DRAFT REPORT

ENERGY AND COST IMPACTS OF PROPOSED NEW COMMERCIAL BUILDING ENERGY CODES FOR THE COMMONWEALTH OF MASSACHUSETTS

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ABSTRACT

The energy and cost impacts of several proposed new commercial building energy codes for the Commonwealth of Massachusetts were examined using DOE-2 simulations. Six building types were examined in three climates typical of Massachusetts. Simulation results were post-processed using New England regional building stock estimates to generalize the results to Massachusetts buildings. The base case buildings for Massachusetts were modeled using the requirements of ASHRAE/IESNA Standard 90.1-1989. Proposed new commercial building energy codes examined included adoption of the lighting requirements from the public review draft of ASHRAE/IESNA Standard 90.1-1989R, adoption of the mechanical equipment efficiencies from the public review draft of ASHRAE/IESNA Standard 90.1-1989R, and adoption of both the lighting and mechanical equipment requirements from ASHRAE/IESNA Standard 90.1-1989R. No changes to building envelope requirements were considered.

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SUMMARY

BACKGROUND

On August 8, 1995, the Commonwealth of Massachusetts requested the assistance of Pacific Northwest National Laboratory (PNNL) in determining the cost-effectiveness of adopting a new commercial building energy code. Review by U.S. Department of Energy (US DOE) staff indicated that the request was appropriate and PNNL began work in mid-September , 1995. The primary contact in Massachusetts was Tom Riley, the code development manager for the State Board of Building Regulations and Standards. Other technical contacts in Massachusetts included Doug Baston (of Northeast by Northwest) and Sue Coakley (of Susan E. Coakley and Associates) representing the Boston Edison DSM Settlement Board. The primary contact at PNNL was Mark Halverson.

Conversations between Tom Riley and Mark Halverson continued through much of 1996, culminating in a number of decisions about proposed new commercial building energy codes for Massachusetts and PNNL's analysis of these proposed codes. The final decision was that PNNL would examine the energy and cost impacts of several proposed new commercial building energy codes for the Commonwealth of Massachusetts were examined using DOE-2 simulations. Six building types would be analyzed in three climates typical of Massachusetts. Simulation results would be post-processed using New England regional building stock estimates to generalize the results to Massachusetts buildings. The base case buildings for Massachusetts would be modeled using the requirements of ASHRAE/IESNA Standard 90.1-1989. Proposed new commercial building energy codes to be examined would include adoption of the lighting requirements from the public review draft of ASHRAE/IESNA Standard 90.1-1989R, adoption of the mechanical equipment efficiencies from the public review draft of ASHRAE/IESNA Standard 90.1-1989R, and adoption of both the lighting and mechanical equipment requirements from ASHRAE/IESNA Standard 90.1-1989R. No changes to building envelope requirements were to be considered. The selection of building types, locations, base case, and new proposed codes is discussed below.

Selection of Building Types - Simulation building types were chosen to provide examples of both the most common buildings being built in Massachusetts and also to capture some of the variation present in current construction. ASHRAE/IESNA Standard 90.1-1989 provides typical simulation parameters for 10 building types: Office, Retail, Warehouse, Assembly, School, Hotel/Motel, Restaurant, Health Facility, Multi-Family Apartment, and Light Industrial. From this list the Office, Retail, School, Health Facility, Multi-Family Apartment, and Light Industrial building types were chosen. The Office and School building types were modeled as typical offices and schools. The Retail building type was modeled as dry goods or department store rather than as a grocery store. The Health building type was modeled as a hospital with 24 hour occupancy rather than as a clinic. The Multi-Family Apartment building type was modeled as a high-rise (greater than 3 stories) building in accordance with ASHRAE/IESNA Standard 90.1-1989. The Light Industrial building type was modeled as an light manufacturing and assembly facility. The final choice of these six building types was made in consultation with Tom Riley.

Selection of Locations - Simulation locations were chosen to provide coverage for the different climatic zones in Massachusetts. Since a simulation approach has been chosen, the locations must have long-term typical weather files available for simulation use. While the only such data file for Massachusetts available is the Boston TMY weather data, the TMY weather data for Providence RI, Hartford CT, Albany NY, Portland ME, Concord NH, and Burlington VT offered a range of conditions that cover the climatic range found in Massachusetts. Table 1 compares the weather data listed in the Massachusetts State Building Code, Article 31, with available Typical Meteorological Year (TMY) data. From this table, it appeared that Boston, Massachusetts; Albany, New York; and Concord, New Hampshire covered the range of climates typically found in Massachusetts. The final choice of these three locations was made in consultation with Tom Riley.

Table 1. Comparison of Massachusetts and Available TMY Weather Data (Data Sorted by HDD65)

City	HDD50	HDD65	CDD50	Source
Burlington VT	4211	7932	2118	TMY
Pittsfield MA	NA	7578	~2800	CMR
Concord NH	3742	7425	2254	TMY
Portland ME	3531	7305	1946	TMY
Worcester MA	3364	6989	~2203	CMR
Albany NY	3488	6770	2812	TMY
Clinton MA	3107	6517	~2457	CMR
Hartford CT	2953	6277	2857	TMY
Lawrence MA	2867	6195	~2648	CMR
Taunton MA	2800	6184	~2461	CMR
Framingham MA	2855	6144	~2695	CMR
Lowell MA	NA	6056	~2715	CMR
Providence RI	2610	6022	2756	TMY
Springfield MA	2706	5844	~3037	CMR
Boston MA	2416	5775	2810	TMY
Fall River MA	NA	5774	~2800	CMR
New Bedford MA	2107	5395	~2973	CMR
Boston MA	2383	5364	~2897	CMR
Lakehurst NJ	2174	5265	3299	TMY
New York NY	1986	5022	3273	TMY

Bold - Massachusetts Cities
CMR - 780 CMR, Article 31, Massachusetts State Building Code
TMY - Typical Meteorological Year climate data (available for use with simulation tool)
NA - Not Available

Selection of Base Case New Commercial Building Code - An extensive survey of current practice in Massachusetts by Doug Baston of Northeast by Northwest and by Xenergy indicated that current practice in Massachusetts commercial building construction met or exceeded ASHRAE/IESNA Standard 90.1-1989 requirements. This was not surprising since Massachusetts has used the second public review version of Standard 90.1 as their commercial building energy code since 1989. Given the difficulty of developing baseline models that differ from Standard 90.1, and the fact that the analysis would not be sensitive to minor differences from Standard 90.1, a base case of Standard 90.1 was assumed for all locations and building types.

Selection of Proposed New Commercial Building Codes - Extensive discussions were carried out between Tom Riley, Mark Halverson, and Jeff Johnson of PNNL on the subject of proposed new commercial building energy codes. Candidate codes included the existing ASHRAE/IESNA Standard 90.1-1989, the public review draft of BSR/ASHRAE/IESNA Standard 90.1-1989R, the new Federal commercial building energy code (10CFR435) just released for public comment, and a new code under development by a group of interested states (the Multi-State Commercial Code). Representatives from Massachusetts are participating in the development of the Multi-State Commercial Code, which is based on the codified version of Standard 90.1 and the new lighting requirements in BSR/ASHRAE/IESNA Standard 90.1-1989R.

The final selection of proposed new commercial building codes for Massachusetts were various combination of the lighting and mechanical requirements from BSR/ASHRAE/IESNA Standard 90.1-1989R. Considering the lighting and envelope separately and in conjunction with each other provided three possible options for new codes. Note that the level of controversy surround the envelope requirements in BSR/ASHRAE/IESNA Standard 90.1-1989R precluded the use of these requirements.

The final comparison of codes is shown in Table 2.

Table 2. Building Energy Code Comparison

	Lighting	Mechanical	Envelope
Baseline	Standard 90.1	Standard 90.1	Standard 90.1
Case 1	Standard 90.1R	Standard 90.1	Standard 90.1
Case 2	Standard 90.1	Standard 90.1R	Standard 90.1
Case 1	Standard 90.1R	Standard 90.1R	Standard 90.1

ENERGY ANALYSIS

Simulation Process

Building energy simulations were conducted with the DOE-2.1e hourly energy simulation tool (LBL 1993) using the Typical Meteorological Year (TMY) weather data set for each of the selected locations. The building prototype used is a three-story building with five thermal zones on each floor (4 perimeter and 1 core). The annual energy use calculated for each zone is weighted and scaled for different size buildings as described in Friedrich and Messinger (1995). Each building type was modeled with wall and roof constructions and window-to-wall ratios that are typical for that type of building in the New England census region. The construction information was obtained from the Commercial Building Energy Consumption Survey (CBECS) (EIA 1994). Insulation levels, window construction (tinting and number of panes), and use of economizers were obtained by assuming the buildings complied with ASHRAE/IES Standard 90.1-1989 (Standard 90.1-1989)(ASHRAE 1989). Lighting levels and mechanical equipment efficiencies were taken from the appropriate base or proposed new building energy code.

Ventilation requirements for the six building types were based on a number of "real" buildings examined in a study of ventilation impacts on energy usage (Halverson et al, 1995). Ventilation requirements were calculated as a function of ASHRAE Standard 62-89 requirements and ASHRAE/IESNA Standard 90.1-1989 occupancies for a number of real buildings. Final modeling inputs for this report were:

Building Type	Ventilation - cfm per ft2
Office	0.38
Retail	0.25
School	0.61
Hospital	0.38 (modeled similar to office)
Apartment	0.33
Light Industrial	0.38 (modeled similar to office)

Mechanical equipment efficiencies used in this analysis were developed as weighted averages of the equipment efficiencies in Standards 90.1 and 90.1R. The weighting data used for cooling equipment was proprietary American Refrigeration Institute (ARI) shipping data. This weighting is discussed in more detail in Appendix A. For all building types, two types of mechanical systems were examined - a central system using boilers and chillers, and a distributed system using package air conditioning, furnaces, and rooftop units. The common systems used in each building type were identified from CBECS data (EIA 1994) and RECS data (EIA 1995). Tables 3 through 8 identifies these common systems, in addition to providing additional building simulation parameters, including envelope characteristics for each of the three locations and six building types.

Table 3. Office Building Simulation Parameters

Building Type	Office	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Masonry	DOE/EIA CBECS 1992
Roof Construction	Built-Up	DOE/EIA CBECS 1992
Window to Wall Ratio	0.32	DOE/EIA CBECS 1992
Occupant Density	275	ASHRAE/IESNA 90.1-1989
Equipment Density	0.75	ASHRAE/IESNA 90.1-1989
Occupant Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Lighting Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Plug Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	Boiler	Furnace
Cooling Equipment Type	Package AC	Chiller
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, medium ILD and HC=10, and WWR=32%	
Boston	0.106	ASHRAE/IESNA 90.1-1989
Albany	0.091	ASHRAE/IESNA 90.1-1989
Concord	0.084	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.68	ASHRAE/IESNA 90.1-1989
Albany	0.45	ASHRAE/IESNA 90.1-1989
Concord	0.45	ASHRAE/IESNA 90.1-1989
Glazing Shading Coefficient		
Boston	0.38	ASHRAE/IESNA 90.1-1989
Albany	0.5	ASHRAE/IESNA 90.1-1989
Concord	0.5	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	1.72	ASHRAE/IESNA 90.1-1989
	1.26	BSR/ASHRAE/IESNA 90.1-1989R
Heating Efficiency	boiler constant at 75% thermal efficiency furnace constant at 80% combustion efficiency	
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R) chiller COP from 4.5 (90.1) to 5.35 (90.1R)	

Table 4. Retail Building Simulation Parameters

Building Type	Retail	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Masonry	DOE/EIA CBECS 1992
Roof Construction	Built-Up	DOE/EIA CBECS 1992
Window to Wall Ratio	0.23	DOE/EIA CBECS 1992

Occupant Density	300	ASHRAE/IESNA 90.1-1989
Equipment Density	0.25	ASHRAE/IESNA 90.1-1989
Occupant Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Lighting Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Plug Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	Boiler	Furnace
Cooling Equipment Type	Package AC	
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, medium ILD, and HC=10, and WWR=23%	
Boston	0.107	ASHRAE/IESNA 90.1-1989
Albany	0.091	ASHRAE/IESNA 90.1-1989
Concord	0.085	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.68	ASHRAE/IESNA 90.1-1989
Albany	0.68	ASHRAE/IESNA 90.1-1989
Concord	0.68	ASHRAE/IESNA 90.1-1989
Glazing Shading Coefficient		
Boston	0.71	ASHRAE/IESNA 90.1-1989
Albany	0.6	ASHRAE/IESNA 90.1-1989
Concord	0.6	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	2.83	ASHRAE/IESNA 90.1-1989
	2.25	BSR/ASHRAE/IESNA 90.1-1989R
Heating Efficiency	boiler constant at 75% thermal efficiency	
	furnace constant at 80% combustion efficiency	
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R)	

Table 5. School Building Simulation Parameters

Building Type	School	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Masonry	DOE/EIA CBECS 1992
Roof Construction	Built-Up	DOE/EIA CBECS 1992
Window to Wall Ratio	0.25	DOE/EIA CBECS 1992
Occupant Density	75	ASHRAE/IESNA 90.1-1989
Equipment Density	0.5	ASHRAE/IESNA 90.1-1989
Occupant Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Lighting Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Plug Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	Boiler	
Cooling Equipment Type	Package AC	
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, medium ILD, and HC=10, and WWR=25%	

Boston	0.106	ASHRAE/IESNA 90.1-1989
Albany	0.091	ASHRAE/IESNA 90.1-1989
Concord	0.084	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.68	ASHRAE/IESNA 90.1-1989
Albany	0.68	ASHRAE/IESNA 90.1-1989
Concord	0.68	ASHRAE/IESNA 90.1-1989
Glazing Shading Coefficient		
Boston	0.6	ASHRAE/IESNA 90.1-1989
Albany	0.5	ASHRAE/IESNA 90.1-1989
Concord	0.38	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	1.8	ASHRAE/IESNA 90.1-1989
	1.29	BSR/ASHRAE/IESNA 90.1-1989R
Heating Efficiency	boiler constant at 75% thermal efficiency	
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R)	

Table 6. Health (Hospital) Building Simulation Parameters

Building Type	Health	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Masonry	DOE/EIA CBECS 1992
Roof Construction	Built-Up	DOE/EIA CBECS 1992
Window to Wall Ratio	0.31	DOE/EIA CBECS 1992
Occupant Density	200	ASHRAE/IESNA 90.1-1989
Equipment Density	1	ASHRAE/IESNA 90.1-1989
Occupant Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Lighting Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
Plug Schedule	Table 13-3	ASHRAE/IESNA 90.1-1989
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	Boiler	
Cooling Equipment Type	Package AC	Chiller
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, high ILD, and HC=10, and WWR=31%	
Boston	0.107	ASHRAE/IESNA 90.1-1989
Albany	0.091	ASHRAE/IESNA 90.1-1989
Concord	0.085	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.45	ASHRAE/IESNA 90.1-1989
Albany	0.45	ASHRAE/IESNA 90.1-1989
Concord	0.45	ASHRAE/IESNA 90.1-1989

Glazing Shading Coefficient		
Boston	0.5	ASHRAE/IESNA 90.1-1989
Albany	0.38	ASHRAE/IESNA 90.1-1989
Concord	0.5	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	2.08	ASHRAE/IESNA 90.1-1989
	1.44	BSR/ASHRAE/IESNA 90.1-1989R
Heating Efficiency	boiler constant at 75% thermal efficiency	
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R)	
	chiller COP from 4.5 (90.1) to 5.35 (90.1R)	

Table 7. Multi-Family (High-Rise) Building Simulation Parameters

Building Type	Apartment	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Masonry	Tom Riley
Roof Construction	Built-Up	Tom Riley
Window to Wall Ratio	0.2	Tom Riley
Occupant Density	500	ASHRAE/IESNA 90.1-1989
Equipment Density	1.1	ASHRAE/IESNA 90.1-1989
Occupant Schedule	Chapter 13	ASHRAE/IESNA 90.1-1989
Lighting Schedule	Chapter 13	ASHRAE/IESNA 90.1-1989
Plug Schedule	Chapter 13	ASHRAE/IESNA 90.1-1989
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	boiler	
Cooling Equipment Type	package	
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, high ILD,	
	and HC=10, and WWR=20%	
Boston	0.107	ASHRAE/IESNA 90.1-1989
Albany	0.091	ASHRAE/IESNA 90.1-1989
Concord	0.085	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.68	ASHRAE/IESNA 90.1-1989
Albany	0.68	ASHRAE/IESNA 90.1-1989
Concord	0.68	ASHRAE/IESNA 90.1-1989
Glazing Shading Coefficient		
Boston	0.71	ASHRAE/IESNA 90.1-1989
Albany	0.6	ASHRAE/IESNA 90.1-1989
Concord	0.71	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	1.7	ASHRAE/IESNA 90.1-1989 (estimated)
	1.15	BSR/ASHRAE/IESNA 90.1-1989R

Heating Efficiency	boiler constant at 75% thermal efficiency
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R)

Table 8. Light Industrial Building Simulation Parameters

Building Type	Industrial	
Simulation Element	Assumption	Reference
BUILDING TYPE SPECIFIC SIMULATION PARAMETERS		
Wall Construction	Metal	Tom Riley
Roof Construction	Metal	Tom Riley
Window to Wall Ratio	0.1	Tom Riley
Occupant Density	750	BSR/ASHRAE/IESNA 90.1-1989R
Equipment Density	0.2	BSR/ASHRAE/IESNA 90.1-1989R
Occupant Schedule	Retail	BSR/ASHRAE/IESNA 90.1-1989R
Lighting Schedule	Retail	BSR/ASHRAE/IESNA 90.1-1989R
Plug Schedule	Retail	BSR/ASHRAE/IESNA 90.1-1989R
SPECIFIED EQUIPMENT TYPES		
Heating Equipment Type	Package	
Cooling Equipment Type	Package	
CLIMATE DEPENDENT ENVELOPE AND HVAC REQUIREMENTS		
Wall U-value	assume interior/integral insulation, medium ILD, and HC=1 and WWR=10%	
Boston	0.089	ASHRAE/IESNA 90.1-1989
Albany	0.08	ASHRAE/IESNA 90.1-1989
Concord	0.075	ASHRAE/IESNA 90.1-1989
Roof U-value		
Boston	0.06	ASHRAE/IESNA 90.1-1989
Albany	0.053	ASHRAE/IESNA 90.1-1989
Concord	0.053	ASHRAE/IESNA 90.1-1989
Glazing U-value		
Boston	0.68	ASHRAE/IESNA 90.1-1989
Albany	0.68	ASHRAE/IESNA 90.1-1989
Concord	0.68	ASHRAE/IESNA 90.1-1989
Glazing Shading Coefficient		
Boston	1	ASHRAE/IESNA 90.1-1989
Albany	1	ASHRAE/IESNA 90.1-1989
Concord	1	ASHRAE/IESNA 90.1-1989
Temperature Economizer		
Boston	Yes	ASHRAE/IESNA 90.1-1989
Albany	Yes	ASHRAE/IESNA 90.1-1989
Concord	Yes	ASHRAE/IESNA 90.1-1989
REFERENCE STANDARD DEPENDENT VARIABLES		
Lighting Power Density	2	ASHRAE/IESNA 90.1-1989
	0.95	BSR/ASHRAE/IESNA 90.1-1989R
Heating Efficiency	furnace constant at 80% combustion efficiency	
Cooling Efficiency	packaged ac EER from 8.7 (90.1) to 10.1 (90.1R)	

ECONOMIC ANALYSIS

Overall Economic Analysis

This report section describes the methods of measuring worth between alternatives, data sources,

and references used in this impact analysis. The purpose of the economic analysis is to determine if implementing improvements to building energy code are cost effective. Several factors influence the cost and savings from an improvement to an energy code. As previously mentioned, the factors considered in this study include building type, mechanical equipment type, climate zone, and delineation of the improved energy code.
This 30-year life-cycle economic analysis only considered the impact to mechanical and lighting types of equipment. For these equipment types, the initial cost, operations, maintenance, energy, and replacement costs were considered. No dismantlement or salvage was computed at the end of the 30-year analysis. All costs given are in 1996 dollars.

The economic analysis methodology was to generate 30-year cash flows (both discounted and undiscounted) for each building type, mechanical type, climate zone, and energy code. The base energy code cash flows were subtracted from the improved energy code cash flows, and delta present worth between the alternatives, internal rate of return, and simple payback were computed from these cash flow differences. The resulting comparisons were generated for each building and mechanical type.

There are several ways to measure the worth of differing alternatives. Three different methods were chosen for this analysis: present worth, internal rate of return, and simple payback. Each of these are discussed below.

Present Worth - The present worth method converts all discounted cash flows to a single sum equivalent at the beginning of the analysis. The alternative comparison with the largest present worth is chosen as the most cost effective comparison. For this analysis, the cash flows were converted to ?constant worth dollar amounts? using a discount rate. These constant worth amounts were summed to get the present worth according to Equation 1.

Equation 1.

$$PW(i_r) = \sum_{t=0}^{n} C_r (1 + i_r)^{-t}$$

Internal Rate of Return - The internal rate of return method determines the interest rate that yields a present worth of zero from a series of undiscounted cash flows. This implicitly assumes all of the recovered funds are reinvested at the internal rate of return. This measure is used to give an approximate rate of return between the base and analyzed alternative. Equation 2 defines the internal rate of return method.

Equation 2.

Simple Payback - Simple payback determines how long at zero interest it takes to recover the initial ?extra? investment required by the improved code to the standard code. The shorter the payback, the better the alternative comparison. Equation 3 displays the formula used to compute simple payback.

Equation 3.

Data Sources and Assumptions - The following data were required to analyze the alternatives. A description and source of information is given for each.

Discount Factor - The real discount factor used for the analysis was 3%. This value was obtained from OMB Circular No. A-94, Appendix C, February 6, 1996 revision. This document can be found on the internet at the following address: [http://www.whitehouse.gov/WH/EOP/OMB/html/circulars/a094.html].

Cost of Natural Gas - The cost of commercial natural gas for Massachusetts as of January 1996 was found in Energy User News, June 1996, page 45. The value used in the analysis is $7.36/Mcf. The projected commercial natural gas costs were obtained by multiplying the 1996 cost by the index for the desired future year. See Projected Fuel Price Indices below for further details.

Cost of Electricity - A value of $0.0991 per kilowatthour was used for the commercial buildings in Massachusetts for 1996. This value was obtained by extrapolating the 1993 and 1994 commercial Massachusetts data from EIA Electric Power Annual 1994, Volume II, Table 7. The 1996 value is multiplied by the yearly projected electric price indices to obtain projected commercial electrical rates throughout the 30-year analysis period. See Projected Fuel Price Indices below for further details.

Projected Fuel Price Indices - The projected fuel price indices for years 1996-2025 were obtained from NISTIR 85-3273-10: Energy Price Indices and Discount Factors for Life-Cycle Cost

Analysis 1996, (Rev. 10/95) , Table Ca-1. Both commercial electricity and natural gas indices were obtained from this reference.

City Cost Index - Massachusetts was divided into 3 climate zones. Energy usage was calculated by climate zone for each building, mechanical type, and energy code. The costs vary by zone as well. Unfortunately, not all of the climate zones that could be modeled were in the state of Massachusetts. Therefore, cities specified by climate zone were mapped to corresponding cities in Massachusetts for costing purposes only. The following table gives this mapping.

City Mapping Table

Climate Zone	Reference Cost City
Albany	Worcester
Boston	Boston
Concord	Pittsfield

The cost indices (both labor and material) for the reference cities was obtained from MEANS Building Construction Cost Data, 1996, City Cost Indexes table (pages 581-582). Each labor and material cost for a particular climate zone is multiplied by the corresponding MEANS index to approximate the climate zone*s cost.

Lighting Economic Analysis

It is considered most likely that a lighting design change based on a stricter energy code will involve primarily technology changes only. The other potential methods of complying with a new code include simple lighting level reduction and/or total redesign of the space using advanced lighting techniques. Lighting level reduction is expected to occur along with standard technology changes. Total redesign of the space, however, is considered to be uncommon in practice.

It is understood that basic lighting designs are typically made to meet code requirements and offer as flexible (or high) a lighting level as possible. To meet stricter codes (90.1R), it is considered probable that design changes for the stricter code will involve reductions in numbers of lamps along with improvements in technology choices. This combination of technology improvement and lamp reduction to achieve lighting levels closer to recommended values is chosen as the model for this assessment.

A typical lighting design is needed for typical building types to determine the actual cost impact based on actual fixture quantities. A typical design is hard to achieve because, although many designs may be commonly used in standard spaces, the design of lighting in a space may take many forms. For this analysis, the application models for various building types developed by the ASHRAE/IES lighting committee for the development of 90.1R will be used. These models are based on actual designer and experience input and are considered the most accurate and detailed of their kind available.

The first step in the analysis is to identify the most commonly used fixtures in each building type that provide the greatest contribution of lighting power density. These common fixtures then need to considered with respect to what kind of technology change would be commonly applied to meet the stricter code. These technology differences for common fixtures can then be applied to the 90.1 and 90.1R codes. Any differences in values remaining can then be attributed to reduction in lamp quantities. The difference in lamp quantities and the difference in technologies is then equated to a cost and energy difference between the two codes.

The 90.1R application models for each building type are made up of other individual space type models. Each space type model includes multiple fixture types. For each building type the models were expanded to provide all details for the fixtures used in the building and in what proportions. Next, sorting was done for each building type to determine common fixtures based on percentage of use in that building. In most cases, the common fixture (as expected) were standard fluorescent fixtures. In apartments more compact fluorescent were used and in industrial more MH was used. The proportion of incandescent in all building types was very small.

In terms of technology application, little is considered commonly done with compact fluorescent and MH. They are already generally efficient and in this age are commonly applied in place of their predecessors (incandescent and MV) as standard practice regardless of code. Based on this situation, standard fluorescent were considered to be the most common fixture type that was available for technology changes. These are also usually used in spaces that are generally "overlit" and potentially available for lamp reduction.

To determine appropriate lighting equipment levels for the 90.1 case (90.1R being known from the models), a series of recalculations of the application models using older standard fluorescent technologies (T12 instead of T8, EEF instead of ELC ballasts) and adjusting the lamp quantity. This process mimics the changes in technologies and reduction of lighting levels that are considered to be the most common method of complying with a stricter energy code for lighting. Changes in lamp quantities going from 90.1R (T8) to 90.1 (T12) were restricted to a range of 0 to 2 times the count. This range corresponds to the range of overlit conditions typically found in modern buildings.

Each of the six building type models was successfully changed within appropriate technology and lamp quantity changes to match the existing 90.1 code value.

Bldg Type	Changes from 90.1R conditions to 90.1
Health	T8 becomes T12 with 25% more fixtures
Apartment	T8 becomes T12 with 75% more fixtures
Office	T8 becomes T12 with 25% more fixtures

Retail	T8 becomes T12 with 25% more fixtures
School	T8 becomes T12 with 50% more fixtures
Industrial	T8 becomes T12 with 100% more fixtures

This use of the standard fluorescent fixture as the only measure of cost change at first glance appears insufficient. However, the variables involved in this analysis do not lend it to a more rigorous accounting of specific fixture changes. The possibilities of change types are much too numerous. What the standard fluorescent does represent is by far the most commonly modified fixture in any building and represents the majority of lighting and costs. Because of this, it is considered a reasonable metric of changing costs.

To create actual 90.1 and 90.1R case total costs for whole building lighting, an estimate of the lights that would not change was made. Again because of the wide variability of lighting design, a typical representative fixture was used for all remaining unchanged wattage per sqft (converted to number of fixtures). For this analysis the same 1 or 2 lamp T12 fluorescent fixture was used. While all lighting costs are not equal per light output, it is the difference in cost that is important and therefore, this use of a typical fixture was considered reasonable and equitable between building type and code cases.

Hours of lighting use are calculated from the ASHRAE lighting use profiles. Values for apartment and industrial (not represented in ASHRAE profiles) are taken as the same as office type. Component cost data (fixture, ballast, lamp, labor) are all taken from the LTSM program (Purcell 1995) at US average values ("com95.dbf"). Component lifetimes for calculating projected maintenance costs were also taken from this data.

Mechanical Equipment Economic Analysis

The HVAC equipment cost estimates include three components; equipment costs to the consumer, installation costs, and annual O&M costs. In addition, O&M costs are divided into materials and labor costs. The data sources and methods used to estimate these costs are described below.

Baseline Equipment Costs - Equipment cost estimates were derived from a variety of sources. The majority of the cooling equipment cost estimates were derived from data used by the ASHRAE Standing Standards Project Committee (SSPC) in the development of a revised standard 90.1. Cost estimates in this analysis were developed from the average of 4 contractor cost estimates for equipment meeting the current standard. The contractor cost estimates were then inflated by 25% to account for contractor markup.

The ASHRAE cost estimates were checked against independently collected cost data developed by PNNL (Barwig 1996), cost estimates developed for the FEDS model, or against equipment cost estimates in Means (Means 1996a, 1996b).

In one case the PNNL cost estimate was used (7.5 ton unitary air conditioner). PNNL cost estimates were also used for boilers. As with the ASHRAE estimates, PNNL estimates were made using the average of several contractor cost estimates inflated by 25% to account for contractor markup. Cost estimates for air cooled chillers were developed from Means data and FEDS estimates. Cost estimates for water cooled positive displacement chillers, furnaces, and large water source heat pumps were also developed from Means data (Means 1996b).

In some cases the equipment sizes for which cost data was needed did not match the available data. Since equipment costs per unit output are often a function of size it is not usually sufficient to apply the cost per unit output to different sizes of equipment. In these instances the cost per unit output was modeled as a function of output to interpolate costs between data points. This method was used for water cooled centrifugal chillers and large unitary air conditioners. Finally equipment costs are converted to costs per unit output capacity by dividing by the nominal capacity.

High Efficiency Equipment Costs - Equipment cost estimates for equipment meeting ASHRAE 90.1R were developed from the baseline cost estimates multiplied by a relative cost factor developed from efficiency cost curves supplied by ARI and GAMA to ASHRAE SSPC 90.1. The cost curves were developed from data provided by ARI and GAMA member companies in the form of relative costs as a function of efficiency, starting from a base efficiency at the current standard level. In some cases the equipment categories did not exactly match the equipment categories used in this analysis. In these cases the incremental cost estimates for the most similar size or type of equipment were used. In addition, a few of the cost curves did not start at the current baseline efficiency level. In these instances the relative costs were estimated from the cost increment for the same magnitude improvement in EER from the shifted baseline efficiency.

Installation Costs - Installation costs were developed from estimates of installation labor requirements in Means (Means 1996a, 1996b). National average labor rates were used to develop baseline installation cost estimates, then these estimates were modified to take into account regional wage rates and material costs (Means 1996b). Finally installation costs are converted to costs per unit output capacity by dividing by the nominal capacity.
O&M Costs - O&M cost estimates were also developed from Means data (Means 1996c). O&M costs in Means are estimated as both material and labor costs. These costs are then modified to take into account regional wage rates and material costs (Means 1996b). Finally O&M costs are converted to costs per unit output capacity by dividing by the nominal capacity. O&M cost estimates in Means are recommended practices, and may not accurately reflect actual practices. Because there are no expected differences in O&M costs at the two efficiency levels, however, this does not impact the outcome of the life-cycle cost estimates.

Building Level Cost Estimates - Equipment, installation, and O&M costs per unit output capacity are converted to costs per unit floorspace using the capacity intensity estimates provided by Dave Winiarski. Capacity intensity is expressed as equivalent full load operating hours. This can be converted to capacity per unit floorspace by dividing energy use intensity (EUI) by capacity intensity in hours. Cost per unit floorspace is then estimated by multiplying capacity per unit floorspace by cost per unit capacity. Finally the building level costs are estimated by multiplying floorspace by cost per unit floorspace. Building level cost estimates are carried out for each of six building types, three climate zones, and four different standards scenarios for both single zone and central systems.

RESULTS

Results of this analysis are presented for both energy savings and economic impact. Energy usage in kBtu/ft2 or watts/ft2 were calculated from weighted averages of CBECS data (or anecdotal information from Massachusetts contacts) for each building type. Energy and economic impacts are based on these weighted consumption numbers applied to the most typical construction and size for each building type. The most typical sizes for each building type are shown below:

Office	2 stories	46,547 ft2
Retail	2 stories	79,648 ft2
School	3 stories	101,667 ft2
Health	7 stories	463,333 ft2
Apartment	6 stories	56,400 ft2
Industry	1 story	20,000 ft2

Energy

From an energy standpoint, the results show that reducing allowable lighting power and improving mechanical equipment efficiencies both lead to lower energy consumption. This is definitely not surprising. The main point of interest is in the magnitude of the energy. savings.

Note that the raw data is below. I haven't prepared summaries of the gas/electricity splits or shown that total energy use decreases. All units in chart below are kWh.