Pacific Northwest NATIONAL LABORATORY

PNNL-28989

Cost Effectiveness of ASHRAE Standard 90.1-2016 for the State of Hawaii

August 2020

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R Hart
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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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Pacific Northwest National Laboratory
Richland, Washington 99354

Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DOE	U.S. Department of Energy
EIA	Energy Information Administration
FEMP	Federal Energy Management Program
HVAC	Heating, Ventilating, and Air-Conditioning
LCC	Life-Cycle Cost
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
UPV	Uniform Present Value

1.0 Highlights

Moving to the ASHRAE Standard 90.1-2016 (ASHRAE 2016) edition from Standard 90.1-2013 (ASHRAE 2013) is cost-effective for Hawaii. The table below shows the statewide economic impact of upgrading to Standard 90.1-2016 in terms of the annual energy cost savings in dollars per square foot, additional construction cost per square foot required by the upgrade, and life-cycle cost (LCC) per square foot. These results are weighted averages for all building types in all climate zones in the state, based on weightings shown in Table 4. The methodology used for this analysis is consistent with the methodology used in the national cost-effectiveness analysis.[1] Additional results and details on the methodology are presented in the following sections.

Average Savings, Construction Cost and LCC (Weighted by Climate Zone and Building Type)	
Annual Cost Savings, $\$/ft^2$	$0.266
Added Construction Cost, $\$/ft^2$	-$0.198
Publicly-owned scenario LCC Savings, $\$/ft^2$	$10.24
Privately-owned scenario LCC Savings, $\$/ft^2$	$8.15

The report provides analysis of two LCC scenarios:

- **Scenario 1**, representing publicly-owned buildings, considers initial costs, energy costs, maintenance costs, and replacement costs—without borrowing or taxes.
- **Scenario 2**, representing privately-owned buildings, adds borrowing costs and tax impacts.

Figure 1 compares annual energy cost savings, first cost for the upgrade, and net annualized LCC savings. The net annualized LCC savings per square foot is the annual energy savings minus an allowance to pay for the added cost under scenario 1. Figure 2 shows overall state weighted net LCC results for both scenarios. When net LCC is positive, the updated code edition is considered cost-effective.

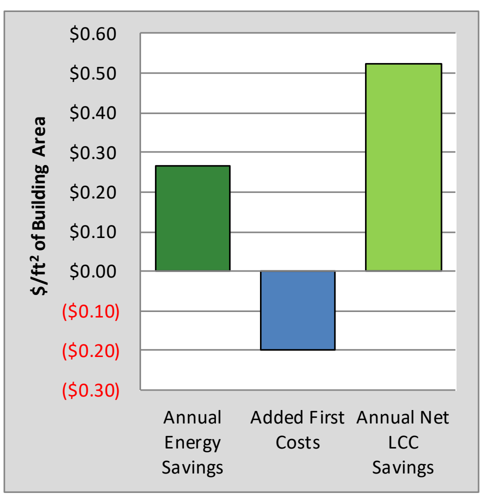

Figure 1. Statewide Weighted Costs and Savings

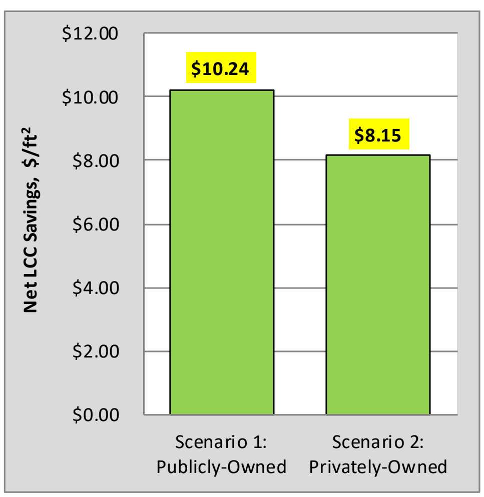

Figure 2. Overall Net Life-Cycle Cost Savings

[1] National cost-effectiveness report: https://www.energycodes.gov/development/commercial/cost_effectiveness

2.0 Cost-Effectiveness Results for ASHRAE Standard 90.1-2016 in Hawaii

This section summarizes the cost-effectiveness analysis results. LCC savings is the primary measure DOE uses to assess the economic impact of building energy codes. Net LCC savings is the calculation of the present value of energy savings minus the present value of non-energy incremental costs over a 30-year period. The non-energy incremental costs include initial equipment and construction costs, and maintenance and replacement costs, less the residual value of components at the end of the 30-year period. When net LCC is positive, the updated code edition is considered cost-effective. Savings are computed for two scenarios:

- **Scenario 1:** represents publicly-owned buildings, includes costs for initial equipment and construction, energy, maintenance and replacement and does not include loans or taxes.
- **Scenario 2:** represents privately-owned buildings, includes the same costs as Scenario 1, with the initial investment financed through a loan amortized over 30 years and federal and state corporate income tax deductions for interest and depreciation.

Both scenarios include the residual value of equipment with remaining useful life at the end of the 30-year assessment period. Totals for building types, climate zones, and the state overall are averages based on Table 4 construction weights. Factors such as inflation and discount rates are different between the two scenarios, as described in the Cost-Effectiveness Methodology section.

LCC is affected by many variables, including the applicability of individual measures in the code, measure costs, measure lifetime, replacement costs, state cost adjustment, energy prices, and so on. The LCC could be negative for a building type in a climate zone based on the interaction of these variables. However, the code is considered cost-effective if the weighted statewide LCC is positive.

Table 1 shows the present value of the net LCC savings over 30 years for buildings in scenario 1 averages $10.24 per square foot for Standard 90.1-2016.

Table 1. Net LCC Savings for Hawaii, Scenario 1 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
Climate zone 1A	$6.78	$3.02	$17.97	$14.62	$13.35	$4.42	$10.24

Table 2 shows the present value of the net LCC savings over 30 years averages $8.15 per square foot for scenario 2.

Table 2. Net LCC Savings for Hawaii, Scenario 2 ($/ft²)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
Climate zone 1A	$4.98	$2.19	$14.90	$10.89	$10.16	$3.40	$8.15

2.1 Energy Cost Savings

Table 3 shows the economic impact of upgrading to Standard 90.1-2016 by building type and climate zone in terms of the annual energy cost savings in dollars per square foot. The annual energy cost savings across the state averages $0.266 per square foot.

Table 3. Annual Energy Cost Savings for Hawaii ($/ft²)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
Climate zone 1A	$0.314	$0.155	$0.291	$0.612	$0.467	$0.145	$0.266

2.2 Construction Weighting of Results

Energy and economic impacts were determined and reported separately for each building type and climate zone. Cost-effectiveness results are also reported as averages for all prototypes and climate zones in the state. To determine these averages, results were combined across the different building types and climate zones using weighting factors shown in Table 4. These weighting factors are based on the floor area of new construction and major renovations for the six analyzed building prototypes in state-specific climate zones. The weighting factors were developed from construction start data from 2003 to 2007 (McGraw Hill Construction 2007) based on an approach developed by Jarnagin and Bandyopadhyay (2010).

Table 4. Construction Weights by Building Type

Climate Zone & Representative City	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
1A Honolulu	13.4%	0.0%	32.0%	9.4%	2.3%	42.9%	100.0%

2.3 Incremental Construction Cost

Cost estimates were developed for the differences between Standard 90.1-2013 and Standard 90.1-2016 as implemented in the six prototype models. Costs for the initial construction include material, labor, commissioning, construction equipment, overhead and profit. Costs were also estimated for replacing equipment or components at the end of the useful life. The costs were developed at the national level for the national cost-effectiveness analysis and then adjusted for local conditions using a state construction cost index (Hart et al. 2019, Means 2018a,b).

Table 5 shows incremental initial cost for individual building types in state-specific climate zones and weighted average costs by climate zone and building type for moving to Standard 90.1-2016 from Standard 90.1-2013.

The added construction cost can be negative for some building types, which represents a reduction in first costs and a savings that is included in the net LCC savings. This is due to the following:

- Fewer light fixtures are required when the allowed lighting power is reduced. Also changes from fluorescent to LED technology results in reduced lighting costs in many cases and longer lamp lives, requiring fewer lamp replacements.
- Smaller heating, ventilating, and air-conditioning (HVAC) equipment sizes can result from the lowering of heating and cooling loads due to other efficiency measures, such as better building envelopes. For example, Standard 90.1-2016 has more stringent fenestration U-factors for some climate zones. This results in smaller equipment and distribution systems, resulting in a negative first cost.

Table 5. Incremental Construction Cost for Hawaii ($/ft^2)

Climate Zone & Representative City	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
1A Honolulu	$0.281	$0.346	$0.931	($1.908)	($2.957)	($0.668)	($0.198)

2.4 Simple Payback

Simple payback is the total incremental first cost divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. Simple payback is not used as a measure of cost-effectiveness as it does not account for the time value of money, the value of energy cost savings that occur after payback is achieved, or any replacement costs that occur after the initial investment. However, it is included in the analysis for states who wish to use this information. Table 6 shows simple payback results in years.

Table 6. Simple Payback for Hawaii (Years)

Climate Zone & Representative City	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
1A Honolulu	0.9	2.2	3.2	Immediate	Immediate	Immediate	Immediate

3.0 Overview of the Cost-Effectiveness Methodology

This analysis was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy's (DOE) Building Energy Codes Program. DOE supports the development and implementation of energy efficient and cost-effective residential and commercial building energy codes. These codes help adopting states and localities establish minimum requirements for energy efficient building design and construction, as well as ensure significant energy savings and avoided environmental impacts. LCC savings is the primary measure DOE uses to assess the cost-effectiveness of building energy codes.

3.1 Cost-Effectiveness

DOE uses standard economic LCC cost-effectiveness analysis methods in comparing Standard 90.1-2016 and Standard 90.1-2013, which are described in *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes* (Hart and Liu 2015). Under this methodology, two metrics are used:

- **Net LCC Savings:** This is the calculation of the present value of energy savings minus the present value of non-energy incremental costs over a 30-year period. The costs include initial equipment and construction costs, maintenance and replacement costs, less the residual value of components at the end of the 30-year period. When net LCC is positive, the updated code edition is considered cost-effective.
- **Simple Payback:** While not a true cost-effectiveness metric, simple payback is also calculated. Simple payback is the number of years required for accumulated annual energy cost savings to exceed the incremental first costs of a new code.

Two cost scenarios are analyzed:

- **Scenario 1** represents publicly-owned buildings, considers initial costs, energy costs, maintenance costs, and replacement costs without borrowing or taxes.
- **Scenario 2** represents privately-owned buildings and includes the same costs as Scenario 1 plus financing of the incremental first costs through increased borrowing with tax impacts including mortgage interest and depreciation deductions. Corporate tax rates are applied. Economic analysis factors such as discount rates are also different, as described in Table 8.

The cost-effectiveness analysis compares the cost for new buildings meeting Standard 90.1-2016 versus new buildings meeting Standard 90.1-2013. The analysis includes energy savings estimates from building energy simulations and LCC and simple payback calculations using standard economic analysis parameters. The analysis builds on work documented in *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016* (DOE 2017), and the national cost-effectiveness analysis documented in *National Cost-effectiveness of ANSI/ASHRAE/IES Standard 90.1-2016* (Hart et al. 2019).

3.2 Building Prototypes and Energy Modeling

The cost-effectiveness analysis uses six building types represented by six prototype building energy models. These six models 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. These models provide coverage of the significant changes in

ASHRAE Standard 90.1 from 2013 to 2016 and are used to show the impacts of the changes on annual energy usage. The prototypes represent common construction practice and include the primary conventional HVAC systems most commonly used in commercial buildings.[2]

Each prototype building is analyzed for each of the climate zones found within the state. Using the U.S. DOE EnergyPlus software, the six building prototypes summarized in Table 7 are simulated with characteristics meeting the requirements of Standard 90.1-2013 and then modified to meet the requirements of the next edition of the code (Standard 90.1-2016). The energy use and energy cost are then compared between the two sets of models.

Table 7. Building Prototypes

Building Prototype	Floor Area (ft²)	Number of Floors
Small Office	5,500	1
Large Office	498,640	13
Stand-Alone Retail	24,690	1
Primary School	73,970	1
Small Hotel	43,210	4
Mid-Rise Apartment	33,740	4

3.3 Climate Zones

Climate zones are defined in ASHRAE Standard 169 and include eight primary climate zones in the United States, the hottest being climate zone 1 and the coldest being climate zone 8. Letters A, B, and C are applied in some cases to denote the level of moisture, with A indicating humid, B indicating dry, and C indicating marine. Figure 3 shows the national climate zones. For this state analysis, savings are analyzed for each climate zone in the state using weather data from a selected city within the climate zone and state, or where necessary, a city in an adjoining state with more robust weather data.

[2] More information on the prototype buildings and savings analysis can be found at www.energycodes.gov/development/commercial/90.1_models

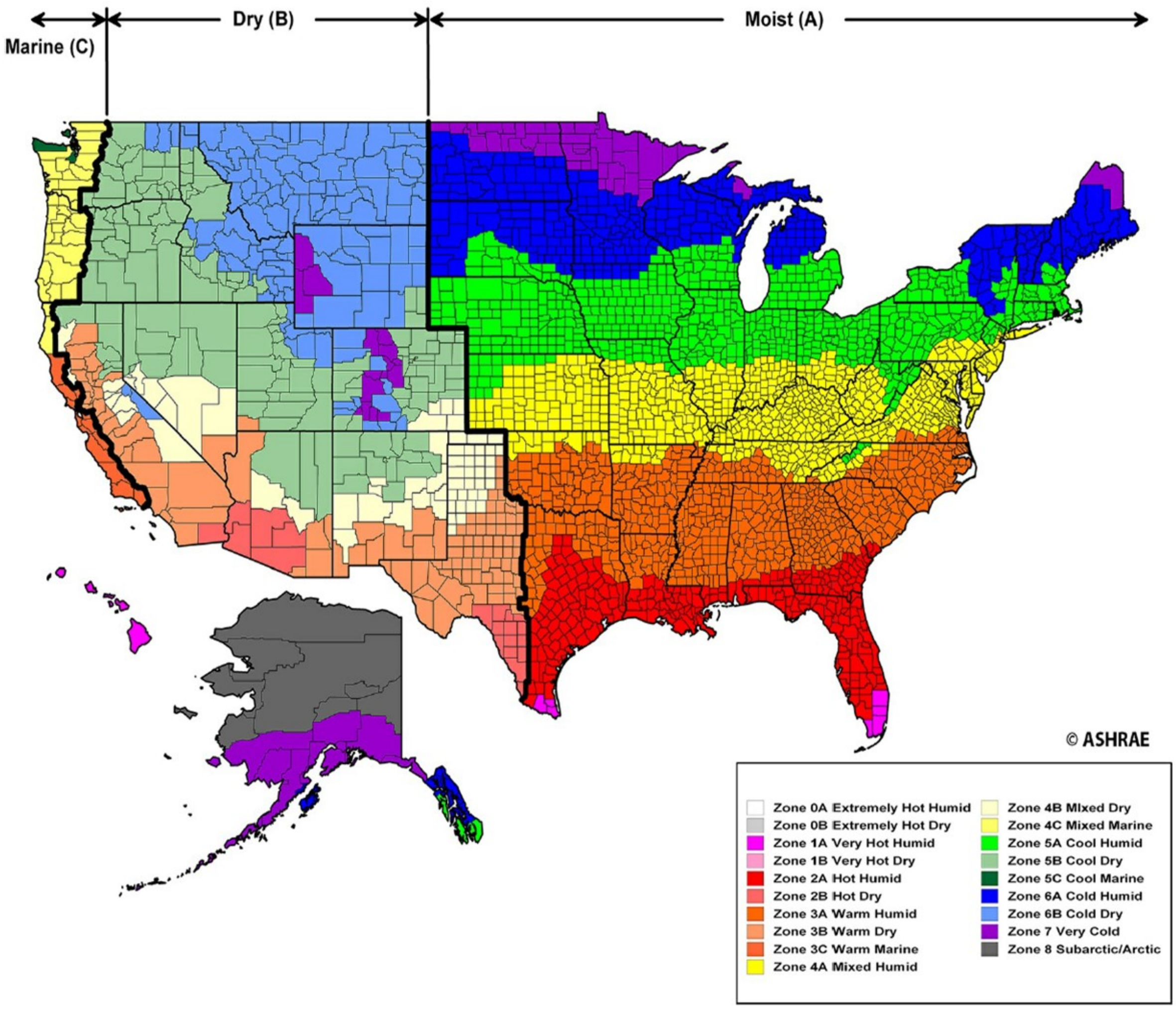

Figure 3. National Climate Zones

3.4 Cost-Effectiveness Method and Parameters

The DOE cost-effectiveness methodology accounts for the benefits of energy-efficient building construction over a multi-year analysis period, balancing initial costs against longer term energy savings. DOE evaluates energy codes and code proposals based on LCC analysis over a multi-year study period, accounting for energy savings, incremental investment for energy efficiency measures, and other economic impacts. The value of future savings and costs are discounted to a present value, with improvements deemed cost-effective when the net LCC savings (present value of savings minus cost) is positive.

The U.S. DOE Building Energy Codes Program uses an LCC analysis similar to the method used for many federal building projects, as well as other public and private building projects (Fuller and Petersen 1995). The LCC analysis method consists of identifying costs (and revenues if any) and in what year they occur; then determining their value in today's dollars (known as the present value). This method uses economic relationships about the time value of money. Money in-hand today is normally worth more than money received in the future, which is why we pay interest on a loan and earn interest on savings. Future costs are discounted to the present based on a discount rate. The discount rate may reflect the interest rate at which money can be borrowed for projects with the same level of risk or the interest rate that can be earned on other conventional investments with similar risk.

The LCC includes incremental initial costs, repairs, maintenance and replacements. Scenario 2 also includes loan costs and tax impacts including mortgage interest and depreciation deductions. The residual value of equipment (or other component such as roof membrane) that has remaining useful life at the end of the 30-year study period is also included for both scenarios. The residual value is calculated by multiplying the initial cost of the component by the years of useful life remaining for the component at year 30 divided by the total useful life, a simplified approach included in the Federal Energy Management Program (FEMP) LCC method (Fuller and Petersen 1995). A component will have zero residual value at year 30 only if it has a 30-year life, or if it has a shorter than 30-year life that divides exactly into 30 years (for example, a 15-year life).

The financial and economic parameters used for the LCC calculations are shown in Table 8.

Table 8. LCC Economic Parameters

Economic Parameter	Scenario 1	Scenario 2
Study Period – Years[1]	30	30
Nominal Discount Rate[2]	3.10%	6.00%
Real Discount Rate[2]	3.00%	4.05%
Effective Inflation Rate[3]	-0.20%	1.87%
Electricity Prices[4] (per kWh)	$0.3000	$0.3000
Natural Gas Prices[4] (per therm)	$3.2390	$3.2390
Energy Price Escalation Factors[5]	*Uniform present value factors*	*Uniform present value factors*
Electricity Price UPV[5]	21.94	16.16
Natural Gas Price UPV[5]	23.69	17.45
Loan Interest Rate[6]	NA	6.00%
Federal Corporate Tax Rate[7]	NA	21.00%
State Corporate Tax Rate[8]	NA	6.40%
Combined Income Tax Impact[9]	NA	26.06%
State and Average Local Sales Tax[10]	4.35%	4.35%
State Construction Cost Index[11]	1.186	1.186

[1] A 30-year study period captures most building components useful lives and is a commonly used study period for building project economic analysis. This period is consistent with previous and related national 90.1 cost-effectiveness analysis. It is also consistent with the cost-effectiveness analysis that was done for the residential energy code as described in multiple state reports and a summary report (Mendon et al. 2015). The federal building LCC method uses 25 years and the ASHRAE Standard 90.1 development process uses up to 40 years for building envelope code improvement analysis. Because of the time value of money, results are typically similar for any study periods of 20 years or more.

[2] The Scenario 1 real and nominal discount rates are from the National Institute of Standards and Technology (NIST) 2018 annual update in the *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the NIST 2018 annual supplement without citation (Lavappa and Kneifel 2018). The Scenario 2 nominal discount rate is taken as the marginal cost of capital, which is set equal to the loan interest rate (see footnote 6). The real discount rate for Scenario 2 is calculated from the nominal discount rate and inflation.

[3] The Scenario 1 effective inflation rate is from the NIST 2018 annual update for the federal LCC method (Lavappa and Kneifel 2018). The Scenario 2 inflation rate is the Producer Price Index for non-residential construction, 1988 to 2018 (Bureau of Labor Statistics 2019).

[4] Scenario 1 and 2 electricity and natural gas prices are state average annual prices for 2018 from the United States Energy Information Administration (EIA) *Electric Power Monthly* (EIA 2019a) and *Natural Gas Monthly* (EIA 2019b).

[5] Scenario 1 energy price escalation rates are from the NIST 2018 annual update for the FEMP LCC method (Lavappa and Kneifel 2018). The NIST uniform present value (UPV) 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 escalation rates for 30 years. Scenario 2 UPV factors are based on NIST UPVs with an adjustment made for the scenario difference in discount rates.

[6] The loan interest rate is estimated from multiple online sources listed in the references (Commercial Loan Direct 2019; Watts 2019).

[7] The highest federal marginal corporate income tax rate is applied.

[8] The highest marginal state corporate income tax rate is applied from the Federation of Tax Administrators (FTA 2019).

[9] The combined tax impact is based on state tax being a deduction for federal tax, and is applied to depreciation and loan interest.

[10] The combined state and average local sales tax is included in material costs in the cost estimate (Tax Foundation 2018).

[11] The state construction cost index based on weighted city indices from the state (Means 2018b).

4.0 Detailed Energy Use and Cost

On the following pages, specific detailed results for Hawaii are included:

- Table 9 shows the average energy rates used.
- Table 10 shows the per square foot energy costs for Standard 90.1-2013 and Standard 90.1-2016 and the cost savings from Standard 90.1-2016.
- Table 11 shows the per square foot energy use for Standard 90.1-2013 and Standard 90.1-2016 and the energy use savings from Standard 90.1-2016.
- Table 12.A shows the energy end use by energy type for each climate zone in the state.

Table 9. Energy Rates for Hawaii, Average $ per unit

Electricity	$0.3000	kWh
Gas	$3.2390	Therm

Source: Energy Information Administration, annual average prices for 2018 (EIA 2019a,b)

Table 10. Energy Cost Saving Results in Hawaii, $ per Square Foot

Climate Zone:	1A			
Code:	90.1-2013	90.1-2016	Savings	
Small Office				
Electricity	$2.978	$2.665	$0.314	10.5%
Gas	$0.000	$0.000	$0.000	-
Totals	$2.978	$2.665	$0.314	10.5%
Large Office				
Electricity	$6.783	$6.629	$0.153	2.3%
Gas	$0.040	$0.038	$0.002	5.0%
Totals	$6.823	$6.668	$0.155	2.3%
Stand-Alone Retail				
Electricity	$4.401	$4.118	$0.283	6.4%
Gas	$0.181	$0.172	$0.008	4.4%
Totals	$4.581	$4.290	$0.291	6.4%
Primary School				
Electricity	$4.291	$3.679	$0.612	14.3%
Gas	$0.200	$0.200	$0.000	0.0%
Totals	$4.491	$3.879	$0.612	13.6%
Small Hotel				
Electricity	$3.736	$3.294	$0.443	11.9%
Gas	$0.786	$0.762	$0.024	3.1%
Totals	$4.522	$4.055	$0.467	10.3%
Mid-Rise Apartment				
Electricity	$3.731	$3.586	$0.145	3.9%
Gas	$0.000	$0.000	$0.000	-
Totals	$3.731	$3.586	$0.145	3.9%

Table 11. Energy Use Saving Results in Hawaii, Energy Use per Square Foot

Climate Zone:	1A			
Code:	90.1-2013	90.1-2016	Savings	
Small Office				
Electricity, kWh/ft^2	9.928	8.882	1.046	10.5%
Gas, therm/ft^2	0.000	0.000	0.000	-
Totals, kBtu/ft^2	33.885	30.314	3.572	10.5%
Large Office				
Electricity, kWh/ft^2	22.609	22.098	0.511	2.3%
Gas, therm/ft^2	0.012	0.012	0.001	8.3%
Totals, kBtu/ft^2	78.398	76.600	1.798	2.3%
Stand-Alone Retail				
Electricity, kWh/ft^2	14.669	13.726	0.943	6.4%
Gas, therm/ft^2	0.056	0.053	0.003	5.4%
Totals, kBtu/ft^2	55.646	52.167	3.479	6.3%
Primary School				
Electricity, kWh/ft^2	14.303	12.263	2.040	14.3%
Gas, therm/ft^2	0.062	0.062	0.000	0.0%
Totals, kBtu/ft^2	55.000	48.030	6.971	12.7%
Small Hotel				
Electricity, kWh/ft^2	12.455	10.979	1.475	11.8%
Gas, therm/ft^2	0.243	0.235	0.007	2.9%
Totals, kBtu/ft^2	66.772	60.989	5.783	8.7%
Mid-Rise Apartment				
Electricity, kWh/ft^2	12.437	11.954	0.483	3.9%
Gas, therm/ft^2	0.000	0.000	0.000	-
Totals, kBtu/ft^2	42.448	40.799	1.649	3.9%

Table 12.A. Annual Energy Usage for Buildings in Hawaii in Climate Zone 1A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr
ASHRAE 90.1-2013												
Heating, Humidification	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.001	0.000	0.000	0.000	0.000
Cooling	2.519	0.000	6.045	0.000	5.715	0.000	4.869	0.000	4.404	0.000	2.722	0.000
Fans, Pumps, Heat Recovery	0.960	0.000	1.899	0.000	2.031	0.000	1.880	0.000	1.939	0.000	1.588	0.000
Lighting, Interior & Exterior	2.848	0.000	2.277	0.000	4.738	0.000	2.829	0.000	2.526	0.000	1.487	0.000
Plugs, Refrigeration, Other	2.438	0.000	12.388	0.000	2.186	0.000	4.629	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	1.162	0.000	0.000	0.012	0.000	0.033	0.097	0.015	0.000	0.150	2.433	0.000
Total	9.928	0.000	22.609	0.012	14.669	0.056	14.303	0.062	12.455	0.243	12.437	0.000
ASHRAE 90.1-2016												
Heating, Humidification	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.001	0.001	0.000	0.000	0.000
Cooling	2.417	0.000	5.904	0.000	5.953	0.000	4.372	0.000	3.876	0.000	2.648	0.000
Fans, Pumps, Heat Recovery	0.949	0.000	1.866	0.000	1.845	0.000	1.720	0.000	1.353	0.000	1.535	0.000
Lighting, Interior & Exterior	1.914	0.000	1.954	0.000	3.742	0.000	1.471	0.000	2.165	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.374	0.000	2.186	0.000	4.603	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	1.163	0.000	0.000	0.012	0.000	0.033	0.097	0.015	0.000	0.143	2.433	0.000
Total	8.882	0.000	22.098	0.012	13.726	0.053	12.263	0.062	10.979	0.235	11.954	0.000
Total Savings	1.046	0.000	0.511	0.001	0.943	0.003	2.040	0.000	1.475	0.007	0.483	0.000

5.0 References

(ASHRAE) ANSI/ASHRAE/IES – American National Standards Institute, American Society of Heating, Refrigerating and Air-Conditioning Engineers, and Illuminating Engineering Society. 2013. *ANSI/ASHRAE/IES 90.1-2013, Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

(ASHRAE) ANSI/ASHRAE/IES – American National Standards Institute, American Society of Heating, Refrigerating and Air-Conditioning Engineers, and Illuminating Engineering Society. 2016. *ANSI/ASHRAE/IES 90.1-2016, Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

Bureau of Labor Statistics. 2019. “Producer Price Indexes.” Washington, D.C. Accessed January 17, 2019 at www.bls.gov/data

Commercial Loan Direct. 2019. “Commercial Mortgage Interest Rates - Nationwide Lending, Mid Balance - Investor/Owner Occupied.” Atlanta, Georgia. Accessed January 17, 2019 at www.commercialloandirect.com/commercial-rates.php

DOE – U.S. Department of Energy. 2017. *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016.* DOE/EE-1614, U.S. Department of Energy, Washington, D.C. Available at https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf

EIA – United States Energy Information Administration. 2019a. *Electric Power Monthly, February 2019.* Energy Information Administration, Washington, D.C. Available at https://www.eia.gov/electricity/monthly/

EIA – United States Energy Information Administration. 2019b. *Natural Gas Monthly, February 2019*. Energy Information Administration, Washington, D.C. Available at https://www.eia.gov/naturalgas/monthly/

FTA – Federation of Tax Administrators. 2019. “Range of State Corporate Income Tax Rates.” Washington, D.C. Accessed February 26, 2019 at https://www.taxadmin.org/assets/docs/Research/Rates/corp_inc.pdf

Fuller SK and SR Petersen. 1995. *Life-Cycle Costing Manual for the Federal Energy Management Program*, NIST Handbook 135. U.S. Department of Commerce, Washington, D.C.

Hart PR and B Liu. 2015. *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.* PNNL-23923 Rev 1. Pacific Northwest National Laboratory, Richland, WA. Available at https://www.energycodes.gov/sites/default/files/documents/commercial_methodology.pdf

Hart PR, M Myer, M Halverson, Y Chen, M Rosenberg, Y Xie, S Loper, J Zhang, and E Poehlman. 2019. *National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2016.* PNNL-28206. Pacific Northwest National Laboratory, Richland, WA.

Jarnagin RE and GK Bandyopadhyay. 2010. *Weighting Factors for the Commercial Building Prototypes Used in the Development of ANSI/ASHRAE/IESNA 90.1-2010*. PNNL-19116. Pacific Northwest National Laboratory, Richland, Washington.

Lavappa P and J Kneifel. 2018. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2018: Annual Supplement to NIST Handbook 135*. National Institute of Standards and Technology, U.S. Department of Commerce, Washington, D.C. Available at https://doi.org/10.6028/NIST.IR.85-3273-33

McGraw Hill Construction. 2007. *McGraw Hill Construction Database (2003-2007)*. McGraw Hill Construction, New York, New York. Available for purchase at http://dodge.construction.com

Mendon VV, A Selvacanabady, M Zhao, and ZT Taylor. 2015. *National Cost-Effectiveness of the Residential Provisions of the 2015 IECC*. PNNL-24240. Pacific Northwest National Laboratory, Richland, WA. Available at www.energycodes.gov/development/residential/iecc_analysis

RS Means. 2018a. *RSMeans Mechanical Cost Data*, 41st Ed. Construction Publishers & Consultants. Norwell, Massachusetts.

RS Means. 2018b. *RSMeans Building Construction Cost Data*, 41st Ed. Construction Publishers & Consultants. Norwell, Massachusetts.

Tax Foundation. 2018. “State and Local Sales Tax Rates 2018.” Washington, D.C. Available at https://taxfoundation.org/state-and-local-sales-tax-rates-2018/

Watts R. 2019. “RealtyRates.com Investor Survey – 4th Quarter 2018 Permanent Financing.” Palma Sola, Florida. Accessed January 17, 2019 at www.realtyrates.com/commercial-mortgage-rates.html

The U.S. Department of Energy (DOE) provides estimates of energy and cost savings from code adoption at the National, Climate Zone, and State levels. For more information on how these estimates were developed, visit the DOE Building Energy Codes website: www.energycodes.gov/development/commercial

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