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Simulation Analyses in Support of DOE's Fossil Fuel Rule for Single Component Equipment and Lighting Replacements

MA Halverson
W Wang

October 2013

Pacific Northwest NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

At the request of the US Department of Energy's (DOE) Federal Energy Management Program (FEMP), Pacific Northwest National Laboratory (PNNL) conducted a series of building energy simulations using a large office model to investigate the potential savings that could be accrued from a typical chiller, boiler, or lighting replacement in a Federal office building. FEMP's interest was in knowing whether or not single component replacements like these would have any chance of achieving the fossil- fuel-based energy consumption reduction requirements specified in Section 433 of the Energy Independence and Security Act (EISA) of 2007[1]. Specifically, FEMP was interested in whether an older Federal building, built in the 1980s or 1990s and designed to meet energy standards in place at the time the building was designed, could meet the requirements of Section 433 of EISA for renovations. Many single component renovations like chiller replacements, boiler replacements, and lighting retrofits may meet the minimum cost requirement of Section 433 of EISA but may not offer any opportunity to achieve fossil-fuel-generated energy consumption reductions on the order of 55% or more. If single component renovations such as these would not achieve the necessary reductions, then FEMP would consider modifying rules based on Section 433 of EISA to exempt these types of single component renovations from the overall fossil-fuel-generated energy consumption reduction provisions. FEMP would instead require Federal agencies to ensure that these renovations use FEMP-designated efficiencies for chillers and boilers or the lighting power density requirements found in ASHRAE Standard 90.1-2010.

The results of PNNL's analysis indicated that it is unlikely that a combined boiler and chiller replacement, or an individual boiler or chiller replacement in an older existing Federal building would meet the requirements of Section 433 of EISA. While buildings can achieve up to 34% reduction in cooling and 11% reduction in heating load with this type of retrofit, these savings fall well short of the minimum savings specified in Section 433 of EISA.

Similarly, a lighting retrofit in an older existing Federal building would also not likely meet the requirements of Section 433 of EISA. While buildings can save up to 52% on lighting loads, the whole buildings savings would be well short of the minimum savings specified in Section 433 of EISA.

[1] Section 433 of EISA requires reductions in fossil fuel-generated energy consumption for both new buildings and existing building undergoing major renovations of at least 55% compared to comparable buildings in the 2003 Commercial Building Energy Consumption Survey. See the Background section of this report for a more detailed discussion.

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Background

Section 433 of the Energy Independence and Security Act (EISA) of 2007 (Pub. L. 110-140)[2] modifies Section 305 of Energy Conservation and Production Act (ECPA) by adding a new section 305(a)(3)(D), which requires the Department of Energy (DOE), through regulation, to update the energy-efficiency requirements for new Federal buildings and Federal buildings undergoing major renovations[3] by requiring that two categories of Federal buildings be designed to reduce their fossil-fuel-generated energy consumption. Specifically, Section 433 of EISA requires that

> "(i) For new Federal buildings and Federal buildings undergoing major renovations, with respect to which the Administrator of General Services is required to transmit a prospectus to Congress under section 3307 of title 40, United States Code, in the case of public buildings (as defined in section 3301 of title 40, United States Code), or of at least $2,500,000 in costs adjusted annually for inflation for other buildings: (I) The buildings shall be designed so that the fossil fuel-generated energy consumption of the buildings is reduced, as compared with such energy consumption by a similar building in fiscal year 2003 (as measured by Commercial Buildings Energy Consumption Survey (CBECS) or Residential Energy Consumption Survey (RECS) data from the Energy Information Agency), by the percentage specified in the following table:
>
> | Fiscal Year | Percentage Reduction |
> |---|---|
> | 2010 | 55 |
> | 2015 | 65 |
> | 2020 | 80 |
> | 2025 | 90 |
> | 2030 | 100." |

DOE's Federal Energy Management Program (FEMP) requested that Pacific Northwest National Laboratory (PNNL) investigate the potential savings that could be accrued from a typical chiller, boiler, or lighting replacement in a Federal office building. FEMP's interest was in knowing whether or not single component replacements like these would have any chance of achieving the fossil-fuel-based energy consumption reduction requirements specified in Section 433 of EISA. Specifically, FEMP was interested in whether an older Federal building, built in the 1970s, 1980s or 1990s and designed to meet energy standards in place at the time the building was designed, could meet the requirements of Section 433 of EISA for renovations.

Many single component renovations like chiller replacements, boiler replacements, and lighting retrofits may meet the minimum cost requirement[4] of Section 433 of EISA but may not offer any opportunity to achieve fossil-fuel-generated energy consumption reductions on the order of 55% or more. If single component renovations such as these would not achieve the necessary reductions, then FEMP would consider modifying rules based on Section 433 of EISA to exempt these types of single component

[2] The complete text of EISA may be found at http://www1.eere.energy.gov/femp/regulations/eisa.html.
[3] Major renovations are defined as building renovations that cost at least $2.5 million in accordance with Section 433 of EISA and that offer a significant opportunity to meet the requirements of Section 433 of EISA.
[4] See footnote 3 for discussion of the $2.5 million minimum cost requirement of Section 433 of EISA.

renovations from the overall fossil-fuel-generated energy consumption reduction provisions. FEMP would instead require Federal agencies to ensure that these renovations use FEMP-designated efficiencies for chillers and boilers or the lighting power density requirements found in ASHRAE Standard 90.1-2010.

Methodology

The approach taken in this analysis was to identify levels of chiller and boiler efficiencies and lighting power densities that might be associated with older existing Federal buildings and compare the results of whole building performance simulations for existing buildings to simulations for an identical building that uses newer higher efficiency chillers and boilers and improved lighting. Once simulation results were available, those results could be compared approximately with the fossil-fuel-based energy consumption reduction requirements in Section 433 of EISA. While a reduction in site energy use intensity (EUI) is not identical to a reduction in fossil-fuel EUI, they are of comparable magnitude. Section 433 of EISA requires a minimum reduction of 55% fossil fuel as compared to a typical building in the 2003 CBECS, increasing to 100% fossil-fuel reduction in FY2030. If site EUI reductions for the high efficiency building models were not on the same order of magnitude, then there would be no opportunity for a building renovation to meet the fossil-fuel reduction requirements of Section 433 of EISA.

PNNL used the large office building model used in the development of Advanced Energy Retrofit Guide for Office Buildings[5] (AERG) prepared by PNNL for DOE. (PNNL 2011) This model includes an example of a typical large office building that sufficiently represents a large Federal office building. Equipment efficiency levels specified in ASHRAE Standard 90-75 (ASHRAE 1975) or ASHRAE Standard 90A-1980 (ASHRAE 1980) were used to characterize the oldest existing chillers, boilers, or lighting that would likely be found in existing Federal buildings. These standards were 32 to 37 years old at the time of the analysis, and it was assumed that most, but not necessarily all, Federal buildings would have had chiller, boiler, or lighting retrofits by 2012. Standard 90.1-1989 (ASHRAE 1989) was assumed for slightly newer buildings and especially for the newer buildings that are represented in the 2003 CBECS, which was the basis of the fossil-fuel-generated energy consumption reduction requirements in Section 433 of EISA. The recommendations in the Advanced Energy Retrofit Guide were used, along with newer Standards 90.1-2004 (ASHRAE 2004) and 90.1-2010 (ASHRAE 2010) for lighting, while FEMP's designated equipment efficiency for Federal procurement was used for chillers and boilers.[6] Two sets of simulations were performed:

1) The first set involved changes to the chiller and boiler efficiencies corresponding to the three different levels required in ASHRAE Standard 90-75, ASHRAE Standard 90.1-1989, and in the FEMP-designated equipment list as of March 2012.

[5] Advanced Energy Retrofit Guide for Office Buildings can be free downloaded at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20761.pdf
[6] FEMP's Designated Equipment List may be found at http://www1.eere.energy.gov/femp/technologies/eep_purchasingspecs.html.

2) The second set involved changes to the lighting power densities corresponding to five different levels required in ASHRAE Standard 90-75, ASHRAE Standard 90.1-1989, the Advanced Energy Retrofit Guide, ASHRAE Standard 90.1-2004, and ASHRAE Standard 90.1-2010.

For both of these analyses, five climate locations representing the climate extremes found in the continental United States were used: Miami, Las Vegas, Seattle, Chicago, and Duluth.

Chiller and Boiler Analysis Input Parameters

Table 1 shows the calculated chiller and boiler sizes for the large office model in each climate location. Two chillers and two boilers are used in the building. The reported sizes are for the individual chillers and boilers. Table 2 lists the boiler and chiller efficiencies used in the analysis for Standard 90-75, Standard 90.1-1989, and the FEMP designated equipment list as of March 2012.

Table 1 Chiller and Boiler Sizes in Large Office Building Model

Location	Chiller size (ton)	Boiler size (kBtu/h)
Miami	219	1361
Las Vegas	287	2282
Seattle	175	2218
Chicago	189	2945
Duluth	166	3301

Table 2 Chiller and Boiler Efficiency (Based on Equipment Size in Table 1)

Plant Equipment	ASHRAE Standard 90-75	ASHRAE Standard 90.1-1989	FEMP-Designated
Gas-fired boiler (thermal efficiency)	75%	77.5%[1]	84%
Water-cooled, centrifugal chiller (COP)	3.78	4.20[2]	5.96[2]

Note [1]: ASHRAE 90.1-1989 specifies combustion efficiency at 80%. Boiler jacket loss of 2.5% was assumed to convert this combustion efficiency to thermal efficiency.
Note [2]: Part load performance of the chiller (as represented by the integrated part-load value (IPLV)) is not considered in this study because of the lack of suitable performance curves.

Results of Chiller and Boiler Analysis

Table 3 shows the resulting cooling energy consumption for each performance level in each location. Table 4 shows the resulting cooling energy percentage increases for equipment with less efficient chiller than a current FEMP-designated chiller for each performance level in each location. Buildings with chillers that meet the requirements of Standard 90-75 will use up to 34% more cooling energy than a building with a FEMP-designated chiller.

Table 3 Cooling Energy Consumption for Each Performance Level and Location

		Cooling Energy Consumption (kBtu/ft^2)				
Source of Equipment Efficiency	**Chiller Efficiency (COP)**	**Miami**	**Las Vegas**	**Chicago**	**Seattle**	**Duluth**
90-75	3.78	25.58	20.72	11.61	9.85	7.96
90.1-1989	4.20	23.22	18.89	10.69	9.09	7.40
FEMP-Designated	5.96	16.99	14.04	8.24	7.08	5.92

Table 4 Cooling Energy Consumption Percentage Increase for Each Performance Level and Location

		Cooling Energy Percentage Increase				
Source of Equipment Efficiency	**Chiller Efficiency (COP)**	**Miami**	**Las Vegas**	**Chicago**	**Seattle**	**Duluth**
90-75	3.78	34%	32%	29%	28%	26%
90.1-1989	4.20	27%	26%	23%	22%	20%
FEMP-Designated	5.96	0%	0%	0%	0%	0%

Table 5 shows the resulting heating energy consumption for each performance level in each location. Table 6 shows the resulting heating energy percentage increases for equipment with lower efficiency level than a current FEMP-designated boiler for each performance level in each location. Buildings with boilers that meet the requirements of Standard 90-75 will use up to 11% more heating energy than a building with a FEMP-designated boiler.

Table 5 Heating Energy Consumption in kBtu/ft^2 for Each Performance Level and Location

		Heating Energy Consumption (kBtu/ft^2)				
Source of Equipment Efficiency	**Boiler Efficiency (thermal efficiency)**	**Miami**	**Las Vegas**	**Chicago**	**Seattle**	**Duluth**
90-75	75.0%	15.24	23.57	26.61	34.44	33.45
90.1-1989	77.5%	14.75	22.81	25.75	33.33	32.37
FEMP-Designated	84.0%	13.61	21.05	23.76	30.75	29.86

Table 6 Heating Energy Consumption Percentage Increase for Each Performance Level and Location

		Heating Energy Percent Increase				
Source of Equipment Efficiency	**Boiler Efficiency (thermal efficiency)**	**Miami**	**Las Vegas**	**Chicago**	**Seattle**	**Duluth**
90-75	75.0%	11%	11%	11%	11%	11%
90.1-1989	77.5%	8%	8%	8%	8%	8%
FEMP-Designated	84.0%	0%	0%	0%	0%	0%

Lighting Analysis Input Parameters

Table 7 lists the lighting power densities (LPD) assumed for Standard 90-75, Standard 90.1-1989, the AERG, Standard 90.1-2004, and Standard 90.1-2010. Table 7 also shows the total estimated lighting energy use for the building in kBtu/ft^2.

Table 7 Lighting Power Density and Lighting Energy Use

Lighting Level Description	LPD (w/ft^2)	Lighting Energy Use (kBtu/ft^2)
90-75	1.9	21
90.1-1989	1.8	20
AERG	1.33	15
90.1-2004	1.0	11
90.1-2010	0.9	10

Only lighting power densities were changed for this analysis. No attempt was made to include the impact of lighting controls. Newer versions of ASHRAE Standard 90.1 include more advanced control requirements than older versions.

Results of Lighting Analysis

Table 8 shows reduction in lighting energy and the percentage reduction in lighting energy relative to ASHRAE Standard 90-75. Lighting energy and percentage reduction in lighting energy are constant across all cities. Buildings with lighting power densities from ASHRAE Standard 90.1-2010 will have a lighting energy usage 52% less than buildings with lighting power densities from ASHRAE Standard 90-75.

Table 8 Lighting Energy and Percentage Reduction in Lighting Energy Relative to Standard 90-75

Lighting Level Description	Lighting Level (w/ft^2)	Lighting Percent Savings over 90-75
90-75	1.9	0%
90.1-1989	1.8	5%
AERG	1.33	29%
90.1-2004	1.0	48%
90.1-2010	0.9	52%

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