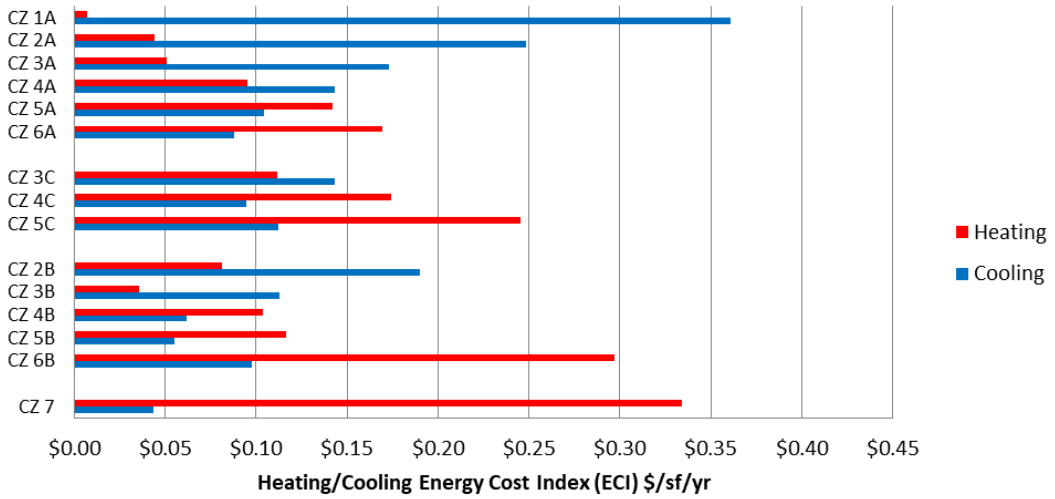


Figure 14. Building ECI heating and cooling by climate zone (CZ)

While Figure 14 shows individual climate zone ECIs, Figure 15 shows the relative contribution of each climate zone's heating and cooling to the total U.S. energy cost. This graph indicates that reducing heating in climate zone 5A is more important than reducing heating in climate zones 6, 7, or 8.

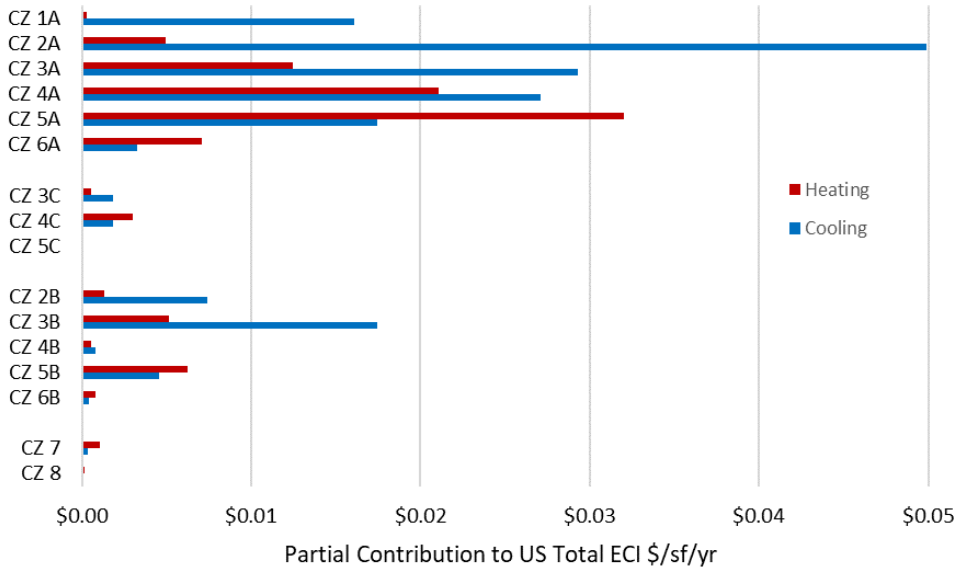
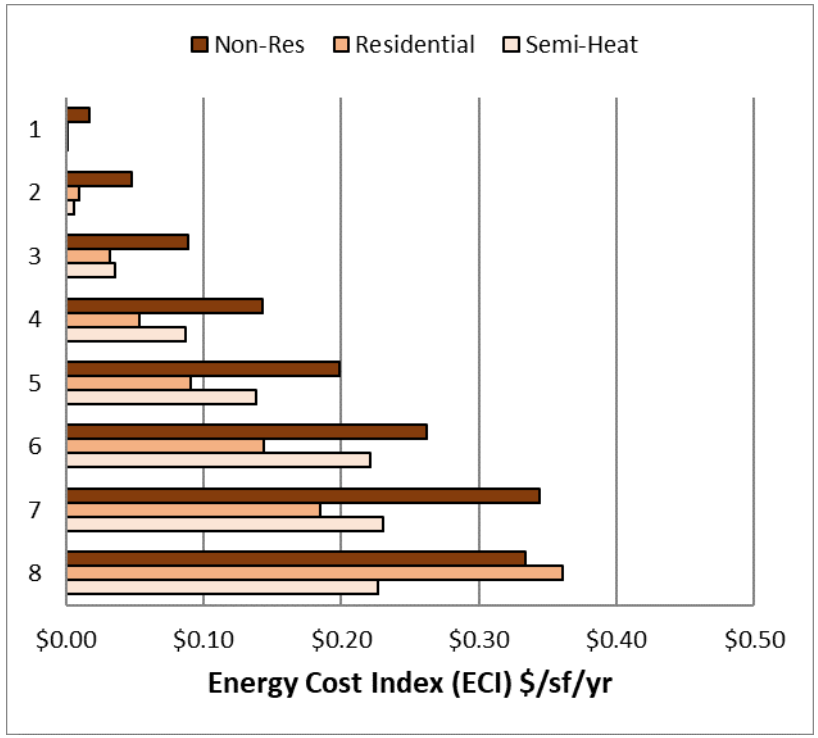


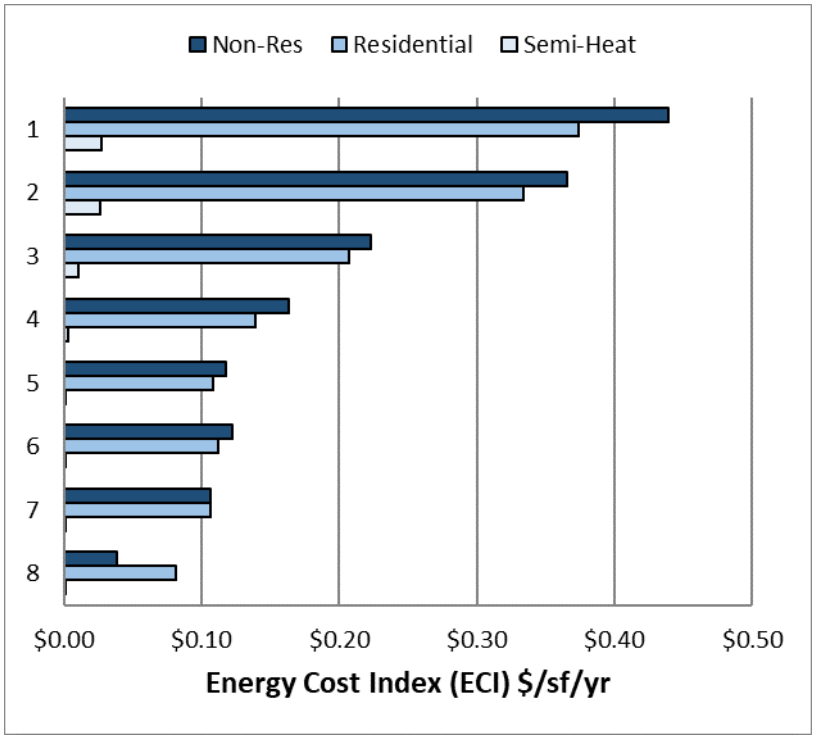
Figure 15. Weighted impact of climate zone heating and cooling on U.S. heating and cooling costs

HVAC Building ECI by Numerical Climate Zone and Space Conditioning Category

To more closely evaluate the prescriptive insulation categories in Standard 90.1, the heating and cooling data was split by building category and numerical climate zone (without moisture regimes). Climate zone 1B is not included because there are no U.S. locations in this climate zone. Heating and cooling energy cost indices, by climate zone, are shown in Figure 16. Apartments and hotels are grouped in the residential category, warehouses in the semi-heated category, and all other buildings in the non-residential category. Note that although some residential areas exist in hospitals, some non-residential areas can be found in large hotels, and only about half of the warehouse prototypes are semi-heated; this grouping used in Figure 16 is based on the predominant category in each individual building type. In addition, different building types have different HVAC systems and ventilation or other HVAC differences, but are not excluded from this analysis. Heat rejection is included with cooling; humidification is included with heating.



(a) heating

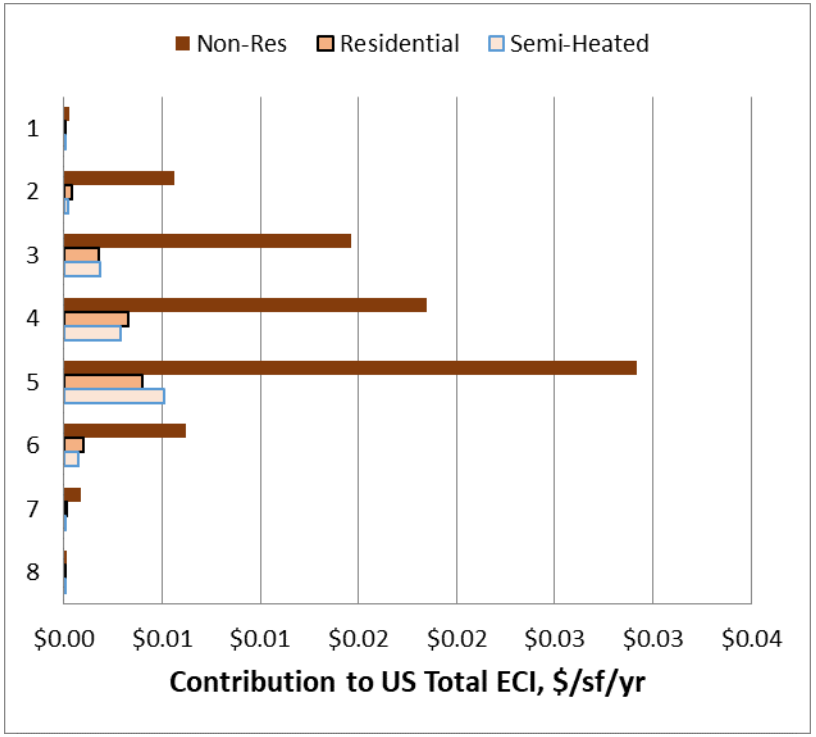


(b) cooling

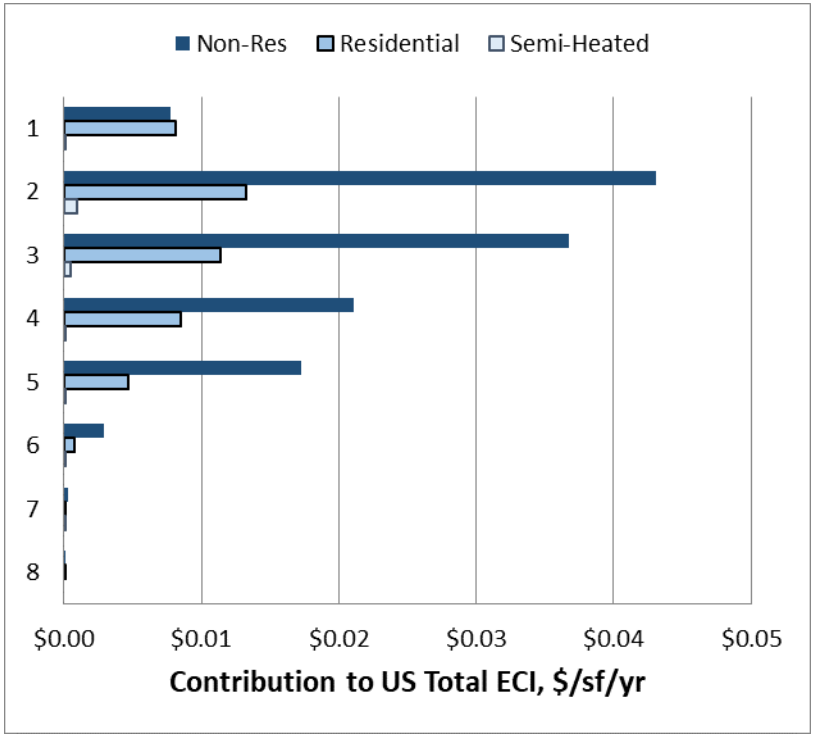
Figure 16. Total (a) heating and (b) cooling ECI by climate zone

HVAC Weighted Cost Impact by Numerical Climate Zone and Space Conditioning Category

While Figure 16 shows individual climate zone building ECIs (weighted for building type construction in each numerical climate zone), Figure 17 shows the relative contribution of each climate zone's heating and cooling to the total U.S. energy cost. Groupings for building type and climate zone are the same as in Figure 16. Figure 17 indicates the importance of reducing heating in climate zone 5 and cooling in zones 2 and 3.



(a) heating



(b) cooling

Figure 17. Weighted impacts on total U.S. (a) heating and (b) cooling costs

Heating ECI Detail by Climate Zone

A heat map (see Table 6) is used to display detailed heating ECI by climate zone. Darker red indicates a higher heating cost for the building type and climate zone. Because these values are not weighted, all climate zones are included. Heat map shading is provided separately for the medical and restaurant groups because their heating costs are much higher than the other building prototypes. Heat rejection is included with cooling; humidification is included with heating.

Table 6. Heating ECI detail by climate zone

	Moist Climates						Marine Climates			Dry Climates						Cold	
Building	CZ 1A	CZ 2A	CZ 3A	CZ 4A	CZ 5A	CZ 6A	CZ 3C	CZ 4C	CZ 5C	CZ 1B	CZ 2B	CZ 3B	CZ 4B	CZ 5B	CZ 6B	CZ 7	CZ 8
AptHR	$0.000	$0.004	$0.063	$0.059	$0.112	$0.190	$0.002	$0.060	$0.048	$0.000	$0.001	$0.004	$0.021	$0.079	$0.117	$0.177	$0.245
AptMR	$0.000	$0.003	$0.035	$0.031	$0.057	$0.103	$0.003	$0.040	$0.039	$0.001	$0.002	$0.004	$0.020	$0.055	$0.061	$0.098	$0.134
HotLrg	$0.007	$0.035	$0.077	$0.071	$0.105	$0.174	$0.072	$0.066	$0.071	$0.028	$0.025	$0.035	$0.037	$0.066	$0.135	$0.239	$0.367
HotSml	$0.000	$0.007	$0.040	$0.084	$0.141	$0.228	$0.005	$0.043	$0.046	$0.004	$0.007	$0.017	$0.033	$0.076	$0.144	$0.262	$0.354
OffL	$0.000	$0.027	$0.082	$0.125	$0.172	$0.213	$0.033	$0.100	$0.112	$0.003	$0.105	$0.110	$0.142	$0.179	$0.221	$0.236	$0.316
OffM	$0.000	$0.020	$0.083	$0.097	$0.156	$0.231	$0.011	$0.071	$0.072	$0.010	$0.016	$0.030	$0.038	$0.086	$0.159	$0.172	$0.265
OffS	$0.000	$0.004	$0.024	$0.034	$0.066	$0.103	$0.004	$0.018	$0.023	$0.001	$0.005	$0.014	$0.019	$0.042	$0.068	$0.113	$0.166
RtlStA	$0.000	$0.005	$0.027	$0.049	$0.080	$0.141	$0.012	$0.093	$0.107	$0.015	$0.013	$0.030	$0.054	$0.114	$0.084	$0.164	$0.268
RtlMall	$0.000	$0.017	$0.072	$0.157	$0.249	$0.327	$0.011	$0.117	$0.143	$0.009	$0.006	$0.031	$0.047	$0.130	$0.224	$0.396	$0.570
SchPri	$0.006	$0.026	$0.056	$0.070	$0.096	$0.135	$0.049	$0.131	$0.100	$0.021	$0.030	$0.059	$0.086	$0.133	$0.110	$0.163	$0.259
SchSec	$0.007	$0.016	$0.035	$0.039	$0.058	$0.096	$0.029	$0.092	$0.050	$0.013	$0.016	$0.037	$0.066	$0.113	$0.070	$0.117	$0.210
Whse	$0.000	$0.005	$0.043	$0.092	$0.150	$0.229	$0.023	$0.064	$0.074	$0.005	$0.012	$0.027	$0.047	$0.086	$0.143	$0.230	$0.227
MedOP	$0.183	$0.254	$0.403	$0.425	$0.521	$0.655	$0.219	$0.295	$0.309	$0.179	$0.353	$0.347	$0.426	$0.474	$0.612	$0.791	$1.081
MedHos	$0.152	$0.210	$0.327	$0.421	$0.474	$0.554	$0.249	$0.314	$0.325	$0.165	$0.302	$0.300	$0.325	$0.348	$0.433	$0.655	$0.805
RestFS	$0.022	$0.217	$0.619	$1.029	$1.439	$1.856	$0.387	$0.902	$1.105	$0.124	$0.212	$0.368	$0.613	$0.992	$1.446	$2.296	$3.143
RestQS	$0.126	$0.449	$1.082	$1.624	$2.238	$2.856	$0.785	$1.473	$1.690	$0.321	$0.501	$0.775	$1.113	$1.678	$2.317	$3.515	$4.769

Cooling ECI Detail by Climate Zone

A heat map (Table 7) is also used to show detailed cooling ECI by climate zone. Darker blue indicates a higher cooling cost for the building type and climate zone. Because these values are not weighted, all climate zones are included. Heat map shading is provided separately for the medical and restaurant groups because their cooling costs are much higher than the other building prototypes.

Table 7. Cooling ECI detail by climate zone

	Moist Climates						Marine Climates			Dry Climates						Cold	
Building	CZ 1A	CZ 2A	CZ 3A	CZ 4A	CZ 5A	CZ 6A	CZ 3C	CZ 4C	CZ 5C	CZ 1B	CZ 2B	CZ 3B	CZ 4B	CZ 5B	CZ 6B	CZ 7	CZ 8
AptHR	$0.365	$0.285	$0.150	$0.135	$0.078	$0.088	$0.048	$0.041	$0.031	$0.362	$0.226	$0.175	$0.150	$0.101	$0.071	$0.088	$0.068
AptMR	$0.264	$0.209	$0.120	$0.104	$0.067	$0.071	$0.063	$0.039	$0.029	$0.290	$0.181	$0.140	$0.113	$0.079	$0.063	$0.067	$0.053
HotLrg	$0.776	$0.683	$0.405	$0.287	$0.190	$0.198	$0.245	$0.124	$0.082	$0.840	$0.473	$0.353	$0.264	$0.201	$0.143	$0.160	$0.093
HotSml	$0.348	$0.297	$0.196	$0.150	$0.111	$0.110	$0.165	$0.108	$0.093	$0.366	$0.241	$0.196	$0.161	$0.129	$0.098	$0.094	$0.069
OffL	$0.494	$0.391	$0.264	$0.201	$0.149	$0.155	$0.181	$0.095	$0.069	$0.566	$0.339	$0.292	$0.208	$0.165	$0.118	$0.132	$0.085
OffM	$0.332	$0.296	$0.179	$0.130	$0.084	$0.091	$0.112	$0.053	$0.030	$0.384	$0.240	$0.173	$0.135	$0.096	$0.064	$0.074	$0.034
OffS	$0.180	$0.154	$0.093	$0.072	$0.045	$0.047	$0.066	$0.036	$0.029	$0.195	$0.136	$0.099	$0.083	$0.061	$0.041	$0.042	$0.028
RtlStA	$0.417	$0.300	$0.181	$0.126	$0.078	$0.088	$0.081	$0.042	$0.020	$0.515	$0.278	$0.194	$0.139	$0.102	$0.066	$0.058	$0.028
RtlMall	$0.399	$0.346	$0.179	$0.118	$0.067	$0.079	$0.070	$0.039	$0.020	$0.460	$0.280	$0.176	$0.125	$0.096	$0.065	$0.057	$0.025
SchPri	$0.346	$0.299	$0.190	$0.137	$0.086	$0.094	$0.131	$0.053	$0.043	$0.423	$0.251	$0.188	$0.128	$0.094	$0.066	$0.076	$0.037
SchSec	$0.416	$0.359	$0.220	$0.159	$0.099	$0.111	$0.142	$0.061	$0.040	$0.514	$0.277	$0.211	$0.148	$0.110	$0.075	$0.087	$0.037
Whse	$0.027	$0.024	$0.009	$0.003	$0.001	$0.001	$0.000	$0.000	$0.000	$0.090	$0.037	$0.013	$0.004	$0.001	$0.000	$0.000	$0.000
MedOP	$1.053	$0.931	$0.601	$0.439	$0.306	$0.311	$0.465	$0.259	$0.194	$1.074	$0.671	$0.528	$0.413	$0.325	$0.247	$0.252	$0.148
MedHos	$0.622	$0.565	$0.364	$0.290	$0.221	$0.226	$0.264	$0.162	$0.132	$0.618	$0.339	$0.271	$0.212	$0.170	$0.147	$0.184	$0.109
RestFS	$1.498	$1.297	$0.692	$0.399	$0.212	$0.247	$0.179	$0.086	$0.025	$1.840	$0.985	$0.694	$0.358	$0.250	$0.161	$0.165	$0.043
RestQS	$1.794	$1.612	$0.831	$0.470	$0.235	$0.284	$0.185	$0.088	$0.028	$2.259	$1.197	$0.795	$0.436	$0.302	$0.190	$0.180	$0.042

Construction Weightings by Building Type and Climate Zone

To estimate the energy savings impact on a national scale, PNNL acquired disaggregated construction volume data from McGraw-Hill Construction (MHC) Project Starts Database. The MHC database contains the floor area of new construction in the United States for the years 2003 to 2007. PNNL analyzed this MHC database to develop detailed construction weights by climate zones, subzones, and states (Jarnagin and Bandyopadhyay, 2010). These weights were used in developing a weighted national energy savings estimate for the impact of ASHRAE standards. Table 8 summarizes the percentage weights by building type and climate zone. The 16 prototypes cover 80% of new construction floor area and percentages; however, percentages in Table 8 have been normalized to result in 100% coverage. Weightings have been applied in the following three ways:

- For national results, weightings in Table 8 were applied to individual results for each building type and climate zone.
- For average building type results, normalized climate zone weightings, totaling 100% for each building type or group, were applied.
- For heating and cooling results within each climate zone, normalized building type results were applied.

Table 8. U.S. new construction weighting (basis 2003 to 2007 MHC database)

Building	Moist Climates					Marine Climates				Dry Climates						General		U.S.
Type	CZ 1A	CZ 2A	CZ 3A	CZ 4A	CZ 5A	CZ 6A	CZ 3C	CZ 4C	CZ 5C	CZ 1B	CZ 2B	CZ 3B	CZ 4B	CZ 5B	CZ 6B	CZ 7	CZ 8	All CZ
AptHR	1.69%	1.48%	0.62%	2.38%	1.25%	0.06%	0.17%	0.36%	0.00%	0.00%	0.08%	0.74%	0.00%	0.12%	0.02%	0.01%	0.00%	8.97%
AptMR	0.34%	1.19%	0.82%	1.58%	1.15%	0.23%	0.26%	0.36%	0.01%	0.00%	0.09%	0.86%	0.02%	0.32%	0.06%	0.03%	0.00%	7.32%
HotLrg	0.13%	0.69%	0.70%	0.90%	0.90%	0.16%	0.11%	0.12%	0.00%	0.00%	0.12%	0.79%	0.04%	0.20%	0.05%	0.03%	0.00%	4.95%
HotSml	0.03%	0.30%	0.27%	0.32%	0.35%	0.08%	0.02%	0.04%	0.00%	0.00%	0.03%	0.11%	0.02%	0.09%	0.03%	0.02%	0.00%	1.72%
OffL	0.13%	0.39%	0.49%	1.05%	0.44%	0.08%	0.12%	0.15%	0.00%	0.00%	0.06%	0.28%	0.00%	0.12%	0.00%	0.01%	0.00%	3.33%
OffM	0.21%	0.85%	0.83%	1.16%	1.00%	0.21%	0.14%	0.19%	0.01%	0.00%	0.29%	0.72%	0.04%	0.35%	0.03%	0.02%	0.01%	6.05%
OffS	0.17%	1.13%	1.02%	0.84%	0.89%	0.18%	0.08%	0.12%	0.01%	0.00%	0.29%	0.47%	0.06%	0.32%	0.03%	0.02%	0.00%	5.61%
RtlStA	0.41%	2.33%	2.57%	2.44%	3.36%	0.69%	0.19%	0.41%	0.02%	0.00%	0.51%	1.25%	0.13%	0.79%	0.08%	0.06%	0.01%	15.25%
RtlMall	0.20%	1.08%	1.11%	0.89%	0.96%	0.09%	0.10%	0.11%	0.00%	0.00%	0.25%	0.63%	0.02%	0.20%	0.01%	0.00%	0.00%	5.67%
SchPri	0.16%	0.99%	0.96%	0.87%	0.82%	0.12%	0.05%	0.09%	0.00%	0.00%	0.16%	0.45%	0.03%	0.23%	0.03%	0.02%	0.00%	4.99%
SchSec	0.32%	1.59%	1.99%	1.97%	2.15%	0.30%	0.11%	0.23%	0.01%	0.00%	0.23%	0.82%	0.06%	0.45%	0.08%	0.05%	0.01%	10.36%
Whse	0.51%	3.07%	2.70%	2.84%	3.01%	0.29%	0.15%	0.43%	0.00%	0.00%	0.58%	2.30%	0.08%	0.70%	0.03%	0.03%	0.00%	16.72%
MedOP	0.08%	0.62%	0.63%	0.81%	1.06%	0.23%	0.06%	0.17%	0.01%	0.00%	0.13%	0.28%	0.02%	0.22%	0.03%	0.03%	0.00%	4.37%
MedHos	0.06%	0.51%	0.49%	0.66%	0.80%	0.12%	0.04%	0.10%	0.00%	0.00%	0.10%	0.27%	0.03%	0.21%	0.02%	0.03%	0.00%	3.45%
RestFS	0.02%	0.11%	0.12%	0.12%	0.13%	0.02%	0.01%	0.01%	0.00%	0.00%	0.02%	0.05%	0.01%	0.03%	0.00%	0.00%	0.00%	0.66%
RestQS	0.02%	0.10%	0.10%	0.09%	0.12%	0.02%	0.01%	0.01%	0.00%	0.00%	0.02%	0.06%	0.01%	0.03%	0.00%	0.00%	0.00%	0.59%
All Bldg.	4.46%	16.43%	15.42%	18.92%	18.39%	2.89%	1.61%	2.92%	0.07%	0.00%	2.98%	10.08%	0.57%	4.37%	0.49%	0.37%	0.05%	100%

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Appendix A

Heat Maps

Appendix A

Heat Maps

The heat maps presented in this appendix provide multiple views of prototypes by end use. The term "heat map" does not relate to the heating end use. Heat maps represent a relative intensity of a factor by color. Two types of heat maps (i.e., cost and savings) are used here:

- Cost heat maps: In the cost heat maps, red indicates the highest remaining cost impact and white indicates lowest remaining cost impact. Darker reds indicate higher remaining cost and, thus, a higher potential for future savings.
- Savings heat maps: In the savings heat maps, green indicates higher cost savings from Standard 90.1-2004 to Standard 90.1-2016 and red indicates lower cost savings. Darker reds indicate lower savings to date and, thus, a possible higher potential for future savings.

Some of the heat maps are weighted by construction and some represent individual building constructions. The weighting conditions are noted with each map. Likewise, building types and end uses are presented as detailed or in groups, as noted.

Energy Cost Index by Building Type and End Use

Table A.1 shows ECI results grouped by building and end use after Standard 90.1-2016; Table A.2 shows the detailed results. Results in this section relate to the prototype independently except the last row (U.S. Weighted), which is weighted for both climate and prototype. The results are national, weighted by relative construction of each prototype in each climate zone.

Table A.1. ECI ($/ft^2/yr) remaining after 90.1-2016, by building group and end use

	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc	Equip	Total
Office	$0.167	$0.025	$0.043	$0.067	$0.154	$0.090	$0.062	$0.470	$1.078
Warehouse	$0.100	$0.031	$0.013	$0.065	$0.011	$0.017		$0.074	$0.310
Retail	$0.401	$0.051	$0.047	$0.064	$0.169	$0.208		$0.205	$1.145
Hotel	$0.190	$0.039	$0.168	$0.071	$0.310	$0.183	$0.223	$0.458	$1.641
Apt	$0.092	$0.031	$0.204	$0.036	$0.162	$0.200	$0.079	$0.323	$1.127
School	$0.131	$0.009	$0.036	$0.051	$0.191	$0.122	$0.040	$0.372	$0.954
Medical	$0.352	$0.029	$0.050	$0.397	$0.419	$0.323	$0.389	$0.882	$2.840
Restaurant	$0.297	$0.097	$0.802	$1.054	$0.678	$0.619	$0.679	$3.645	$7.871
U.S. Weighted	$0.205	$0.032	$0.082	$0.097	$0.178	$0.156	$0.082	$0.380	**$1.213**

Table A.2. ECI ($/ft^2/yr) remaining after 90.1-2016, by building type and detailed end use

	Light.Int	Light.Ext	SHW	Heat	Humidify	Cool	Ht.Rej	Fans	Ht.Rcvy	Pumps	Refrig	Elevator	Txfmr	Equip	Cook	IT	Total
Small Office	0.169	0.029	0.092	0.029		0.094		0.100						0.247			0.761
Medium Office	0.159	0.025	0.014	0.080		0.163		0.043	0.000	0.000		0.087	0.006	0.307			0.884
Large Office	0.179	0.019	0.010	0.031	0.076	0.221	0.019	0.133	0.001	0.024		0.107	0.003	0.301		0.842	1.967
Warehouse	0.100	0.031	0.013	0.065		0.011		0.017						0.074			0.310
Retail Store	0.341	0.044	0.036	0.050		0.163		0.199	0.018					0.221			1.072
Strip Mall	0.564	0.069	0.078	0.101		0.184		0.185						0.160			1.341
Small Hotel	0.189	0.029	0.128	0.075		0.178		0.118		0.000		0.163		0.182	0.111		1.173
Large Hotel	0.191	0.042	0.181	0.069		0.356		0.144	0.047	0.014	0.020	0.219	0.005	0.242	0.274		1.804
Pri School	0.138	0.010	0.024	0.065		0.180		0.090	0.028	0.001	0.042		0.007	0.361	0.103		1.048
Sec School	0.128	0.009	0.042	0.044		0.196		0.096	0.024	0.004	0.024	0.009	0.004	0.256	0.072		0.909
MR Apartment	0.093	0.022	0.313	0.029		0.122		0.161	0.023			0.104		0.322			1.189
HR Apartment	0.092	0.039	0.115	0.042		0.189	0.005	0.172	0.025	0.016		0.053	0.005	0.324			1.077
Clinic	0.317	0.038	0.050	0.305	0.114	0.501		0.246		0.002		0.439		0.861			2.874
Hospital	0.396	0.018	0.050	0.290	0.077	0.286	0.029	0.340	0.021	0.057	0.024	0.292	0.008	0.637	0.272		2.798
Quick-serv Rest	0.310	0.099	0.672	1.323		0.745		0.730			0.961				4.435		9.274
Full-serv Rest	0.285	0.095	0.918	0.815		0.618		0.519		0.002	0.429				2.942		6.623
U.S. Weighted	0.205	0.032	0.082	0.087	0.010	0.176	0.002	0.137	0.014	0.005	0.015	0.065	0.002	0.270	0.083	0.028	**1.213**

National Energy Cost Impact, by Building Type and End Use, U.S. New Construction

Table A.3 shows grouped national new construction energy cost impact results after Standard 90.1-2016; Table A.4 shows the detailed results. Results in this section are weighted by prototype and climate zone based on 8.5 billion square feet of new construction.[14] The numerical results represent the contribution to national new construction energy cost and red shading indicates the greatest national impacts.

Table A.3. Million $/y-U.S. spent on new commercial building energy; after 90.1-2016

	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc	Equip	Total
Office	$214M	$32M	$54M	$86M	$197M	$115M	$79M	$600M	$1,377M
Warehouse	$142M	$44M	$19M	$93M	$15M	$24M		$105M	$442M
Retail	$716M	$90M	$84M	$114M	$301M	$371M		$365M	$2,042M
Hotel	$108M	$22M	$95M	$40M	$176M	$104M	$127M	$260M	$933M
Apt	$128M	$44M	$283M	$50M	$224M	$277M	$109M	$449M	$1,565M
School	$172M	$12M	$48M	$66M	$250M	$160M	$53M	$487M	$1,248M
Medical	$235M	$19M	$34M	$264M	$279M	$215M	$259M	$588M	$1,893M
Restaurant	$32M	$10M	$85M	$112M	$72M	$66M	$72M	$387M	$836M
U.S. Weighted	$1,746M	$274M	$702M	$826M	$1,515M	$1,332M	$699M	$3,243M	$10,336M

Table A.4. Detailed million $/y-U.S. spent on new commercial building energy; after 90.1-2016

	Light.Int	Light.Ext	SHW	Heat	Humidify	Refrig	Elevator	Txfmr	Equip	Cook	IT	Cool	Ht.Rej	Fans	Ht.Rcvy	Pumps	Total
Small Office	$81M	$14M	$44M	$14M					$118M			$45M		$48M			$364M
Medium Office	$82M	$13M	$7M	$41M			$45M	$3M	$158M			$84M		$22M	$0M	$0M	$456M
Large Office	$51M	$6M	$3M	$9M	$21M		$30M	$1M	$85M		$239M	$63M	$5M	$38M	$0M	$7M	$558M
Warehouse	$142M	$44M	$19M	$93M					$105M			$15M		$24M			$442M
Retail Store	$443M	$57M	$46M	$65M					$288M			$212M		$259M	$23M		$1,394M
Strip Mall	$272M	$33M	$38M	$49M					$77M			$89M		$89M			$648M
Small Hotel	$28M	$4M	$19M	$11M			$24M		$27M			$26M		$17M		$0M	$172M
Large Hotel	$81M	$18M	$77M	$29M		$8M	$92M	$2M	$102M	$116M		$150M		$61M	$20M	$6M	$761M
Pri School	$59M	$4M	$10M	$28M		$18M		$3M	$153M	$44M		$77M		$38M	$12M	$0M	$446M
Sec School	$113M	$8M	$37M	$39M		$21M	$8M	$3M	$226M	$64M		$173M		$85M	$21M	$4M	$803M
MR Apartment	$58M	$13M	$195M	$18M			$65M		$201M			$76M		$100M			$742M
HR Apartment	$70M	$30M	$88M	$32M			$40M	$4M	$248M			$145M	$4M	$132M		$12M	$823M
Clinic	$118M	$14M	$19M	$114M	$43M		$164M		$321M			$186M		$92M	$0M	$1M	$1,070M
Hospital	$116M	$5M	$15M	$85M	$23M	$7M	$86M	$2M	$187M	$80M		$84M	$9M	$100M	$6M	$17M	$822M
Quick-serv Rest	$16M	$5M	$34M	$66M		$48M				$222M		$37M		$36M			$464M
Full-serv Rest	$16M	$5M	$52M	$46M		$24M				$165M		$35M		$29M		$0M	$372M
All Buildings	$1,746M	$274M	$702M	$739M	$87M	$126M	$554M	$19M	$2,297M	$691M	$239M	$1,498M	$17M	$1,169M	$83M	$46M	**$10,336M**

[14] New construction floorspace area based on projected estimates.

Energy Cost Savings, by Building Type and End Use

Table A.5 shows grouped results and Table A.6 shows the detailed results. These results are for savings from Standards 90.1-2004 to 2016 and are weighted by climate zone based on new construction. The percentages represent independent savings for each individual end use.

Table A.5. Percentage cost savings by end use and building type, 90.1-2004 to 90.1-2016 (% savings per individual end use)

	Light.Int	Light.Ext	SHW	Heat	Cool	Fan.Aux	Misc	Equip	Total
Office	47.3%	76.6%	0.9%	40.9%	44.3%	27.4%	12.0%	5.5%	30.4%
Warehouse	61.6%	54.0%	3.2%	38.5%	51.2%	53.8%		2.0%	46.5%
Retail	35.6%	66.8%	5.0%	63.1%	52.3%	51.3%		0.4%	42.3%
Hotel	42.7%	43.4%	0.6%	68.9%	34.5%	35.7%	6.6%	4.3%	27.9%
Apartment	25.0%	52.8%	0.2%	66.1%	30.9%	13.1%	7.7%	0.3%	18.0%
School	70.6%	68.8%	1.0%	59.2%	55.4%	60.5%	27.8%	9.0%	48.2%
Medical	21.7%	71.2%	8.6%	54.2%	40.4%	37.7%	3.7%	1.5%	28.8%
Restaurant	67.0%	67.9%	0.7%	12.1%	38.9%	55.1%	21.5%	0.1%	22.9%
U.S. Weighted	45.9%	64.7%	1.5%	52.8%	45.0%	42.5%	9.5%	3.3%	**34.0%**

Table A.6. Detailed percentage cost savings by end use and building type, 90.1-2004 to 90.1-2016 (% savings per individual end use)

	Light.Int	Light.Ext	SHW	Heat	Humidify	Cool	Ht.Rej	Fans	Ht.Rcvy	Pumps	Refrig	Elevator	Txfmr	Equip	Cook	IT	Total
Sm Office	53.4%	77.1%	0.2%	41.8%		52.4%		26.3%						8.5%			38.5%
Md Office	45.2%	79.2%	3.9%	55.5%		36.1%		30.9%				5.5%	65.2%	8.8%			35.9%
Lg Office	38.4%	65.1%	3.2%	65.9%	-1061.7%	31.6%	61.7%	12.9%		60.4%		2.8%	61.8%	9.1%		0.0%	17.7%
Warehouse	61.6%	54.0%	3.2%	38.5%		46.3%		50.6%						2.0%			46.5%
Retail Store	39.2%	66.5%	2.1%	71.2%		50.4%		54.4%						0.4%			44.6%
Strip Mall	28.7%	67.3%	8.3%	40.9%		49.3%		47.7%						0.4%			36.9%
Sm Hotel	41.7%	53.5%	1.5%	64.2%		30.8%		6.7%		0.0%		3.6%		11.1%			30.0%
Lg Hotel	43.0%	40.3%	0.3%	70.3%		36.5%		44.0%	38.2%	73.1%	19.4%	2.8%	61.9%	7.6%			28.5%
Pri School	70.1%	69.2%	3.8%	59.3%		45.6%		37.1%	45.7%	18.1%	19.8%		63.9%	13.6%			45.0%
Sec School	70.9%	68.6%	0.2%	59.1%		51.7%		55.4%	67.0%	82.5%	15.7%	13.1%	62.6%	9.6%			49.8%
Mid Apartment	26.5%	64.4%	0.1%	65.2%		36.8%		20.2%				3.6%		0.5%			16.3%
Hi Apartment	23.6%	44.7%	0.4%	66.6%		24.7%	60.9%	20.2%		35.0%		2.8%	60.0%	0.2%			19.4%
Clinic	24.5%	75.9%	11.9%	61.5%	24.0%	31.0%		36.9%		27.9%		2.0%		0.9%			30.4%
Hospital	18.7%	40.7%	4.0%	48.1%	62.7%	38.8%	61.3%	34.6%		55.4%	21.9%	1.3%	59.1%	3.1%			26.6%
Fast Food	63.3%	67.9%	-0.1%	2.7%		32.1%		48.4%			21.1%				0.1%		19.1%
Restaurant	70.0%	67.9%	1.1%	22.8%		37.1%		62.3%			22.3%				0.1%		27.3%

Appendix B

End-Use Energy Cost by Building Type

Appendix B

End-Use Energy Cost by Building Type

The following figures show the energy cost (ECI, $/ft^2/yr) for each end use on a separate graph. In each graph, the vertical bars represent each building group. These figures show remaining ECI after Standard 90.1-2016 and are weighted for the building type across all U.S. climate zones. Energy cost savings from Standards 90.1-2004 to 90.1-2016 are also shown to indicate which building types have the highest ECI for a particular end use. These figures also show the distribution of individual end-use costs by building type.

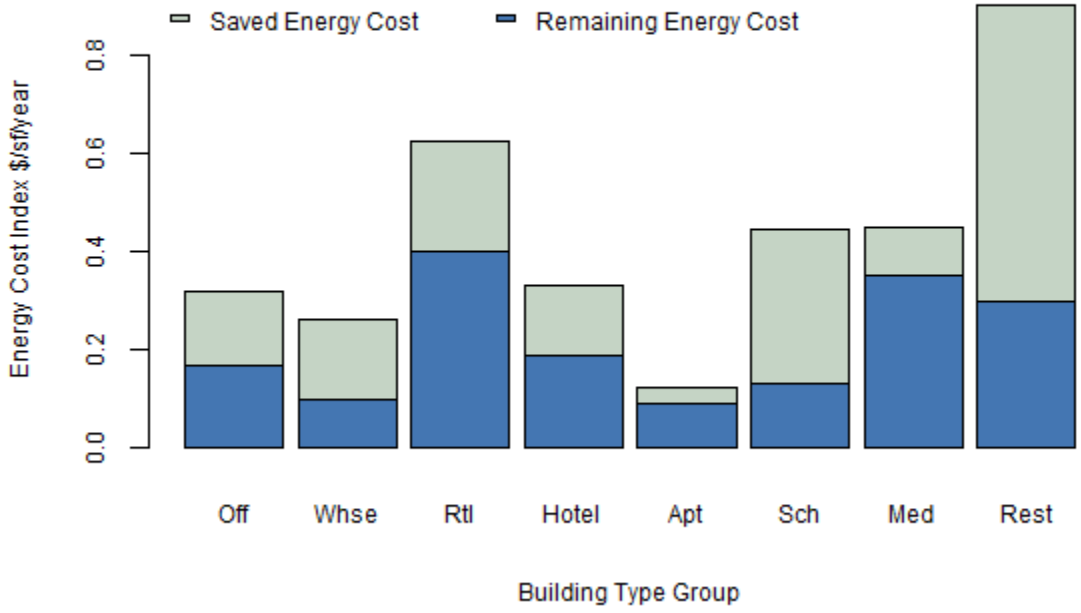

Figure B.1. Interior lighting U.S. energy cost index: 90.1-2016 vs 90.1-2004

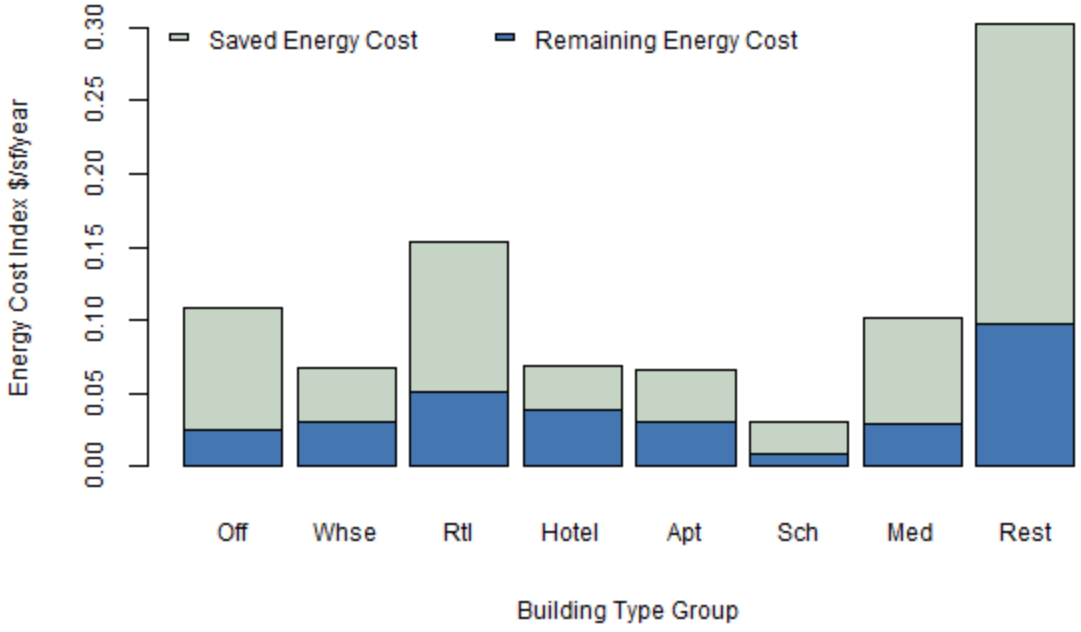

Figure B.2. Exterior lighting U.S. energy cost index: 90.1-2016 vs 90.1-2004

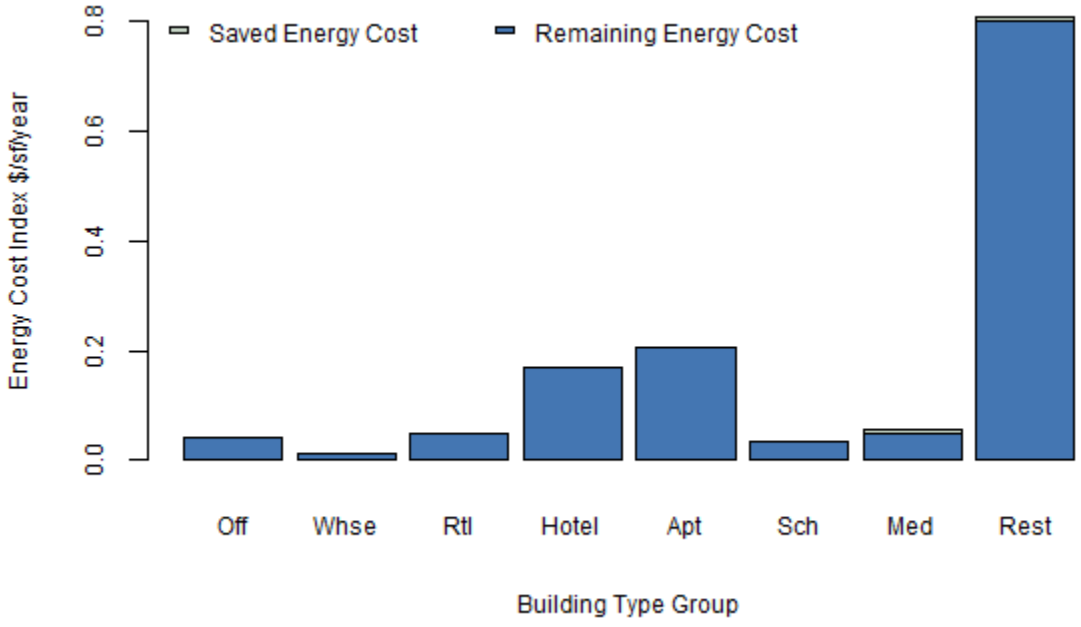

Figure B.3. Service hot water U.S. energy cost index: 90.1-2016 vs 90.1-2004

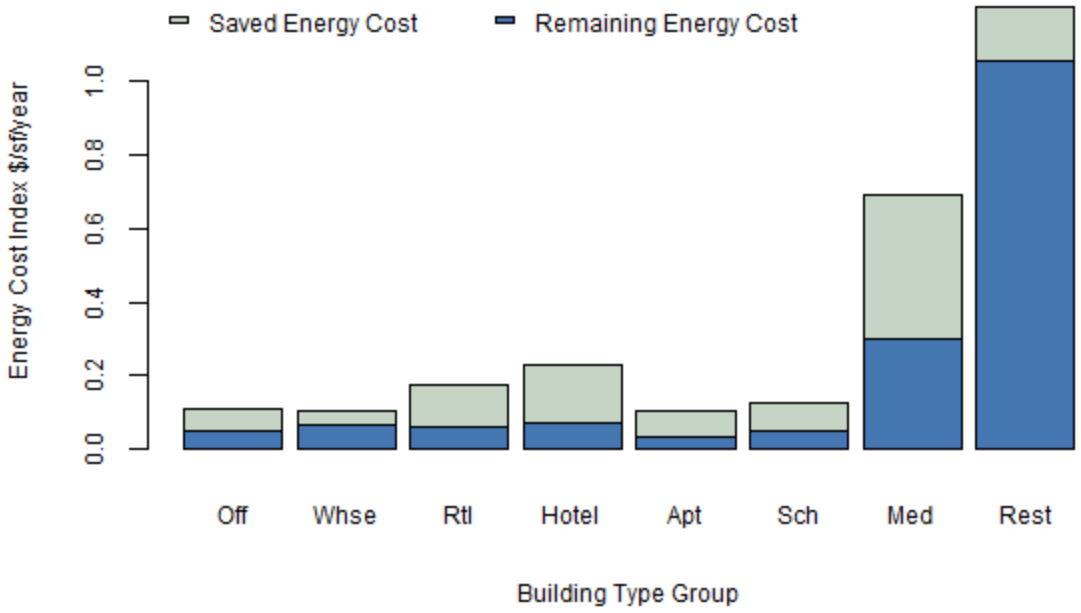

Figure B.4. Heating U.S. energy cost index: 90.1-2016 vs 90.1-2004

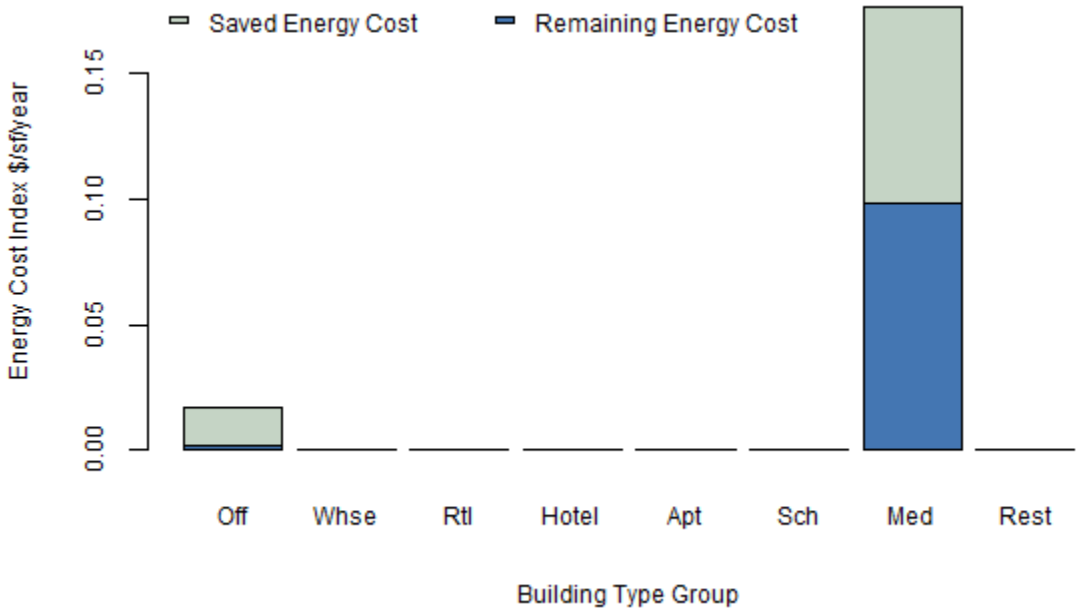

Figure B.5. Humidification U.S. energy cost index: 90.1-2016 vs 90.1-2004

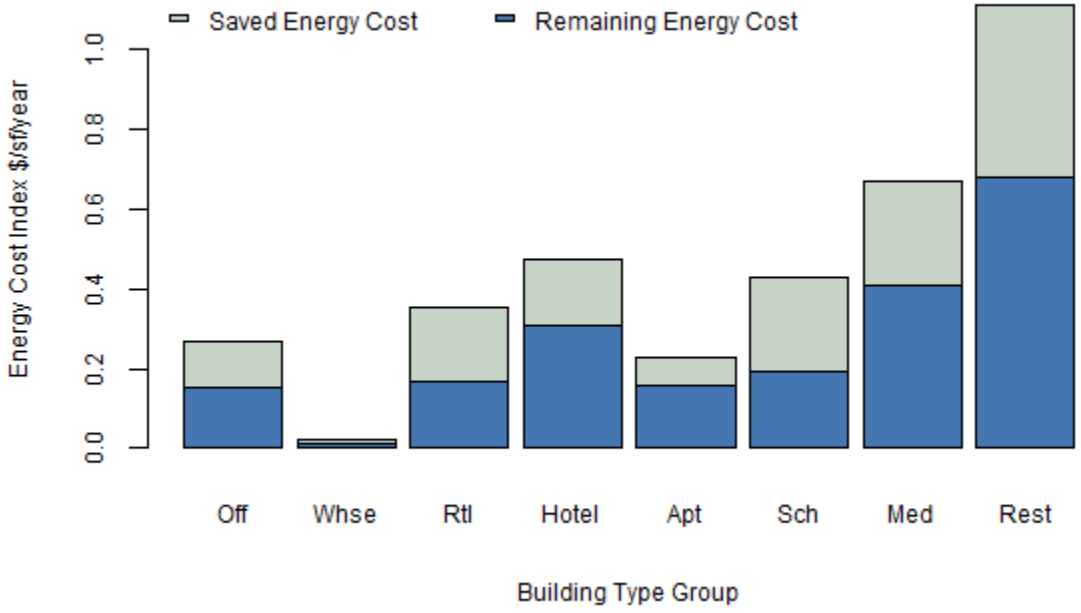

Figure B.6. Cooling U.S. energy cost index: 90.1-2016 vs 90.1-2004

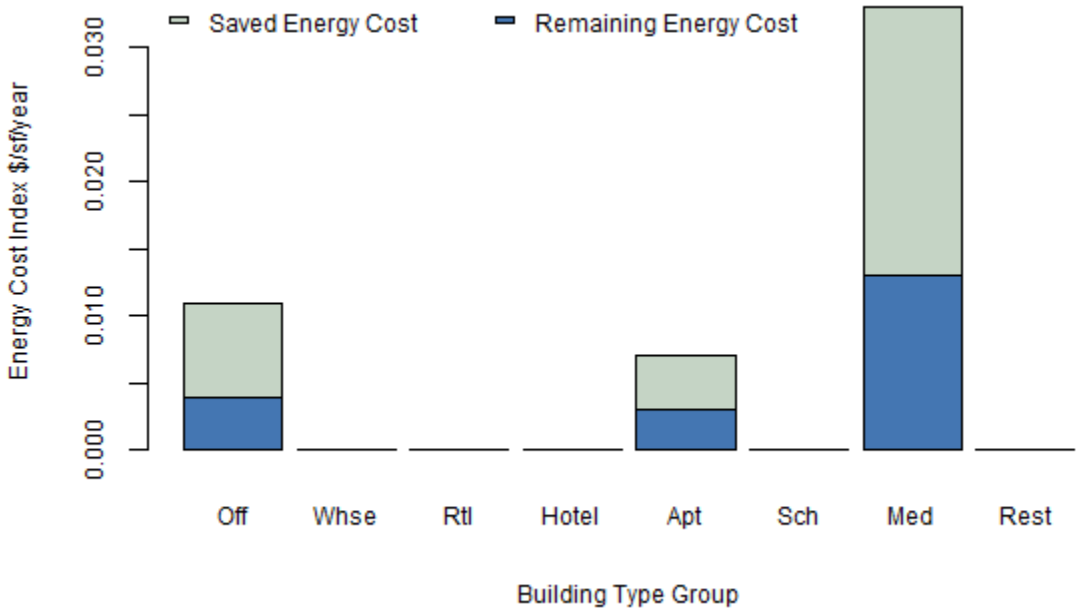

Figure B.7. Heat rejection[15] U.S. energy cost index: 90.1-2016 vs 90.1-2004

[15] For building types with no heat rejection use, heat rejection is included in cooling energy end use.

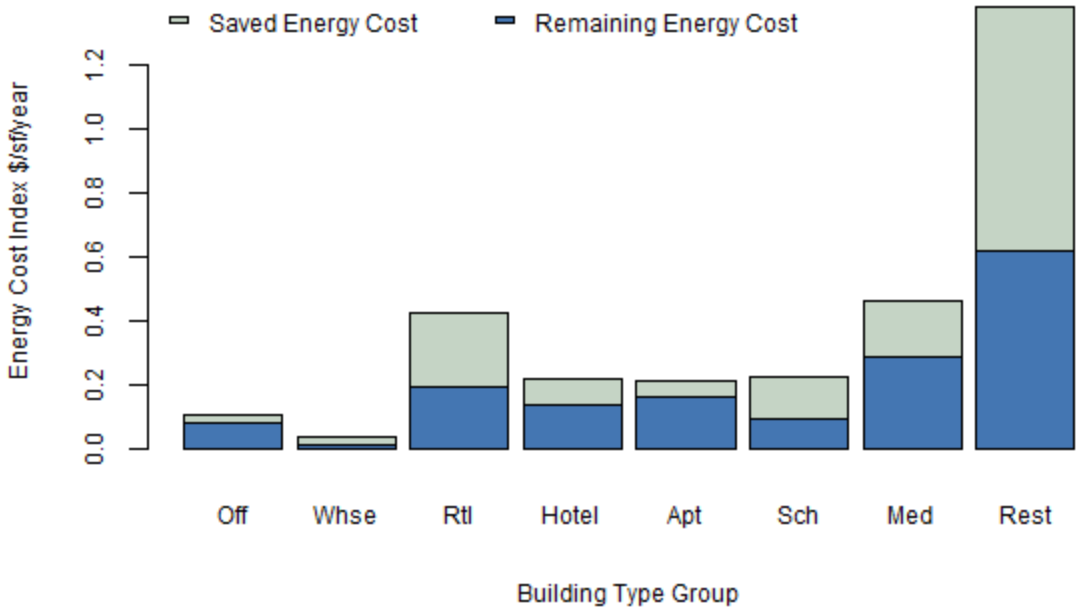

Figure B.8. Fans U.S. energy cost index: 90.1-2016 vs 90.1-2004

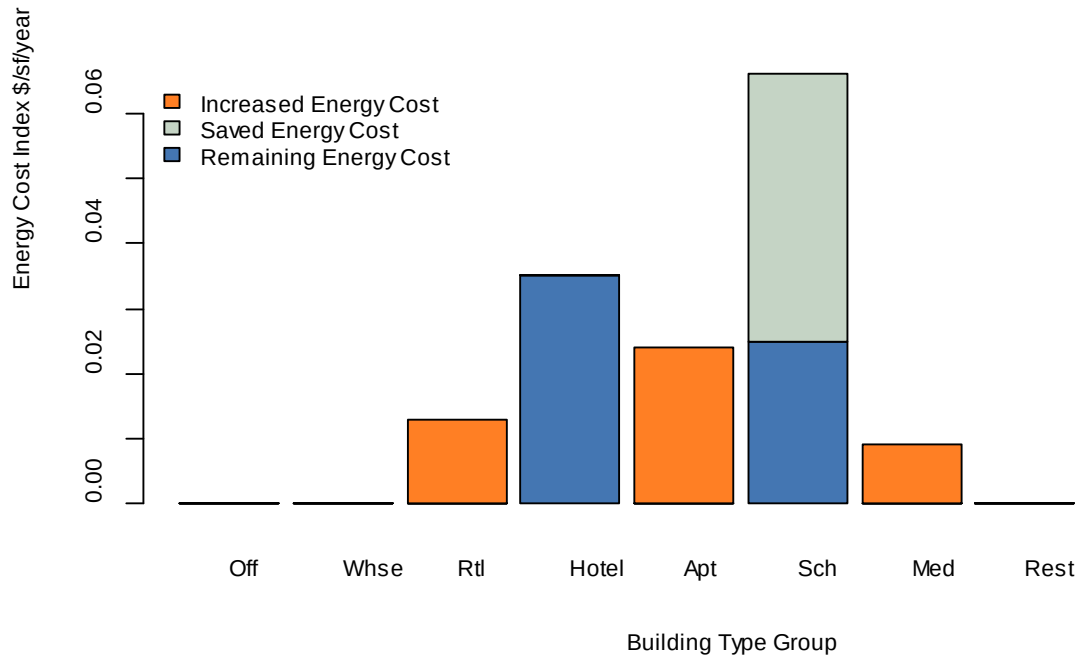

Figure B.9. Heat recovery[16] U.S. energy cost index: 90.1-2016 vs 90.1-2004

[16] For Heat recovery end-use, increase in energy use in Retail, Apartment and Medical building groups are due to changes in heat recovery requirements since 90.1-2004.

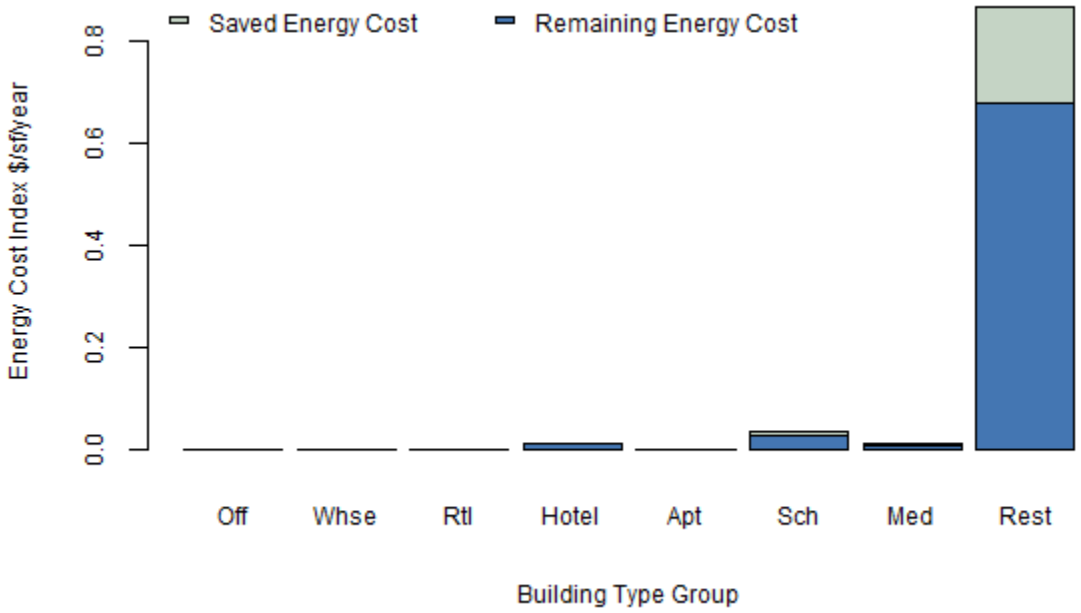

Figure B.10. Refrigeration U.S. energy cost index: 90.1-2016 vs 90.1-2004

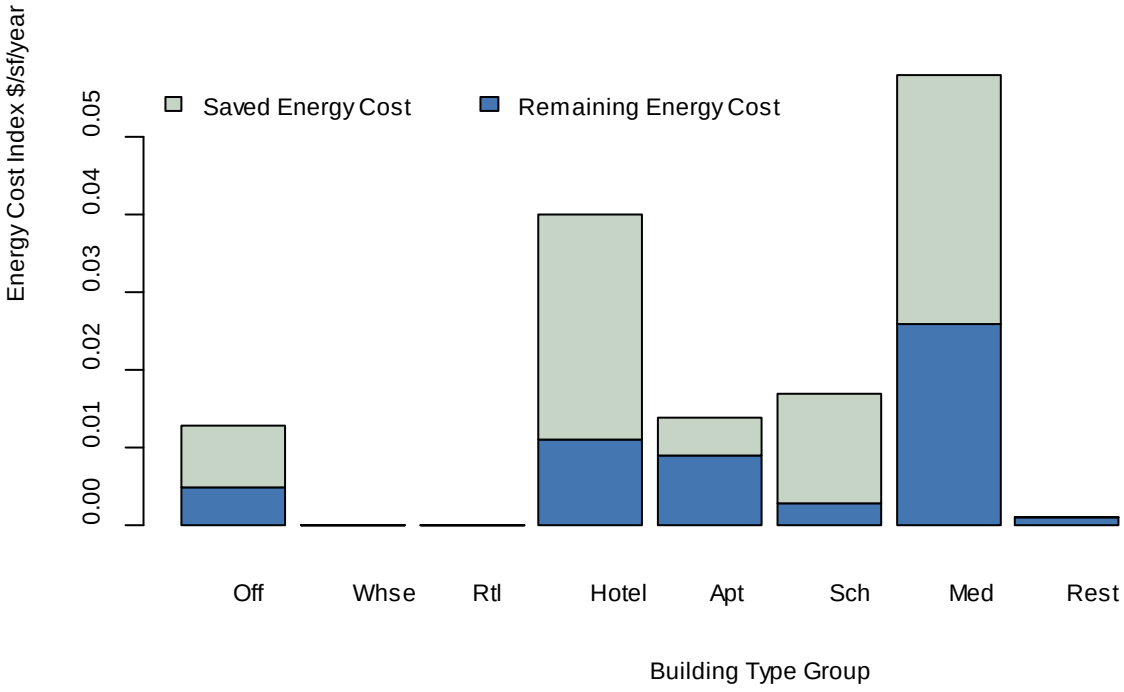

Figure B.11. Pumps U.S. energy cost index: 90.1-2016 vs 90.1-2004

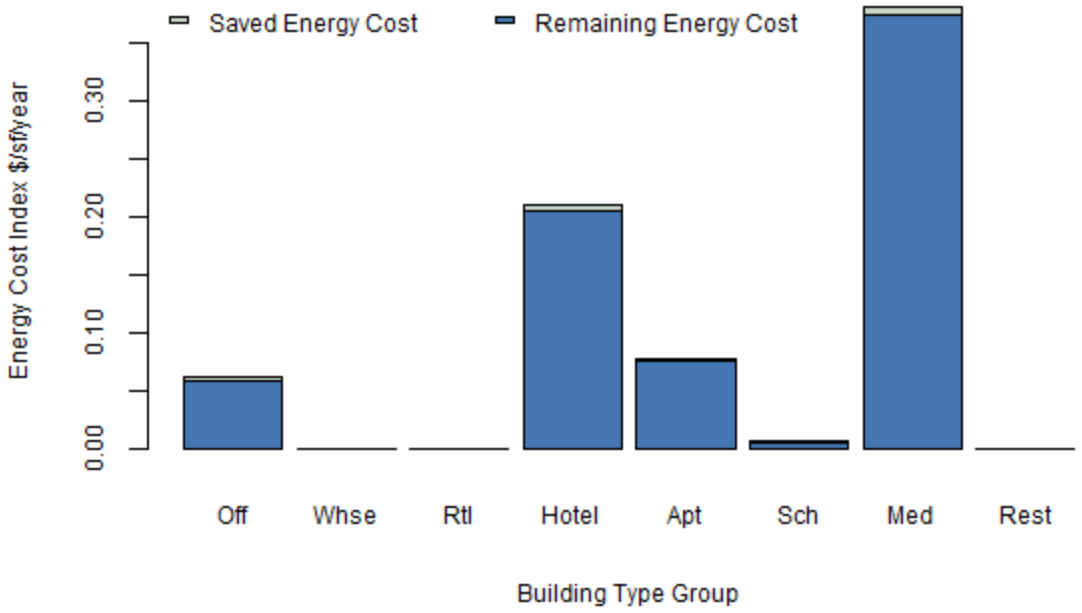

Figure B.12. Elevator U.S. energy cost index: 90.1-2016 vs 90.1-2004

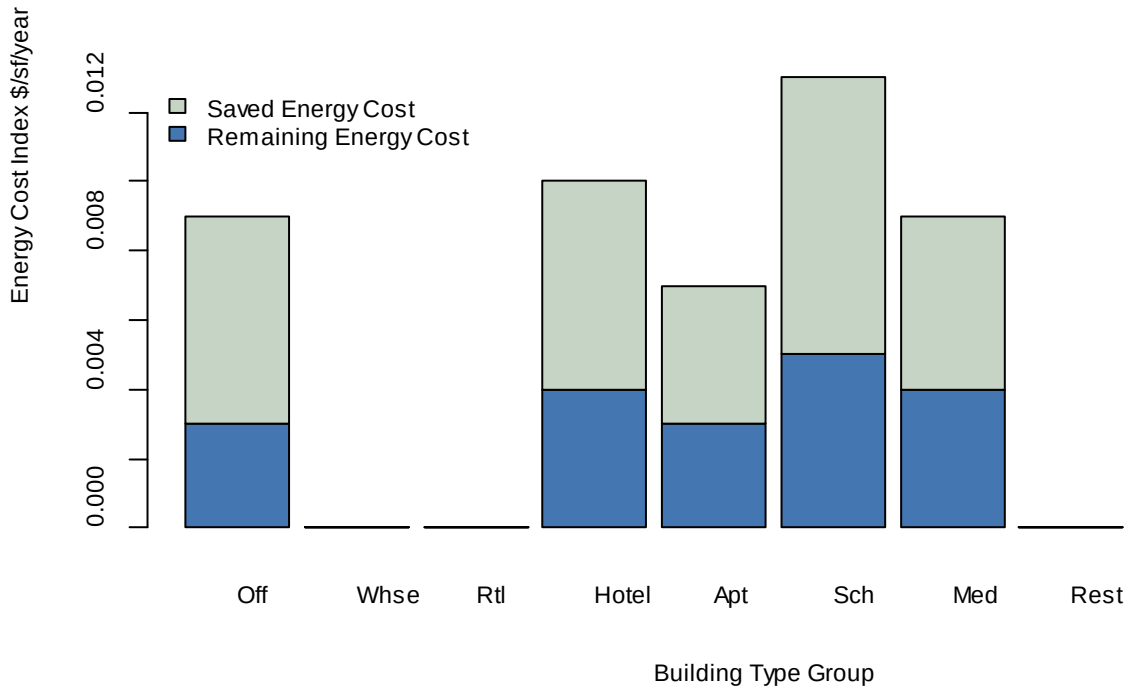

Figure B.13. Transformer loss U.S. energy cost index: 90.1-2016 vs 90.1-2004

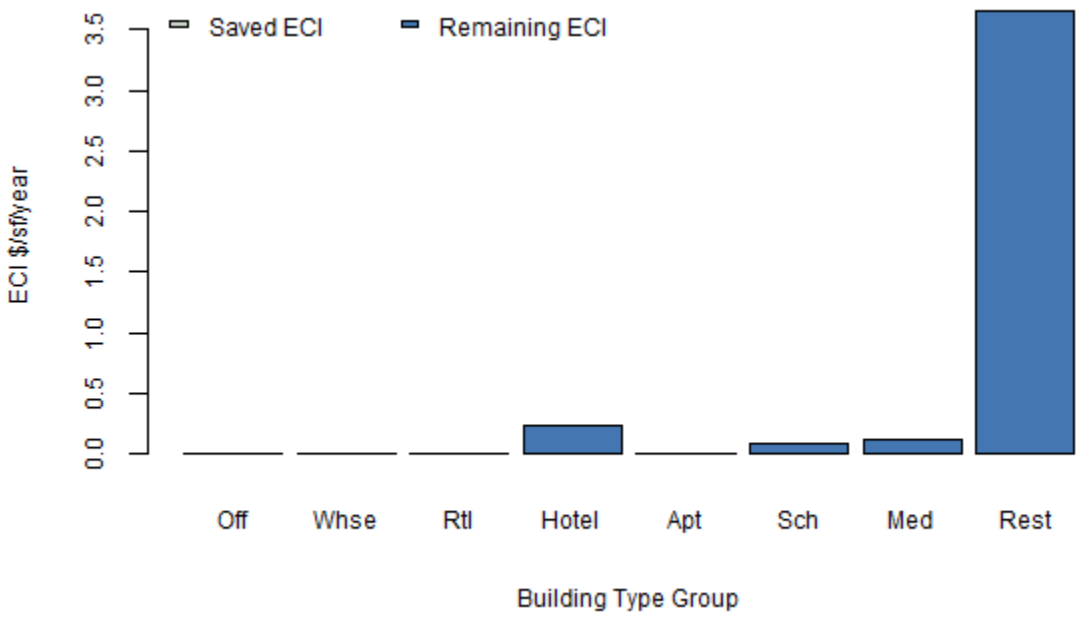

Figure B.14. Cooking[17] U.S. energy cost index: 90.1-2016 vs 90.1-2004

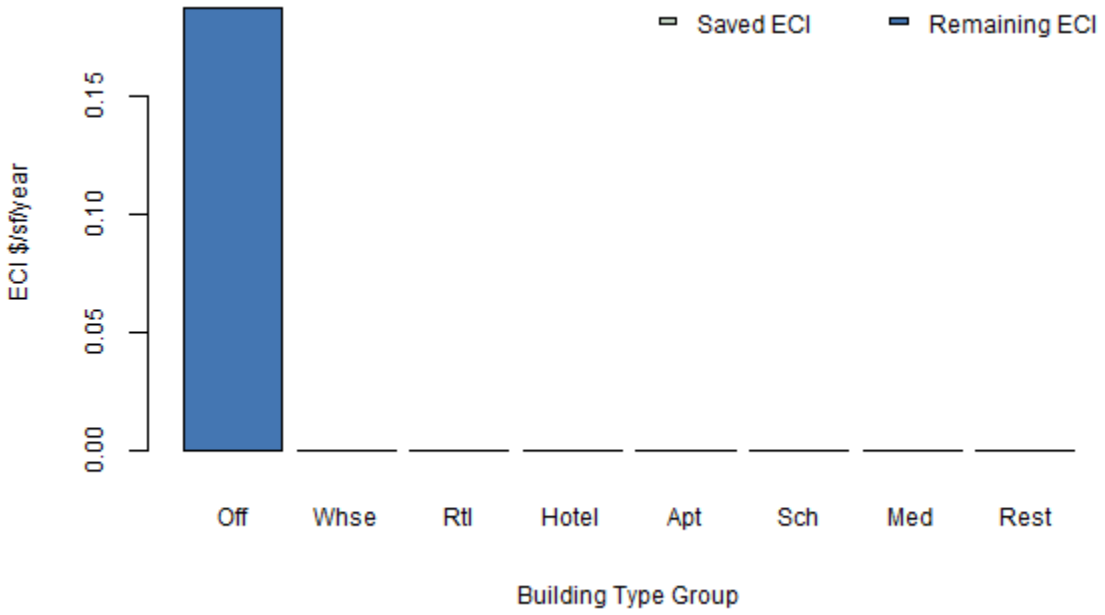

Figure B.15. IT[18] U.S. energy cost index: 90.1-2016 vs 90.1-2004

[17] Apartment cooling equipment is included in the general "Equip" category.
[18] Information technology equipment is only isolated in the large office prototype, it is included in "Equip" for the other prototypes.

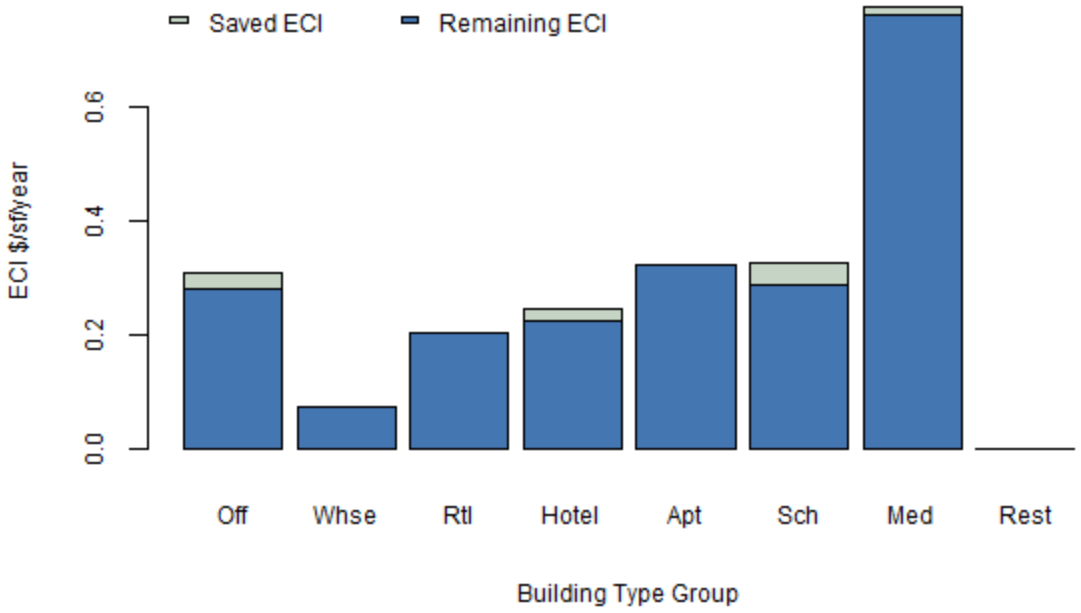

Figure B.16. Equipment U.S. energy cost index: 90.1-2016 vs 90.1-2004

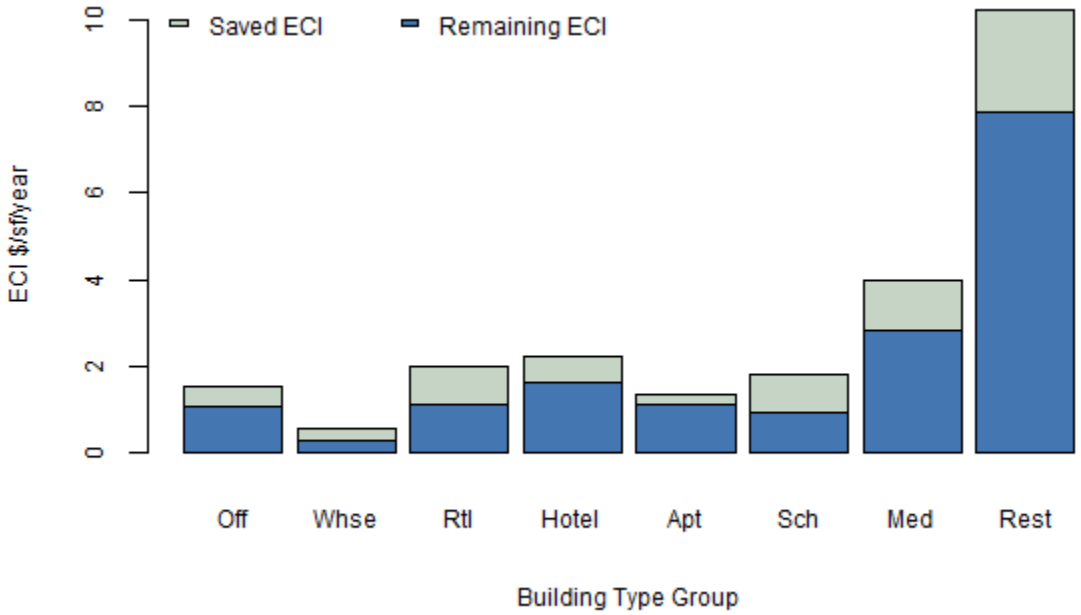

Figure B.17. Total U.S. energy cost index: 90.1-2016 vs 90.1-2004

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