Achieving 30% and 50% over ASHRAE 90.1-2004 in a Low-Rise Office Building

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Abstract:
This report documents technical analysis aimed at understanding the practical and economical impacts of constructing a defined low-rise office building at levels 30% and 50% above the ASHRAE 90.1-2004 Energy Standard. The model evaluated was a 95,000 square foot, four-story, Class A low-rise office building. EnergyPlus was the simulation tool used for modeling building heating, cooling, lighting, ventilating and other energy flows. Practical, above 90.1-2004 energy features were determined by identifying building enhancements with less than a ten-year utility savings' payback period. The analysis was not successful in identifying practical energy feature upgrades to achieve the 30% threshold. The best scenario evaluated achieved 23% over the ASHRAE 90.1-2004 Standard.

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Introduction

Several studies have highlighted the approaches required to design highly efficient theoretical commercial buildings. Fewer though, have focused on the energy saving potential of actual real world buildings. ConSol responded to a request for proposal from NAIOP asking for an analysis of a recently constructed low-rise office building, and the practicality of building it 30% and 50% above the ASHRAE 90.1-2004 Energy Standard. The intention of this study is to form a high level understanding of the above ASHRAE 90.1-2004 Standard potential in a single model representative of a low-rise Class A office new construction.

The objectives of this study are:

- To construct an energy model that accurately predicts the energy use of the low-rise office building provided;
- To determine the baseline regulated energy use for the building model in specific climate zones in the United States;
- To determine the percent over ASHRAE 90.1-2004 that specific energy feature upgrades provide;
- To determine, via marginal cost of the energy feature upgrades, practical limits of energy features within the building model given a ten-year utility savings' payback requirement.

This report is organized into three parts: methodology, results and findings. Methodology describes the methods and assumptions used in this analysis. Results outline the energy use and energy savings potential of the features evaluated. Summary reviews the overall results of the study and describes technical barriers encountered.

Methodology

This section summarizes the methodology and assumptions used in the undertaking of this analysis.

Simulation Software
Due to the important interaction between building energy systems in commercial structures, ConSol deemed it appropriate to use EnergyPlus v2.2 for this analysis. EnergyPlus is the U.S. Department of Energy (DOE) building energy simulation program for modeling building heating, cooling, lighting, ventilating and other energy uses. It is the most advanced building simulation tool to date, building on many popular features of legacy simulation engines, such as BLAST and DOE-2, and including many new capabilities. The EnergyPlus simulations were managed via the DesignBuilder v1.6 platform. DesignBuilder was chosen for its intuitive and powerful 3D modeling capabilities as well as its ability to organize the various energy efficiency measures employed.

Simulation Methodology
A modified version of ASHRAE 90.1-2004 Appendix G was used for this analysis. Modifications include the exception of non-regulated loads, baseline glazing and energy savings, not energy cost, as the above ASHRAE 90.1-2004 metric. Percent savings are based on a code compliant building as described in ASHRAE 90.1-2004 with the exception of unregulated (receptacle and process) loads and baseline glazing percentage. It was deemed appropriate for this study to focus solely on regulated loads as only they could be affected by jurisdictional energy codes such as the International Energy Conservation Code and ASHRAE 90.1 Standard. Baseline glazing was set at 50% to most accurately maintain architectural similarity to the actual building as constructed.

Prototype Building
The scope of this project required analysis of a specific low-rise office building. NAIOP provided construction documents for a recently completed office building with its specifications in the following table:

Feature	Description
Building Type	Low-Rise Office
Total Area	95,000 square feet
Number of Stories	4
Average Story Height	14 feet
Class of Construction	A
Percentage of Façade Glazing	50%
Glazing Sill Height	4 feet
HVAC System	VAV with Terminal Reheat and Gas Fired Boiler

Table 1: Prototype Building Description

Climate Zones

Of the seven International Energy Conservation Code (IECC)/ASHRAE climate zones in the continental United States (as depicted in Figure 1), the scope of this analysis covers IECC Climate Zones 3, 4 and 5. Table 2 describes the specific cities in which the office building was evaluated. The IECC zones are categorized by Heating and Cooling Days (HDD and CDDs), and range from the very hot Zone 1 to the very cold Zone 7. Additional sub-zones A, B and C denote humid, dry and marine climates, respectively.

Figure 1: Continental U.S. Climate Zones

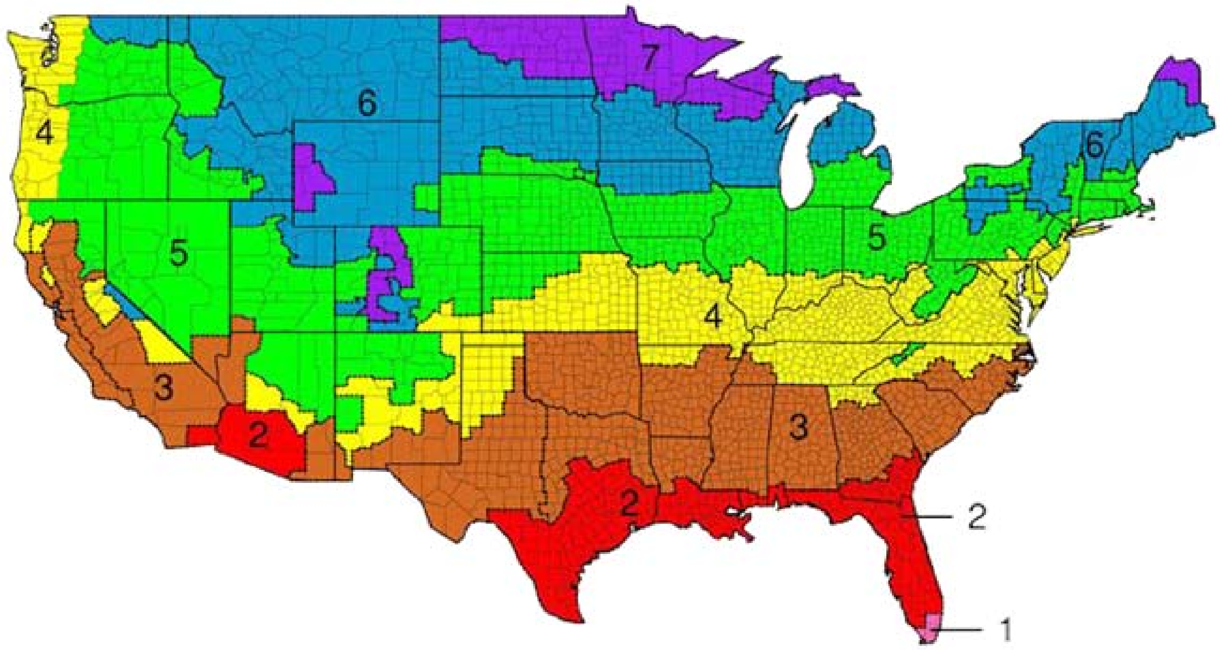


Table 2: Cities and Climate Zones Evaluated

City	Climate Zone
Newport Beach, CA	3B
Baltimore, MD	4A
Chicago, IL	5A

Baseline Energy Features

Energy savings are demonstrated in comparison with a baseline model that is minimally compliant with the ASHRAE 90.1-2004 Standard. Since the 90.1 Standard has separate requirements for each climate zone, the prototype building baseline was modeled individually to each climate zone via the energy feature levels listed in Table 3.

Table 3: ASHRAE 90.1-2004 Energy Features Used in Baseline Model

City	Newport Beach, CA	Baltimore, MD	Chicago, IL
Envelope			
Roof	R-19	R-19	R-19
Walls	R-13	R-13	R-13 + R3.8
Floors	R-19	R-19	R-19
Glazing SHGC	SHGC all = 0.19 SHGC north = 0.26	SHGC all = 0.25 SHGC north = 0.36	SHGC all = 0.26 SHGC north = 0.36
Glazing U-value	0.46	0.46	0.46
HVAC			
EER	10.8	10.8	10.8
Boiler Efficiency	0.78	0.78	0.78
Aux. Energy	3.34 W/sqft	3.34 W/sqft	3.34 W/sqft
Lighting			
Lighting Power Density	1.0 W/sqft	1.0 W/sqft	1.0 W/sqft

It is important to note that while the climate zones evaluated vary from mild to very cold, there are relatively little (slight) changes in the minimally compliant requirements inherent to ASHRAE 90.1-2004.

Energy Efficiency Measures Evaluated
Energy efficiency measures assessed mainly consisted of increasing efficiency in existing energy features of the building. Energy efficiency measures evaluated included:

Enhanced wall insulation
Enhanced roof insulation
Varying levels of exterior glazing
Higher efficiency window assemblies
Reduced air infiltration via the installation of an air barrier
Reduced lighting power densities
Higher efficiency HVAC equipment
Photovoltaic electricity energy generation

Of these measures, several were included as recommendations from the "Advanced Energy Design Guide for Small Offices" (ASHRAE et al. 2004). We did not evaluate all efficiency measures available to office buildings. For measures that could be included in a later study, see Summary.

Cost Data
The majority of cost data was obtained through the "RSMeans Green Building Cost Estimating Database" (Keenan et al. 2006). These costs were usually available in per square foot or linear foot quantities and were multiplied by the appropriate area or distance of material. Increased costs related to HVAC auxiliary energy (fans, dampers, etc.) were determined via "RSMeans

Mechanical Cost Data" (Mossman 2005). Few studies have determined the cost increases associated with reduced lighting power density (LPD); however, the "Development of the Advanced Energy Design Guide for Retail Buildings – 50% Savings" (Hale et al. 2008) provided insight to possible cost ranges. Although Hale's work was based on a retail model, it was the only reduced LPD costing data found suitable. Infiltration was assumed to decrease 0.15% via installation of an air barrier with cost data found in "Investigation of the Impact of Commercial Building Envelope Airtightness" (Emmerich et al., 2005).

Costs not available from the above sources were determined via personal correspondence with equipment manufacturers. Feature costs are assumed constant at all locations. Table 4 outlines the marginal cost increase, from code compliant material, associated with each energy feature. Marginal cost increases were found by subtracting code compliant feature cost from the upgraded energy efficiency measure cost. Cost estimates were installed costs. Labor and material were included.

Table 4: Marginal Cost Increase per Energy Feature

Energy Feature	Marginal Cost		Energy Feature	Marginal Cost
Lighting = 0.8 W/sqft	$ 60,420.00		R-26 Roof	$ 16,362.73
Lighting = 0.9 W/sqft	$ 30,210.00		R-32 Roof	$ 30,387.92
Infiltration = 0.35 ACH	$ 28,751.52		R-38 Roof	$ 44,413.11
HVAC - aux. energy = +10%	$ 29,563.73		R-48 Roof	$ 67,788.44
HVAC - EER = 12.0 EER	$ 12,409.11		R-19 Cool Roof	$ 4,750.00
HVAC - EER = 11.5 EER	$ 7,332.66		R-26 Cool Roof	$ 21,112.73
Boiler Efficiency = 90%	$ 17,500.00		R-38 Cool Roof	$ 49,163.11
R-17 Walls	$ 2,300.65		Window Glazing = 40%	N/A
R-26 Walls	$ 7,870.63		Window Glazing = 30%	N/A

Payback and Utility Rates

Energy efficiency measure marginal cost divided by annual utility savings provided payback periods in years. Peak kilowatt savings were not included. State average utility prices were taken from data compiled by the Energy Information Administration (EIA 2007) and shown in Table 5:

Table 5: Average Commercial Utility Prices per State

City	California	Maryland	Illinois
Electricity ($/kWh)	0.1523	0.0847	0.1346
Natural Gas ($/therm)	1.02	1.33	1.04

Results

This section summarizes the performance of the baseline models as well as the energy efficiency measures evaluated.

Baseline Annual Energy Use
The annual energy use of the baseline, minimally code compliant building is shown in Figure 2. Table 6 outlines the breakdown of energy use by building system.

Figure 2: Baseline Energy Use

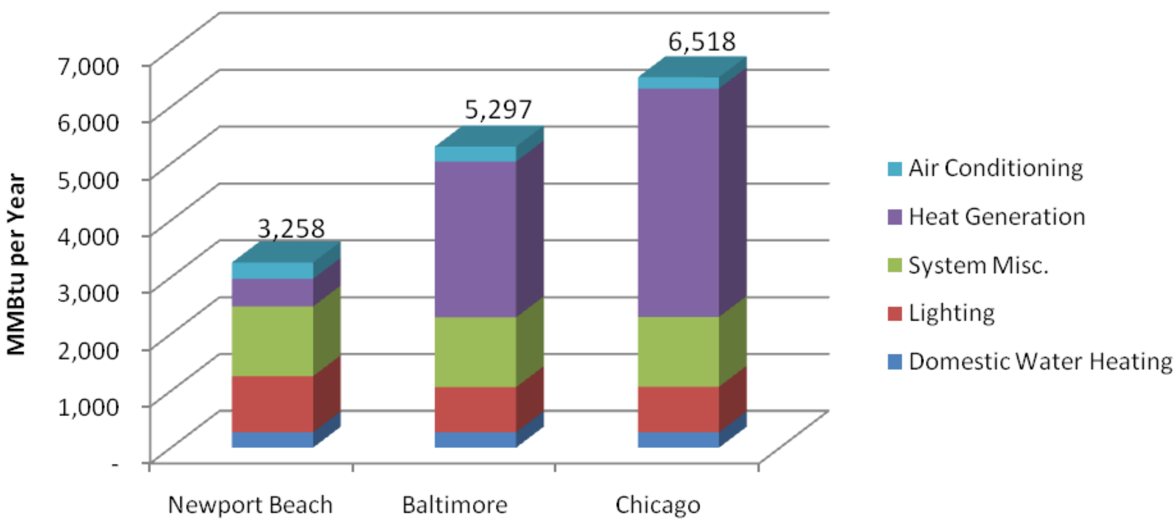


Table 6: Baseline Energy Use Breakdown

	Newport Beach			Baltimore			Chicago	
	MMBtu/year	% of total		MMBtu/year	% of total		MMBtu/year	% of total
Domestic Water Heating	271.3	8.3%		271.3	5.1%		271.3	4.2%
Lighting	985.5	30.2%		792.4	15.0%		801.4	12.3%
System Misc.	1229.0	37.7%		1229.0	23.2%		1229.0	18.9%
Heat Generation	486.4	14.9%		2741.4	51.8%		4018.1	61.7%
Air Conditioning	286.0	8.8%		263.0	5.0%		197.8	3.0%
Total	3258.2			5297.1			6517.5	

An important point is the difference in annual energy use between the mild and cold climates. Even though the minimally code compliant model in Chicago has similar building features as the model in Newport Beach, the colder Chicago climate drives the annual regulated energy use to nearly double that of the Newport Beach model.

Comparison of Baseline Model to CBECS' Derived Benchmarks

Since the outputs from the EnergyPlus simulations are theoretical, it is valuable to compare these predictions to available benchmarks of energy use in comparable office buildings. The most recent Commercial Building Energy Consumption Survey (CBECS) database contains energy use estimates for nearly 4.9 million U.S. commercial buildings (EIA 2005). A brief summary comparing our model's energy estimates and CBECS' office building data is summarized in Table 7.

Table 7: EnergyPlus Model Versus CBECS Commercial Data

	Average of ConSol EP Models MMBtu/year	CBEC Data MMBtu/year
Domestic Water Heating	271.3	494.0
Lighting	859.8	1615.0
System Misc.	1229.0	
Heat Generation	2415.3	3116.0
Air Conditioning	248.9	845.5
Total	4775.3	5225.0

Energy use from fans, dampers and other miscellaneous equipment within the HVAC system are labeled "System Miscellaneous" in EnergyPlus outputs, as opposed to the CBECS' database, which simply adds this energy consumption to the "Air Conditioning" or "Heat Generation" categories. With an approximate 9% difference in overall annual energy consumption, the baseline EnergyPlus model results are reasonable.

Energy Feature Reduction Potential

The following table and figures describe and summarize the percentage above the ASHRAE 90.1-2004 Standard baseline each energy efficiency measure provided. It is important to note that each energy feature was evaluated independently. For example, 5.73% total building energy savings was solely due to reducing the lighting system power in the Newport Beach model from 1.0 watts per square foot (W/sqft) to 0.8 W/sqft.

Table 8: Energy Efficiency Features and Descriptions

Energy Feature Name	Description
Lighting = 0.8 W/sqft	Lighting power reduced from 1.0 watts per square foot
Lighting = 0.9 W/sqft	Lighting power reduced from 1.0 watts per square foot
Infiltration = 0.35 ACH	Building infiltration reduced from 0.5 air changes per hour
HVAC - aux. energy = +10%	Non direct heating/cooling energy use (fans, dampers, controls, etc.) efficiency increased by 10%
HVAC - EER = 12.0 EER	HVAC cooling equipment efficiency increased from ASHRAE 90.1-2004 minimum
HVAC - EER = 11.5 EER	HVAC cooling equipment efficiency increased from ASHRAE 90.1-2004 minimum
Boiler Efficiency = 90%	Service boiler efficiency increase from ASHRAE 90.1-2004 minimum
R17 & R-25 Walls	Wall insulation increased from ASHRAE 90.1-2004 minimum
R-48, R-38, R-32 & R-26 Roof	Roof insulation increased from ASHRAE 90.1-2004 minimum
R-38 & R-26 Cool Roof	Roof insulation increased from ASHRAE 90.1-2004 minimum + roofing material with solar reflectance 0.70 and emittance 0.75
Window Glazing = 30% & 40%	Exterior facade glazing ratio reduced from baseline ratio of 50%

Figure 3: Newport Beach, CA – Energy Feature Potential (% Above ASHRAE 90.1-2004)

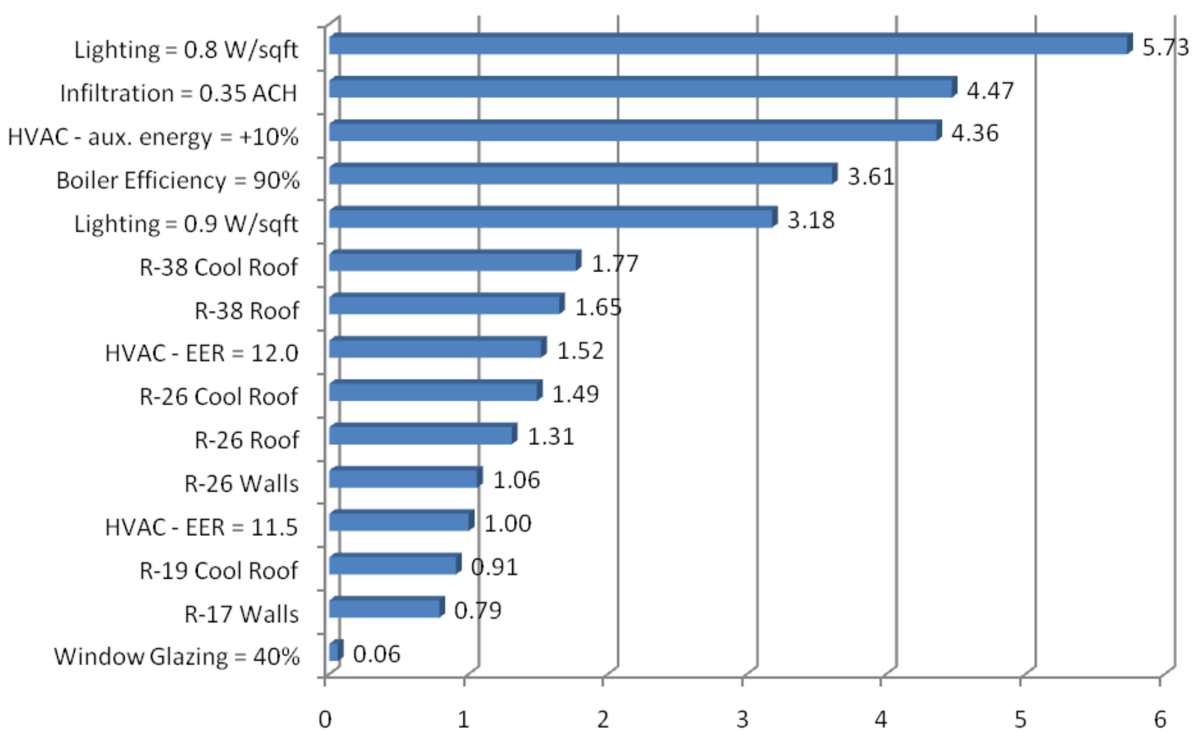


Figure 4: Baltimore, MD – Energy Feature Potential

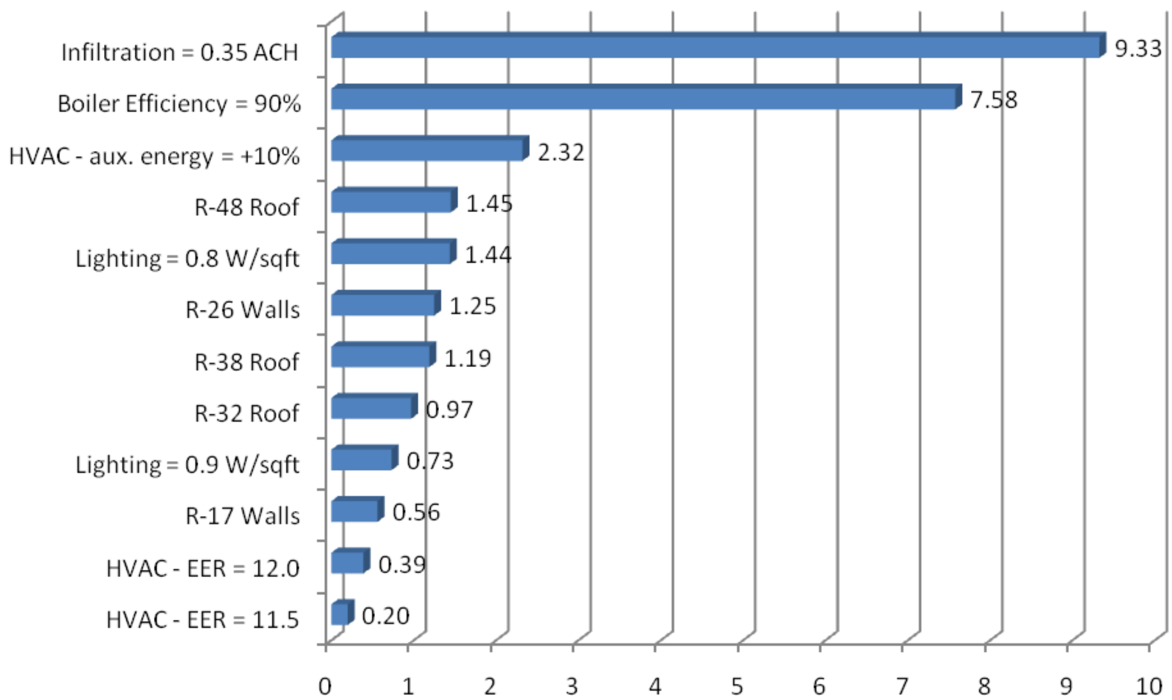
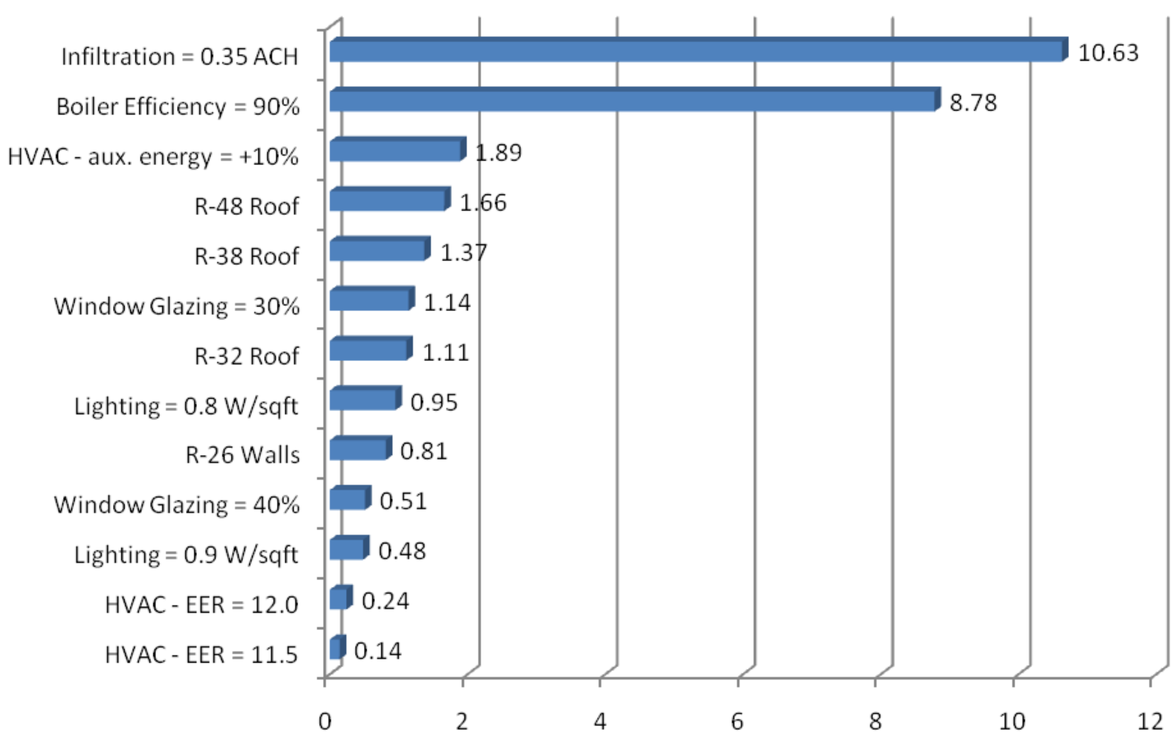


Figure 5: Chicago, IL – Energy Feature Potential



Energy Feature Payback via Utility Savings

Figures 6, 7 and 8 describe the payback period, in years, required for each energy feature to offset its incremental cost via energy savings. The alternative colored data points labeled "PACKAGE" represent a collection of energy features modeled together. These features were chosen because together would have a collective payback period of approximately ten years. The ten-year period was established in the project scope of work and is considered acceptable to a majority of commercial developers and owners. PACKAGE features are summarized in Table 9.

Table 9: PACKAGE Energy Features per Climate Zone

Newport Beach	Baltimore	Chicago
R-26 Walls	R-26 Walls	R-26 Walls
R-38 Cool Roof	R-38 Roof	R-48 Roof
Lighting = 0.9 W/sqft	Lighting = 0.9 W/sqft	Lighting = 0.9 W/sqft
HVAC - EER = 12.0 EER	HVAC - EER = 12.0 EER	HVAC - EER = 12.0 EER
HVAC - aux. energy = +10%	HVAC - aux. energy = +10%	HVAC - aux. energy = +10%
Boiler Efficiency = 90%	Boiler Efficiency = 90%	Boiler Efficiency = 90%
Infiltration = 0.35 ACH	Infiltration = 0.35 ACH	Infiltration = 0.35 ACH

Figure 6: Newport Beach, CA – Energy Feature Payback (Years)

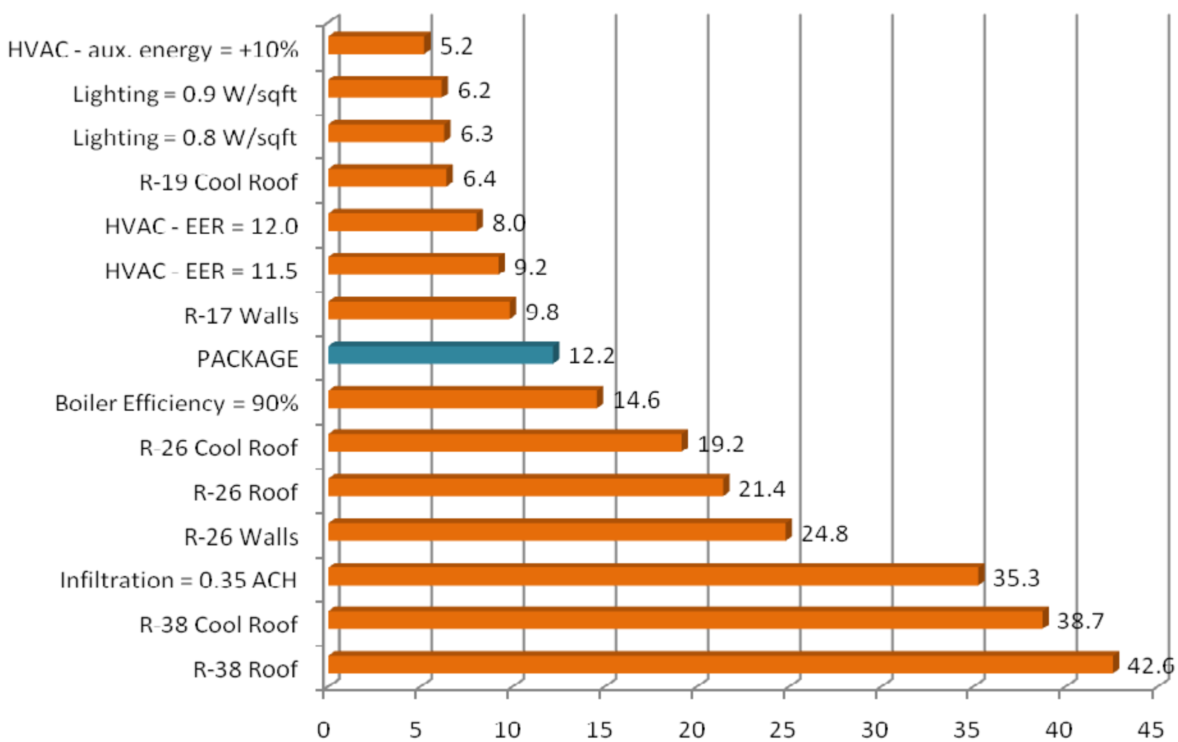


Figure 7: Baltimore, MD – Energy Feature Payback

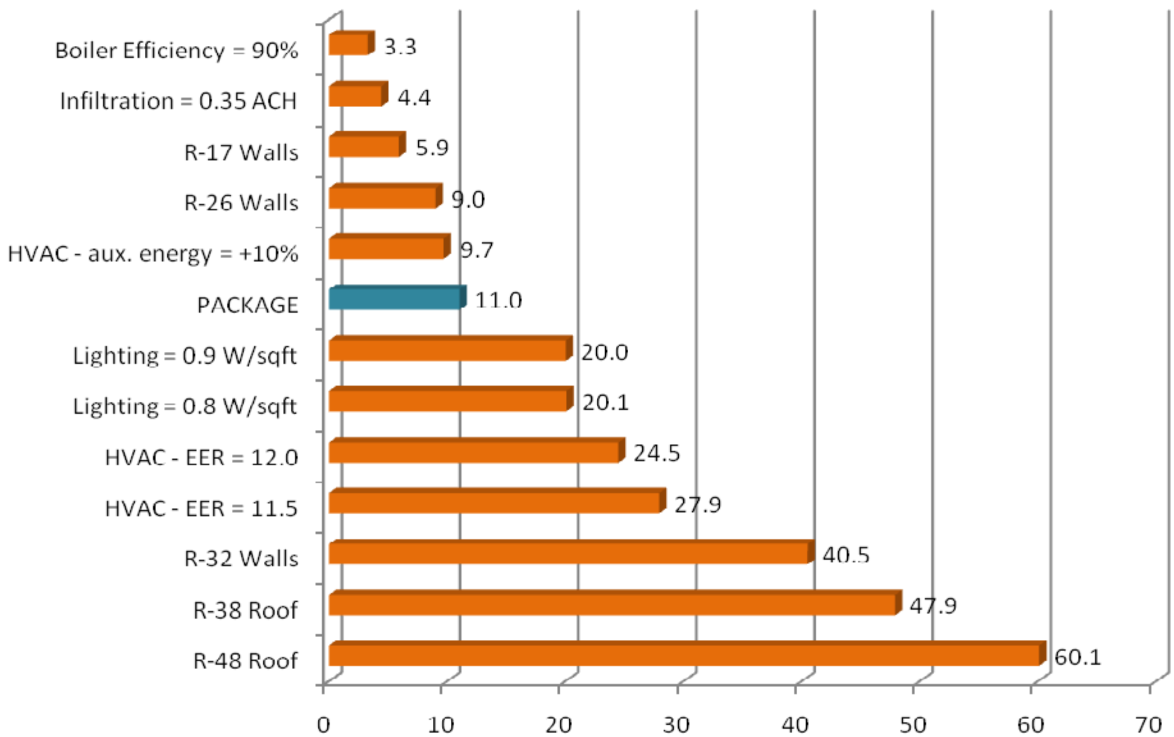
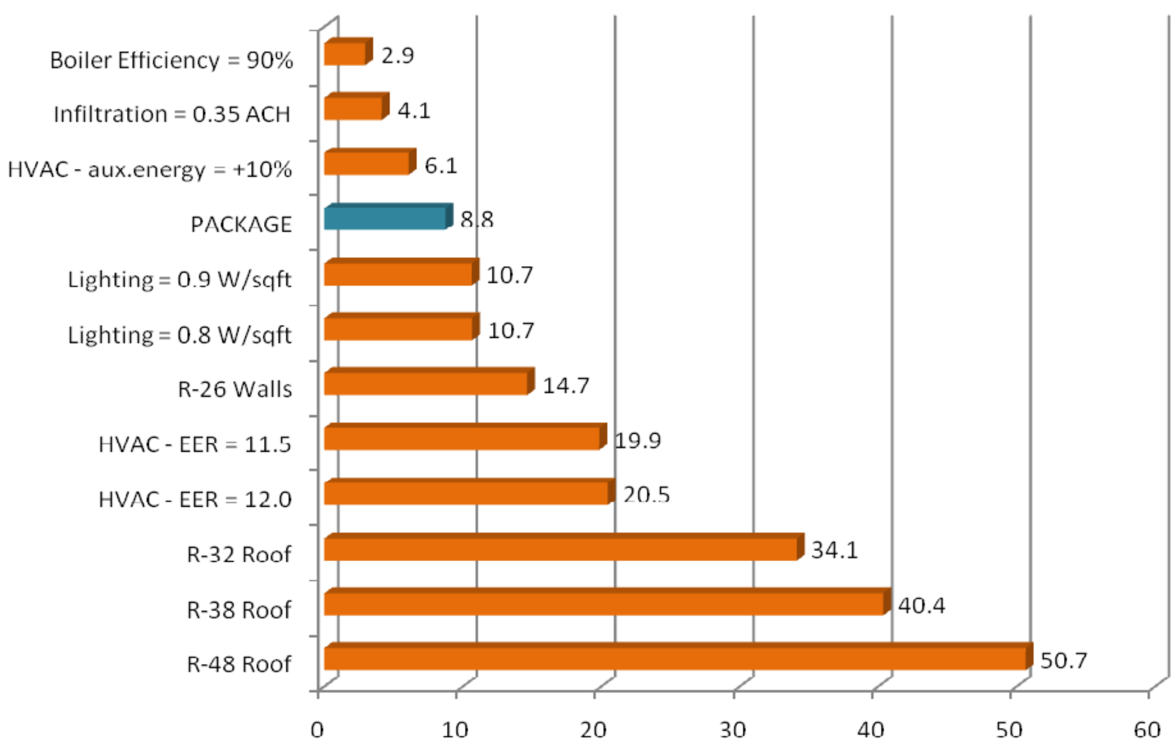


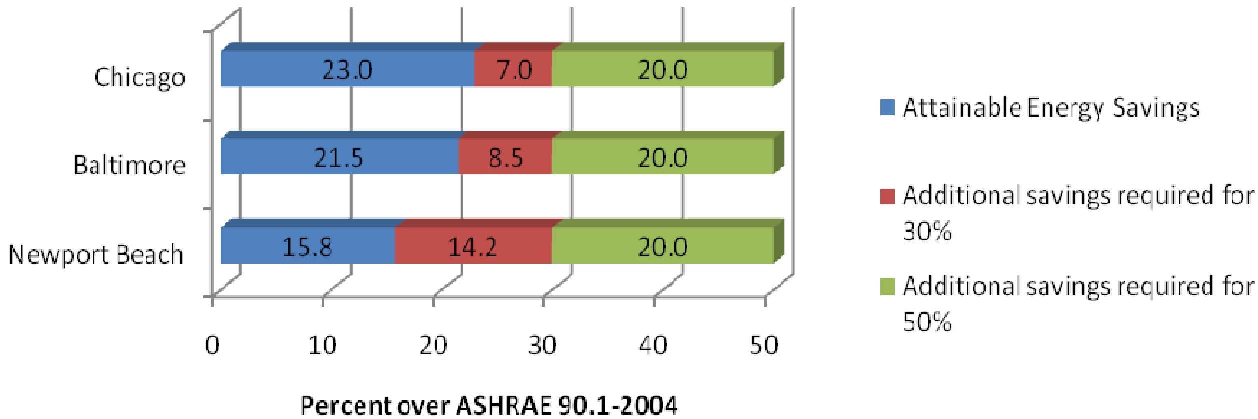
Figure 8: Chicago, IL – Energy Feature Payback



Practical Limits Over ASHRAE 90.1-2004

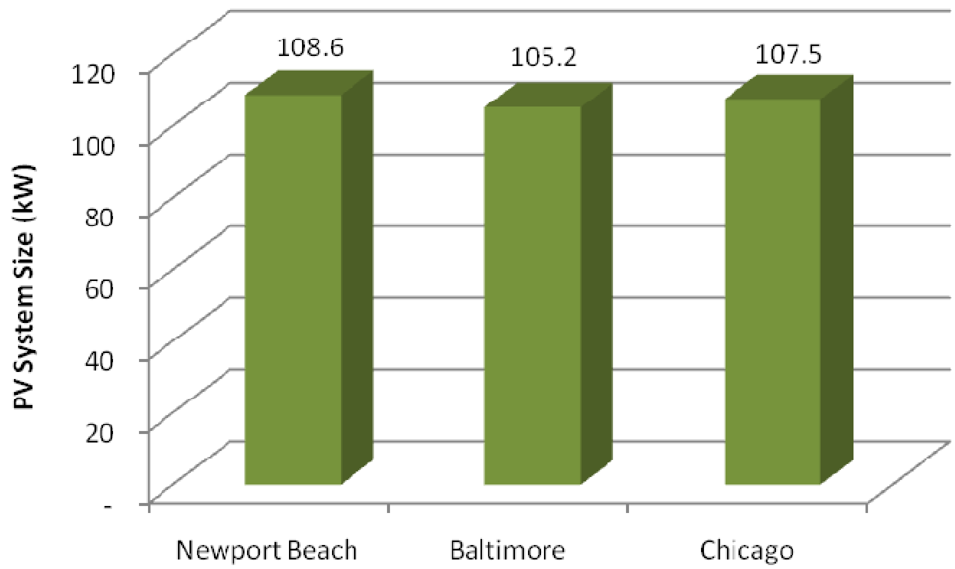
With the PACKAGE features noted in Table 9, the Chicago, Baltimore and Newport Beach models achieved 23.0%, 21.5% and 15.8%, respectively, over the ASHRAE 90.1-2004 Standard. These could represent the practical and economical limits of current construction within this office building model. Increased energy features from these levels would drive the PACKAGE payback period well beyond the ten-year time horizon.

Figure 9: Percentage Achieved Over ASHRAE 90.1-2004 and Additional Savings Required for 30% and 50%



Additional energy savings are required to reach the 30% and 50% goals. Outside of increasing building energy features, one way to do this would be to generate electricity via photovoltaic panels. Assuming the same incident solar radiation in Baltimore and Chicago as Newport Beach, Figure 10 describes the approximate solar system size required for the PACKAGE-enhanced models to achieve 30% over the ASHRAE 90.1-2004 Standard.

Figure 10: Solar System Sizing For PACKAGE Models To Reach 30%



These systems would cover approximately 11,000 square feet and could be installed on the building rooftop. However, with an installed cost of over $1.1 million (Keenan et al. 2006) and a payback period between 55 and 100 years, they would be economically impractical considering the industry accepted ten-year timeframe.

Summary

Findings

This study was to determine if 30% - 50% savings over ASHRAE 90.1-2004 Standard in a defined office building was achievable within a ten-year payback. This report finds that 30%, let alone 50% net site energy savings, will be difficult to achieve in the low-rise office building within the ten-year payback time frame.

The Newport Beach model achieved 15.8% over ASHRAE 90.1-2004. Enhanced energy features used were: R-16 walls; R-38 roofing with a cool roof coating; reduction of lighting power to 0.9 watts per square foot; increasing HVAC cooling efficiency to 12.0 EER; increasing HVAC auxiliary energy efficiency by 10%; increasing boiler efficiency to 90; and reducing overall infiltration to 0.35 air changes per hour. At a marginal cost increase of $169,898.13, this corresponds with a 12.2 year payback via utility savings.

The Baltimore model achieved 21.5% over ASHRAE 90.1-2004. Enhanced energy features used were: R-16 walls; R-38 roofing; reduction of lighting power to 0.9 watts per square foot; increasing HVAC cooling efficiency to 12.0 EER; increasing HVAC auxiliary energy efficiency by 10%; increasing boiler efficiency to 90; and reducing overall infiltration to 0.35 air changes per hour. At a marginal cost increase of $165,148.13, this corresponds with an 11 year payback via utility savings.

The Chicago model achieved 23% over ASHRAE 90.1-2004. Enhanced energy features used were: R-16 walls; R-48 roofing; reduction of lighting power to 0.9 watts per square foot; increasing HVAC cooling efficiency to 12.0 EER; increasing HVAC auxiliary energy efficiency by 10%; increasing boiler efficiency to 90; and reducing overall infiltration to 0.35 air changes per hour. At a marginal cost increase of $188,523.45, this corresponds with an 8.8 year payback via utility savings.

Several energy efficiency measures were not included in this study due to lack of modeling capability, sufficient data or project scope. Measures that warrant future study include solar thermal technologies, geothermal heat pumps, underfloor air distribution systems, radiant space conditioning, evaporative cooling technologies and light emitting diode (LED) lighting systems.

Technical Barriers

As pointed out by Hale et al. in the "Advanced Energy Design Guide for Medium Box Retail" (2008), achieving significant levels above ASHRAE 90.1-2004 cost-effectively requires integrated building design, that is a design approach that analyzes buildings as holistic systems rather than as disconnected collections of individually engineered subsystems. Examples of this type of approach include building design that, at inception, revolve closely around the energy using systems. One approach could be the integration of day lighting, geothermal air conditioning and underfloor air distribution systems. Together, these systems could prove substantial achievement over the 90.1-2004 benchmark. However, the design and subsequent construction of this building, using a holistic approach, would be in significant contrast to standard development practices that are designed to maximize leasable area. This approach is employed by the majority of commercial development in the United States.

As modeled in Newport Beach, a geothermal system (a potential component of a holistic approach) would require more than two acres of space – an impossibility for the project site. Assuming the same bore depth, the geothermal space requirements would increase with colder climates, such as Baltimore or Chicago. In the case of an underfloor air delivery system, architecture and mechanical design would need to accommodate distribution plenums, therefore increasing relative cost and construction complexities.

There are many examples of successful holistic designs, but in the case of this model, these approaches could be considered impractical. This design philosophy will be a hurdle for the architects and build teams of future commercial projects as it involves additional resources during design and construction.

After upgrading building energy features, solar generation is the current solution for additional energy savings over the 90.1-2004 Standard. However, installed solar cost would need to come down by a factor of five for it to meet the ten-year payback criteria. This presents a significant economic barrier. Federal, state and local incentives can further reduce this barrier.

Conclusion

Our model achieved 15.8% (Newport Beach, CA); 21.5% (Baltimore, MD); and 23% (Chicago, IL) over the ASHRAE 90.1-2004 Standard. This was done primarily by upgrading the building envelope insulation and increasing efficiency of energy using sub-systems. Representing the practical limit of current construction, together, these upgrades will save enough energy in approximately ten years to offset their marginal increase in cost. Solar can be used to make up the difference to 30%, but with a payback timeframe exceeding 50 years.

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