Portland Cement Association

Research & Development Information

PCA R&D Serial No. 2880

Modeling Energy Performance of Concrete Buildings for LEED-NC v2.1 EA Credit 1

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KEYWORDS

Building, commercial, concrete, energy, interior thermal mass, LEED, office

ABSTRACT

The objective of this project is to provide information to architects and engineers on the design of concrete buildings to obtain LEED-NC points under EA Credit 1 to optimize energy performance. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a family of voluntary rating systems for designing, constructing, operating, and certifying green buildings. LEED is administered by the U.S. Green Building Council (USGBC)—a coalition of individuals and groups from across the building industry working to promote buildings that are environmentally responsible, profitable, and healthy places to live and work. This project is based on LEED for new construction and major renovation (LEED-NC). Many states and municipalities require that new buildings built with public funds meet the LEED-NC requirements for certification. Many owners, architects, and designers are also seeking LEED-NC ratings for privately funded buildings. Buildings are being built with steel due to the misconception that it is easier to obtain LEED-NC points with steel than with concrete.

This project provides in-depth information on energy savings in mid-rise buildings due to additional thermal mass and for exceeding building envelope thermal performance requirements. We also show how to model the thermal properties of concrete to obtain LEED-NC v2.1 points. The LEED Energy & Atmosphere (EA) Credit 1 on optimizing energy performance provides up to 10 points for energy savings beyond *ASHRAE/IESNA Standard 90.1-1999*. A total of 26 points is required for a basic level of certification. Obtaining points for the EA Credit 1 requires modeling with energy simulation software, and modeling thermal mass effects requires software that models yearly energy use on an hourly basis.

CTLGroup has modeled a five-story prototype building with plan dimensions of 105x105 ft and a window-to-wall ratio of 0.40. The buildings were modeled using two software programs: VisualDOE and Energy 10. Since the effects of thermal mass vary with climate, the buildings were modeled in six locations representing the range of climates in the United States: Miami, Phoenix, Memphis, Salem, Denver, and Chicago. These locations and the building floor plan correspond with those used by ASHRAE committees and various industries to model the effects of materials and energy use. The buildings were modeled using five scenarios:

- EIFS and curtain walls meeting *ASHRAE 90.1-2001* (a LEED-NC prerequisite) with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2001* (a LEED-NC prerequisite) with either structural steel or reinforced concrete frame,
- Precast concrete walls exceeding *ASHRAE 90.1-2001* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2001*, reinforced concrete frame, and high internal load equipment placed near the central core of the building, and
- Precast concrete walls exceeding *ASHRAE 90.1-2001*, reinforced concrete frame, and high internal load equipment placed near the central core of the building.

In most scenarios, the energy modeling shows that the effect of thermal mass is to lower energy *us,* and the overall effect of thermal mass in concrete framed buildings is to lower energy *cost* relative to the baseline steel framed EIFS buildings.

In all cities except Miami, reinforced concrete frame buildings with precast concrete walls and building envelopes that modestly exceed code will most likely qualify for points in LEED-NC EA Credit 1. In the cold climate category (Denver and Chicago), these buildings will most likely qualify for 2 points, that is, at least 20% energy cost savings. In the cool climate category (Salem), these buildings will most likely qualify for 3 points, that is, at least 25% energy cost savings. In the mild climate category (Memphis), these buildings will most likely qualify for 1 point, that is, at least 15% cost savings.

In Memphis, Salem, Denver, and Chicago, significant energy cost savings are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code: 6% to 11% when receptacle loads are not included. This energy cost savings is due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building.

REFERENCE

Marceau, Medgar L. and VanGeem, Martha G., *Modeling Energy Performance of Concrete Buildings for LEED-NC v2.1 EA Credit 1*, R&D Serial No. 2880, Portland Cement Association, Skokie, Illinois, USA, 2005, 54 pages.

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by Medgar L. Marceau and Martha G. VanGeem[1]

INTRODUCTION

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a family of voluntary rating systems for designing, constructing, operating, and certifying green buildings. LEED is administered by the U.S. Green Building Council (USGBC)—a coalition of individuals and groups from across the building industry working to promote buildings that are environmentally responsible, profitable, and healthy places to live and work. This project is based on version 2.1 of LEED for new construction and major renovation (LEED-NC)[2].

LEED-NC has gained widespread acceptance across the United States. Many states and municipalities require that new public and publicly funded buildings meet the LEED-NC requirements for certification. Many owners and architects are also seeking LEED-NC ratings for privately funded buildings.

The LEED rating systems are point-based systems. Points are awarded for meeting certain requirements, such as energy conservation and using recycled-content materials. Previous work by CTLGroup has shown how concrete can contribute to 20 of the 26 points required for the basic level of LEED-NC certification.

The LEED-NC Energy & Atmosphere (EA) Credit 1 on optimizing energy performance can potentially provide up to 10 points for energy cost savings beyond *ASHRAE Standard 90.1-1999*[3]. Obtaining points for EA Credit 1 requires modeling with energy simulation software. The software must be capable of simulating yearly energy use on an hourly basis. Hourly simulation is especially important in concrete construction because it is the best practical way to simulate the thermal interaction of concrete with changing outdoor conditions and changes in the operation of building systems. The thermal behavior of a material is a function of its density, thermal conductivity, and specific heat. Materials like concrete, masonry, and stone have a beneficial effect on a building's thermal environment because they tend to moderate and delay extreme changes in temperature resulting in lower energy use. This complex behavior is often simply called thermal mass effects.

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[2] *Leadership in Energy and Environmental Design for New Construction and Major Renovations, Version 2.1*, United States Green Building Council, November 2002, Revised March 14, 2003, www.usgbc.org.

[3] *ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-rise Residential Buildings*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA USA, 2001, www.ashrae.org. The draft of LEED-NC version 2.2 references *ASHRAE Standard 90.1-2004*.

Although energy simulation software is readily available, many architects and engineers would like guidance on taking full advantage of the EA points available from the inherent beneficial thermal properties of concrete construction.

OBJECTIVE

The objective of this project is to provide information to architects and engineers that will explain how to obtain LEED-NC points related to optimizing energy performance in mid-rise concrete commercial buildings. This report demonstrates how to model thermal mass in buildings and presents results for several buildings in five climates.

METHODOLOGY

Several buildings were modeled in a range of climates to demonstrate how the thermal properties of concrete in buildings can result in energy cost savings beyond *ASHRAE 90.1-1999*. The modeling conforms to the requirements of Informative Appendix G: Performance Rating Method in *ASHRAE 90.1-2001*[4].

Although LEED-NC EA Credit 1 requires that the Energy Cost Budget Method in Section 11 of *ASHRAE 90.1-1999* be used to quantify energy performance, this method was never intended by ASHRAE to perform such a comparison. Therefore, ASHRAE has developed the building performance rating method in Informative Appendix G. This method, which is approved by USGBC, is intended for rating the energy efficiency of a building whose design exceeds the requirements of the standard. In this method, two buildings are modeled: a baseline building that meets the standard and the proposed above-standard building. The energy costs of two buildings are compared using the formula:

$$\text{Percent improvement} = 100 \times \frac{(\text{baseline building performance} - \text{proposed building performance})}{\text{baseline building performance.}}$$

Table 1 shows the number points available under EA Credit 1 for achieving energy cost savings beyond *ASHRAE Standard 90.1-2001*.

Baseline Building and Proposed Buildings

In this study, the buildings are based on the prototype building used by ASHRAE committees and other building industry groups to model the effects of materials and energy use. Wherever possible, the work described in this report is consistent with energy analyses that support the criteria in *ASHRAE Standard 90.1-2004* and the *2003 International Energy Conservation Code*.

[4]*ANSI/ASHRAE/IESNA Addendum e to ANSI/ASHRAE/IESNA Standard 90.1-2001*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, USA, 2001, www.ashrae.org. In *ASHRAE Standard 90.1-2004*, Addendum e has been adopted as Informative Appendix G: Performance Rating Method.

Table 1. Points for Optimizing Energy Performance in LEED-NC v2.1 Energy and Atmosphere Credit 1

Energy cost savings beyond *ASHRAE Standard 90.1-1999*		Points
New buildings	**Existing buildings**	
15%	5%	1
20%	10%	2
25%	15%	3
30%	20%	4
35%	25%	5
40%	30%	6
45%	35%	7
50%	40%	8
55%	45%	9
60%	40%	10

All the buildings in this study are five-story commercial buildings with plan dimensions 105x105 ft. More detail is provided below in the section called Building Description. The baseline building conforms to the requirements of Informative Appendix G. It consists of an exterior insulation finishing system (EIFS) with steel stud walls[5], structural steel frame, and metal deck floors with concrete topping slab. In addition to the baseline buildings, there are nine proposed buildings. All are variations of the structure and building envelope of the baseline building. Table 2 provides a summary of the differences between the baseline building and the proposed buildings. The proposed buildings were chosen to explore the effect of different amounts of concrete on energy use in a variety of scenarios. In addition, the curtain wall building was chosen because it is a common building type. The modeled scenarios are:

- EIFS and curtain walls meeting *ASHRAE 90.1-2001* (a LEED-NC prerequisite) with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2001* (a LEED-NC prerequisite) with either structural steel or reinforced concrete frame,
- Precast concrete walls exceeding *ASHRAE 90.1-2001* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2001*, reinforced concrete frame, and high internal load equipment placed near the central core of the building, and
- Precast concrete walls exceeding *ASHRAE 90.1-2001*, reinforced concrete frame, and high internal load equipment placed near the central core of the building.

The first letter refers to the exterior wall system: "E" for EIFS, "C" for curtain wall, or "M" for precast concrete (the letter M is used because of the thermal mass effects of concrete). The second letter refers to the structural framing system and interior walls and floors: "L" for light and "M" for mass. The light materials are structural steel framing and metal deck floors with concrete topping slab. The mass materials are reinforced concrete framing and 12-in. concrete

[5]Steel studs are light gauge cold formed steel framing. American Iron and Steel Institute, www.steel.org.

Table 2. Buildings Modeled

Designation*	Exterior walls	Structural frame	Floors	Interior walls
EL (baseline)	EIFS & metal stud	structural steel	concrete on metal deck	metal stud
CL	curtain wall	structural steel	concrete on metal deck	metal stud
ML	precast concrete	structural steel	concrete on metal deck	metal stud
EM	EIFS & metal stud	reinforced concrete	12" solid concrete	reinforced concrete
CM	curtain wall	reinforced concrete	12" solid concrete	reinforced concrete
MM	precast concrete	reinforced concrete	12" solid concrete	reinforced concrete
MLX	precast concrete exceeding code	structural steel	concrete on metal deck	metal stud
MMX	precast concrete exceeding code	reinforced concrete	12" solid concrete	reinforced concrete
MMI	precast concrete	reinforced concrete	12" solid concrete	reinforced concrete
MMXI	precast concrete exceeding code	reinforced concrete	12" solid concrete	reinforced concrete

*See text for an explanation of the designations.

floors. An "X" indicates that the building envelope exceeds code requirements and an "I" indicates that the internal loads are clustered near the central core of the building.

Buildings EM, CM, and MM are like EL, CL, and ML, respectively, except they have more concrete in interior floors and walls. Buildings MLX and MMX are like ML and MM, respectively, except their building envelopes exceed code. Buildings MMI and MMXI are like MM and MMX, respectively, except that internal loads are clustered near the central core of the building, where most of the interior concrete is located.

Energy Modeling

Building energy use was modeled using two energy simulation computer programs: VisualDOE and Energy-10.

VisualDOE[6] is a graphic interface to the DOE-2 program modules.[7] On the VisualDOE input screens, the user enters information about the building being modeled. When VisualDOE is run, the information on the input screens is translated into a DOE-2 input file. This file is the input for

[6]VisualDOE, version 4.0.0, Architectural Energy Corporation, San Francisco, CA USA, 2004.

[7]DOE2.1E-119 is a set of modules for energy analysis in buildings. Modules are included (i) to calculate the heating and cooling loads of each space in a building for each hour of a year, (ii) to simulate operation and response of the equipment and systems that control temperature and humidity and distribute heating, cooling and ventilation to the building, (iii) to model energy conversion equipment that uses fuel or electricity to provide the required heating, cooling and electricity, and (iv) to compute the cost of energy and building operation based on utility rate schedule and economic parameters (Winkelmann, 2002).

the DOE-2 program modules. These modules (i) calculate the heating and cooling loads of each space in a building for each hour of a year and (ii) simulate operation and response of the equipment and systems that control temperature and distribute heating, cooling and ventilation to the building. The program simulates energy use for every hour of a typical meteorological year. The typical meteorological year is based on 30-year historical weather data.[8] Energy use and demand in response to thermal mass effect are accurately predicted because the program performs hourly simulation.

Energy-10 is a conceptual design tool for small (less than 10,000 sq ft) low-energy buildings that can be characterized by two thermal zones. It was used in this project primarily as a consistence check in the results. However, Energy-10 is not intended for buildings like the ones in this project, nor does it meet the requirements[9] of Informative Appendix G. Therefore, the results from modeling with Energy-10 are not discussed in detail in this report but the results are shown in the Appendices.

Climates

Since thermal mass effects vary with climate, the buildings were modeled in six cities representing the range of climates in the US. The locations selected are those often used by other energy analysts when estimating national energy use in buildings. Five of these cities are representative cities for the U.S. Department of Energy's climate zones in the *2004 International Energy Conservation Code*. The cities and the climate zone numbers are:

- Miami, Florida—a hot and humid climate (Zone 1A)
- Phoenix, Arizona—a hot and dry climate with large daily temperature swings (Zone 2B)
- Memphis, Tennessee—a mild climate (Zone 3A)
- Salem, Oregon—a cool climate (Zone 4C)
- Denver, Colorado—a cold climate with large daily temperature swings (Zone B, but not a representative city)
- Chicago, Illinois—a cold climate (Zone 5A)

BUILDING DESCRIPTION

This section describes the features that are common to all the buildings and the features that differ because of climate or modeling scenario.

Common Features

All the buildings in this study are five-story commercial buildings with plan dimensions 105x105 ft. They are square in plan to minimize the influence of solar effects due to orientation. The building height (63 ft) is based on 15 ft for the first story and 12 ft for the remaining four stories. The story height is measured from finished floor to finished floor.

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[8]The analyses used the DOE-2 Typical Mean Year Data Set No. 2 (TMY2) for all cities. These weather data consist of the average hourly weather for particular locations, compiled from 1961 to 1990.

[9]The requirements are listed in Informative Appendix G, section G2.1.1, page 3. Energy-10 does not meet the requirements because it can only model two zones.

Floor plans and zones. Each floor is modeled with five zones: four perimeter zones and one central zone. The five zones are shown schematically in Figure 1. The depth of the perimeter zones is 35 ft. The center zone is 35x35 ft. VisualDOE automatically includes partition walls between adjacent zones. The user can accept the default wall construction or input a new wall.

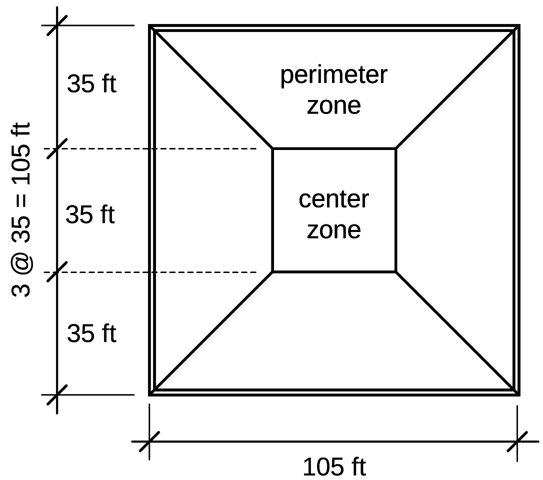

Figure 1. This schematic shows the five zones per floor, which coincide with the VisualDOE partition walls.

Windows. Each façade of each story has a strip of 10 windows measuring approximately 5 ft high by 10½ ft wide. Figure 2 shows the arrangement of windows. Windows are flush-mounted (non-recessed) and are equally spaced. Windows are non-operable and have no blinds or shading devices. The overall window to wall ratio is 0.40.

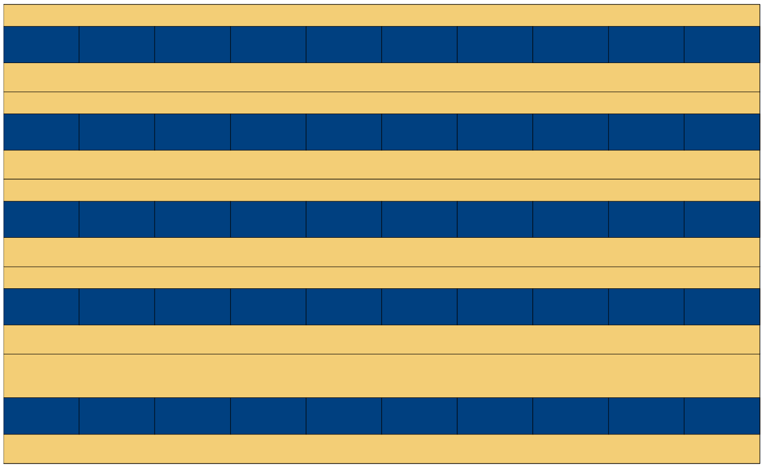

Figure 2. Each façade consists of bands of windows.

Orientation. Energy use is dependent on window orientation. The analyses are not orientation specific since the building modeled has equal amounts of windows on each orientation.

Shading. No exterior shading was assumed around the buildings. This assumption is typical for new construction in rural and suburban locations.

Roofs. The roofs on all the buildings in this study consist of open-web steel joists, ribbed steel deck, ⅝-in. gypsum wallboard, board insulation, and built-up waterproofing membrane. The overall roof U-value is 0.062 Btu/h·ft^2·°F (including air films) for the building meeting code requirements. The built-up roof is medium-colored and has a coefficient of solar absorptance of 0.70 (this is the default value required in Informative Appendix G).

Slab-on-ground. The ground-level floor consists of carpet with fibrous pad and 6-in. cast-in-place concrete slab-on-ground. According to ASHRAE 90.1, an unheated slab-on-ground floor does not require insulation in the six cities considered in this report. However, in order to accurately model the heat transfer between the slab and the ground, a layer of soil and a fictitious insulation layer need to be considered. The heat transfer was modeled using the effective resistance method (Winkelman, 2002). In this method the floor is also assumed to consist of a 12-in. layer of soil with a thermal resistance[10] of 1.0 h·ft^2·°F/Btu and a fictitious insulation layer. This thickness of soil is sufficient to account for most of the thermal mass effects of the ground, and the fictitious insulation layer is required to give the correct effective resistance for the floor. The method yields an R-value of 32.545 h·ft^2·°F/Btu for the fictitious insulation. The inside air-film resistance is omitted from the calculations because VisualDOE adds air film resistances automatically.

Heating, ventilation, and air conditioning. The heating, ventilation, and air conditioning (HVAC) system is a packaged variable air volume system. Each building has three packaged units. One unit serves the zones of the ground floor, another serves the zones of the three intermediate floors, and the remaining unit serves the zones of the top floor. In cooling mode, the supply air temperature is constant and the volume of air is varied from minimum to maximum to satisfy the zone requirements. The minimum flow ratio is set at 30% of the maximum. In heating mode, the supply air temperature is varied in response to the zone requirements and the volume of air is set to the minimum (constant). The efficiency of HVAC equipment is identical for all buildings. Cooling is provided by high efficiency direct expansion. The energy-efficiency ratio is 9.5. The energy simulation program sizes the HVAC equipment automatically. The cooling over-sizing ration is 1.15. Heating is provided by a high efficiency natural gas furnace with a thermal efficiency of 0.8. Each zone also has baseboard heaters for zone reheating using hot water from a central plant. The energy simulation program sizes the supply fan. Its energy use is included in the overall energy-efficiency ratio above. Operational parameters are shown in Table 3. These operational parameters are commonly used for modeling energy use in commercial buildings.

Equipment and lighting. Equipment power density (also called plug or receptacle load) is 0.75 watt/ft^2 and lighting power density is 1.50 watt/ft^2. There is no daylight control. The energy for exterior lighting is not considered. Natural gas water heaters supply domestic hot water.

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[10]The thermal resistance of soil is taken from Winkelmann, 2002, rather than from *ASHRAE 90.1-2001*, section A6, page 81.

Table 3. Building Systems Operational Parameters and Schedules*

Schedule type, unit	Hour of day																		
Day type	**1-5**	**6**	**7**	**8**	**9**	**10-11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Occupancy, %																			
Weekday	0	0	10	20	95	95	95	50	95	95	95	95	30	10	10	10	10	5	5
Saturday	0	0	10	10	30	30	30	10	10	10	10	10	5	5	0	0	0	0	0
Sunday & holidays	0	0	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0
Lighting and equipment, %																			
Weekday	5	10	10	30	90	90	90	80	90	90	90	90	50	30	30	20	20	10	5
Saturday	5	5	10	10	30	30	30	15	15	15	15	15	5	5	5	5	5	5	5
Sunday & holidays	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Infiltration, %																			
Weekday	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100
Saturday	100	100	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100	100
Sunday & holidays	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Domestic hot water, %																			
Weekday	5	10	5	20	35	40	45	60	55	35	35	45	25	20	15	15	10	5	5
Saturday	0	0	5	10	15	20	25	20	20	15	10	15	5	0	0	0	0	0	0
Sunday & holidays	5	5	5	5	5	5	5	5	10	5	5	5	5	5	5	5	5	5	5
Outside air, %																			
Weekday	0	0	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	0	0
Saturday	0	0	F	F	F	F	F	F	F	F	F	F	F	0	0	0	0	0	0
Sunday & holidays	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HVAC supply fan, %																			
Weekday	F	F	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Saturday	F	F	100	100	100	100	100	100	100	100	100	100	100	100	F	F	F	F	F
Sunday & holidays	F	F	100	100	100	100	100	100	100	100	100	100	100	F	F	F	F	F	F
Cooling set point, °F																			
Weekday	99	99	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Saturday	99	99	75	75	75	75	75	75	75	75	75	75	75	75	99	99	99	99	99
Sunday & holidays	99	99	75	75	75	75	75	75	75	75	75	75	75	99	99	99	99	99	99
Heating set point, °F																			
Weekday	55	55	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Saturday	55	55	70	70	70	70	70	70	70	70	70	70	70	70	55	55	55	55	55
Sunday & holidays	55	55	70	70	70	70	70	70	70	70	70	70	70	55	55	55	55	55	55

*Typical schedules based on *ASHRAE 90.1-1989* and VisualDOE defaults.
Note: F is float and % is percent of total.

Air infiltration and fresh air requirements. The overall rate of air infiltration through the building envelope is 0.4 air changes per hour (ach). This is close to the infiltration calculated from window and door air leakage (0.37 ach) using the *ASHRAE Fundamental Handbook* (ASHRAE, 2001). It is also within the normal range for office buildings, that is, 0.1 to 0.6 ach.[11] The air infiltration rate was modified to account for differences in infiltration rates between perimeter zones and the central zone. The infiltration rate was set to 0.42 ach in perimeter zones and zero ach in the central zones. In addition to air infiltration, fresh outside air is supplied at a rate of 20 cfm/person.[12]

Occupancy. The occupancy is 275 sq ft/person.[13] The thermostat throttling range is 4 °F. The operating hours are based on *ASHRAE 90.1-1989*.[14] The schedules are shown in Table 3. These schedules are commonly used for modeling energy use in commercial buildings.

Differing Features

Concrete construction. Concrete is normal weight with density of 145 lb/ft^3, conductivity of 1.333 Btu/h·ft·°F, and specific heat of 0.22 Btu/lb·°F. Buildings EM, CM, MM, MMX, MMI, and MMXI as noted earlier are the “mass” buildings.

Floors. The interior floors of the steel frame buildings consist of ribbed steel deck, an equivalent concrete thickness of 4 in., and carpet with fibrous pad. Ceiling tiles are attached directly to the bottom of the roof and floor framing. Although this is not a common way of installing ceiling tiles, this simplification is necessary because available energy simulation tools do not accurately model the space between a suspended ceiling and interior floor or roof (plenums). The interior floors of the reinforced concrete frame buildings consist of 12 in. of concrete and carpet with fibrous pad.

Exterior walls. The thermal performance requirements for exterior walls are shown in the tables below. Table 4 shows the minimum requirements for EIFS and curtain walls along with the construction of the walls selected to meet code. Table 5 shows the minimum requirements for precast concrete walls along with the insulation selected to meet code. Note that the tabulated U-values include the thermal resistance of interior and exterior air films. Table 6 shows the thermal resistance of materials in the concrete wall assemblies that were used to meet and exceed the code requirements.

Fenestration. The thermal performance requirements for windows are shown in Table 7 along with the properties of the windows selected to meet code. Table 8 shows the properties of the selected windows that were used to exceed the requirements.

[11] *2001 ASHRAE Fundamentals Handbook*, page 26.24 (ASHRAE, 2001).

[12] Table 2, page 8 in *ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA USA, 2001, www.ashrae.org.

[13] *ASHRAE Standard 90.1-1989*, Table 13.2, page 110.

[14] *ASHRAE Standard 90.1-1989,* Table 13.3, page 111.

Table 4. Thermal Performance Requirements in *ASHRAE 90.1-2001* for EIFS and Curtain Walls

Location	Code-required U-factor*	Insulation and resulting wall U-factor to meet code	
		Insulation**	U-factor*
Miami	0.124	R-13 batts	0.124
Phoenix	0.124	R-13 batts	0.124
Memphis	0.124	R-13 batts	0.124
Salem	0.124	R-13 batts	0.124
Denver	0.084	R-13 batts + R-3.8 boards	0.084
Chicago	0.084	R-13 batts + R-3.8 boards	0.084

*These U-factors, in units of Btu/h·ft^2·°F, include the thermal bridging effects of steel stud framing and the thermal resistance of inside and outside air films.
**Batt insulation is installed between steel studs, which are 16 in. on-center. Board insulation is continuous over the steel studs.

Table 5. Thermal Performance Requirements in *ASHRAE 90.1-2001* for Precast Concrete Walls

Location	Code-required U-factor*	Insulation and resulting wall U-factor to meet code	
		Insulation**	U-factor*
Miami	0.580	None	0.405
Phoenix	0.580	None	0.405
Memphis	0.151	R-13 batts	0.130
Salem	0.151	R-13 batts	0.130
Denver	0.123	R-15 batts with ½ in. air space	0.113
Chicago	0.123	R-15 batts with ½ in. air space	0.113

*These U-factors, in units of Btu/h·ft^2·°F, include the thermal bridging effects of steel stud framing and thermal resistance of inside and outside air films.
**Batt insulation is installed between steel studs, which are 16 in. on-center. Board insulation is continuous over the steel studs.

Roofs. The code requires a U-factor no more than 0.063 Btu/h·ft^2·°F (including air films). The thermal performance requirements for roofs are met using R-15 board insulation in all locations. The resulting roof U-factor is 0.062 Btu/h·ft^2·°F (including air films). In addition, Table 9 shows the properties of the selected roofs used to exceed the requirements.

HVAC. Each HVAC is equipped with an average-efficiency air-side economizer, as required in Informative Appendix G. The economizer shutoff limits are shown in Table 10. The limits are based on the 1% cooling design wet-bulb temperature.

Energy costs. The energy costs for each city are show in Table 11.

Table 6. Concrete Wall Assembly Used to Meet Requirements in *ASHRAE Standard 90.1-2001*

Layer	Location			
Thermal resistance, h·ft^2·°F/Btu	Miami & Phoenix	Memphis & Salem	Denver & Chicago	All cities: exceeding code
Outside air film	0.17	0.17	0.17	0.17
Concrete, 6 in.	0.38	0.38	0.38	0.38
Air space*	0	0	0.77	0
Insulation and 3.5-in. framing**	0.79	6.0	6.4	10
Gypsum wallboard, ½ in.	0.45	0.45	0.45	0.45
Inside air film	0.68	0.68	0.68	0.68
Total R-value	**2.47**	**7.68**	**8.85**	**11.68**
U-factor, Btu/h·ft^2·°F	**0.405**	**0.130**	**0.113**	**0.086**

*Although there is a gap between the steel studs and the precast concrete panels, in most cases the thermal resistance of the air spaces can be ignored. However, in Denver and Chicago, the thermal resistance of the ½-in. air space is needed to meet minimum code requirements.
**The effective R-value of insulation and steel studs spaced 16 in. on-center according to *ASHRAE 90.1-2001*, Table A-21, assuming: no insulation in Miami and Phoenix, R-13 batt insulation in Memphis and Salem, R-15 batt insulation in Denver and Chicago, and R-13 batt insulation (effectively R-6) plus R-4 board insulation for the wall exceeding code.

Table 7. Fenestration Requirements in *ASHRAE Standard 90.1-2001*

Location	Code-required		Selected windows			
	U-factor*	SHGC**	U-factor*	SHGC†	VLT††	VisualDOE identifier & name
Miami, Phoenix	1.22	0.25	0.88	0.25	0.13	1411 Single clear LR13
Memphis	0.57	0.25	0.52	0.23	0.18	2420 Double Ref-B Clear-L Air
Salem, Denver & Chicago	0.57	0.39	0.52	0.30	0.27	2426 Double Ref-B Clear-H Air

*U-factor in units of Btu/h·ft^2·°F.
**Solar heat gain coefficient (SHGC) requirement in a non-north orientation.
†Solar heat gain coefficient at a 60° angle of incidence.
††Visible light transmittance (VLT) is not a code requirement.

Table 8. Selected Windows that Exceed Requirements in *ASHRAE Standard 90.1-2001*

Location	U-factor*	SHGC**	VLT†	VisualDOE identifier & name
Miami, Phoenix	0.52	0.23	0.18	2406 Double ref A clear-H IG
Memphis, Salem, Denver & Chicago	0.31	0.15	0.14	2823 Double Electrochromic Ref Bleached/Colored, 12.7-mm Gap

U-factor in units of Btu/h·ft^2·°F.
**Solar heat gain coefficient at a 60° angle of incidence.
†Visible light transmittance (VLT) is not a code requirement.

Table 9. Selected Roof Insulation that Exceeds Requirements in *ASHRAE Standard 90.1-2001*

Location	Insulation and resulting U-factor to exceed code	
	Insulation	U-factor*
Miami & Phoenix	R-15 board	0.062
Memphis, Salem, Denver & Chicago	R-20 board	0.047

*U-factor in units of Btu/h·ft^2·°F.

Table 10. Control Condition for Economizer in Various Locations

Location	1% wet-bulb temperature, °F	Shutoff dry bulb temperature, °F	
		High-limit	Low-limit
Miami	77	65	40
Phoenix	70	70	40
Memphis	77	65	40
Salem	66	75	40
Denver	59	75	40
Chicago	73	70	40

Table 11. Energy Costs

Location	Electricity* ¢/kWh	Electricity $/kWh	Natural gas** $/thousand cu ft	Natural gas $/therm
Miami	7.64	0.0764	10.91	1.091
Phoenix	9.55	0.0955	7.75	0.775
Memphis	7.39	0.0739	8.63	0.863
Salem	5.93	0.0593	7.90	0.790
Denver	8.33	0.0833	5.83	0.583
Chicago	8.07	0.0807	8.23	0.823

*Source: Energy User News, April 2004, Ranking of Electricity Prices Commercial, data from September 2003. Used average of a state's utilities. No data was available for Salem, so the average data for the state of Washington was used instead.
**Source: http://www.eia.doe.gov/emeu/states/_states.html. Used 2003 averages and 100 cu ft natural gas = 1 Therm.

MODELING THERMAL MASS

Custom weighting factors

VisualDOE accounts for thermal mass effect in a space using one of two methods: *custom weighting factors* or *precalculated weighting factors*. By default, VisualDOE uses the custom weighting factor method[15]. In general, the custom weighting factor method requires the most amount of user input but produces the most accurate results. The DOE reference manuals suggest using custom weighting factors for masonry buildings and heavy construction.[16] Precalculated weighting factors are not recommended. Custom weighting factors are based on the actual properties of the room being modeled including wall construction, furniture type, furniture fraction, and furniture weight.

Wall construction. In order to benefit from the thermal properties of the walls, the various layers of the wall must be defined using the VisualDOE Construction Editor. A screen shot of the Construction Editor is shown in Figure 3. A construction is composed of individual layers of materials. The individual materials should be defined according to their material properties, such as thickness, conductivity, density, and specific heat. When several layers of materials are combined to form a construction, the texture, emissivity, and absorptance must also be specified. For common building materials, the *VisualDOE 4.0 User Manual* gives typical values (Architectural Energy Corporation, 2004).

Interior partitions. Buildings modeled with VisualDOE also contain interior partitions by default. If the partitions are lightweight, such as steel studs and gypsum wallboard, their thermal mass is insignificant. However, for concrete partition walls, the mass should not be ignored. The mass of the actual concrete partition walls must be compared to the default arrangement of partition walls (see Figure 1). If the mass differs, the thickness of the partition walls should be adjusted to reflect the actual situation. For example, in the modeling scenarios that have interior reinforced concrete walls, these concrete walls are actually the building shear walls. The total volume of the shear walls in the building (5,447 cu ft) is distributed over the VisualDOE default partition wall area (19,604 sq ft for the entire building). The resulting interior concrete wall thickness of 3.334 in. is used in the VisualDOE model.

Interior thermal mass. Furniture type describes the thermal response of the furniture. Two values are possible: light and heavy. Light represents a furniture density of 40 lb/ft^3 and heavy represents a density of 80 lb/ft^3. Furniture fraction is the fraction of floor area covered by furniture, and furniture weight is the weight of the furniture per unit area of floor. The range of permissible values is 8 to 300 lb/ft^2. The custom weighting factor scenario that was considered for this project is the VisualDOE default amount of thermal mass, which assumes light furniture weighing 8 lb/ft^2 covering 85% of the floor. This scenario is the most common for office buildings.

[15]In order to invoke the custom weighting factor method, VisualDOE sets the FLOOR WEIGHT code word equal to zero. The user can verify this in the Rooms tab of the Advanced Edit dialogue box under the Alternatives menu.

[16]See page III.A.4 of the DOE-2 Supplement. (Winkelmann et al., 1993).

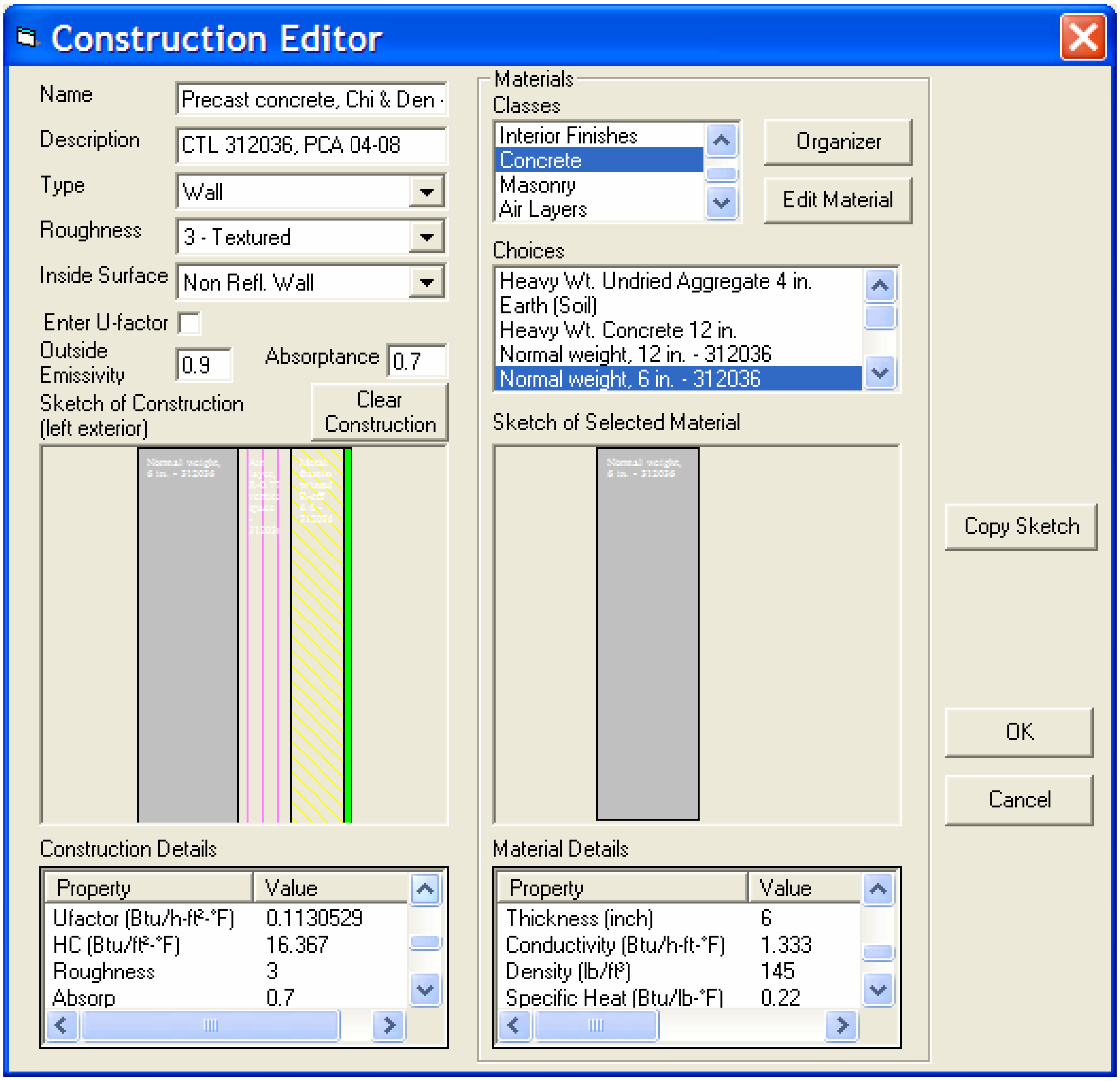

Figure 3. Screen shot of VisualDOE Construction Editor shows that layers of materials are assembled into constructions in order to benefit from thermal mass: in this case a 6-in. precast concrete wall.

RESULTS

The VisualDOE results are summarized in Figure 4 and the Energy-10 data are summarized in Figure 5. The detailed results are presented in Appendices A through D. As was mentioned earlier, since Energy-10 does not meet the requirements of Informative Appendix G, the Energy-10 results are not discussed in detail in this report. However, Energy-10 was useful to check that the VisualDOE results were reasonable. For example, Figures 4 and 5 show that the patterns and trends of energy versus cost are similar using either software option. Summary charts and tabulated data from VisualDOE are presented in Appendices A and B, respectively; summary charts and tabulated data from Energy-10 are presented in Appendices C and D, respectively. For each location, the charts show yearly energy use and cost. Energy use is broken down into its components: heating, cooling, pumps, fans, domestic hot water, lighting, and receptacle loads.

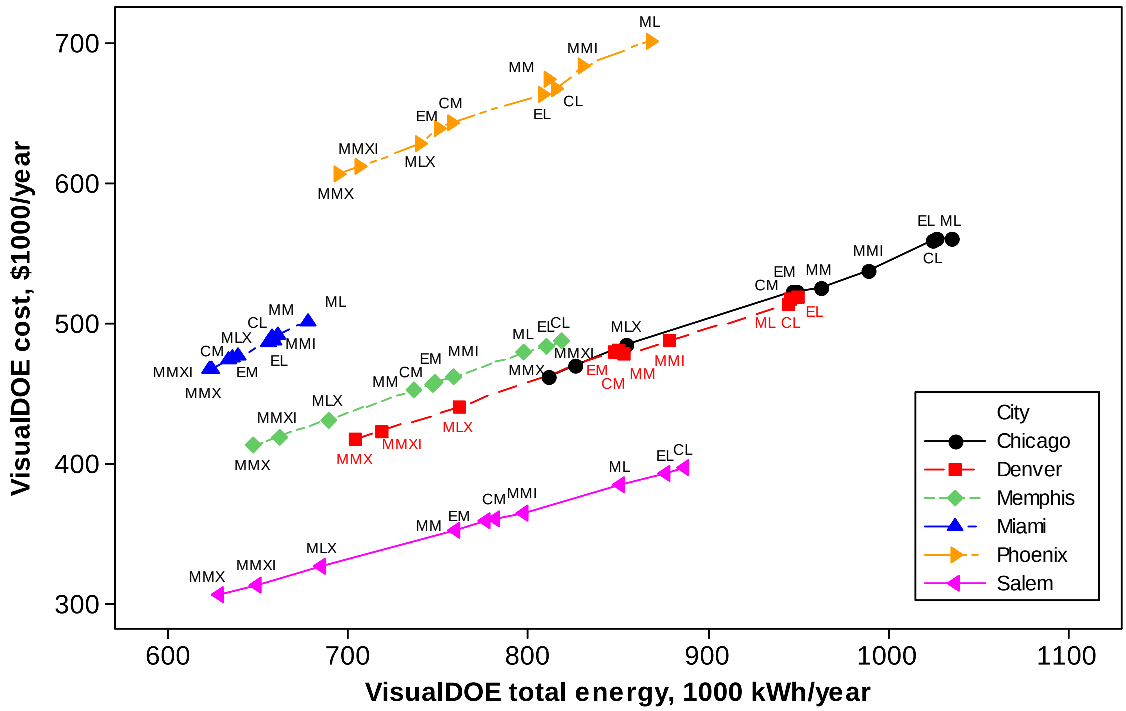

Figure 4. The relationship between annual energy use and cost varies by city (VisualDOE results).

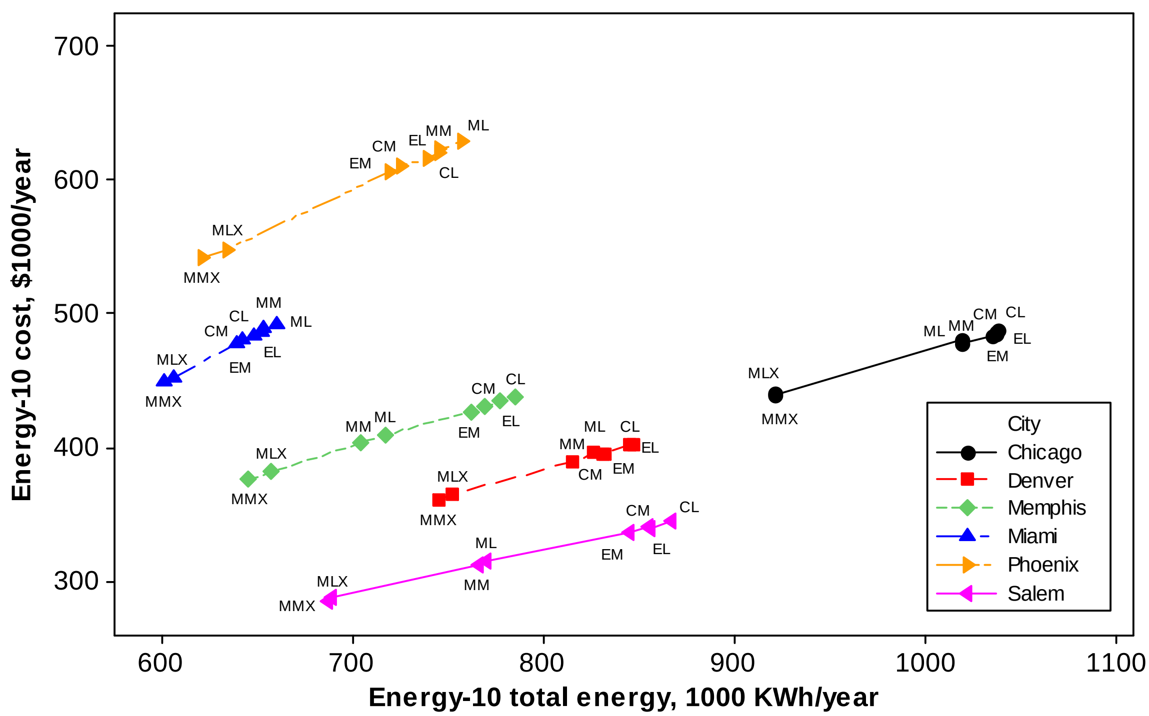

Figure 5. The relationship between annual energy use and cost varies by city (Energy-10 results).

Energy cost savings due to thermal mass effects. In most scenarios, the effect of thermal mass is to lower energy *use,* and in most scenarios, the effect of thermal mass is to lower energy *cost* relative to the baseline building. In Miami, the climate is mild, so the variation in energy cost among scenarios is small; therefore, the difference among scenarios is not as apparent as it is in the other climates. According to the minimum code requirements, precast concrete walls in Miami and Phoenix do not require added insulation, but EIFS and curtain walls in these same cities require at least R-13 batt insulation. However, in these climates, the reinforced concrete frame buildings with uninsulated concrete walls have comparable performance to the steel frame buildings with insulated EIFS and curtain walls (see Figure 4). In Memphis, Salem, Denver, and Chicago, significant energy cost savings are indicated for the three concrete frame buildings meeting code compared to the baseline building: 6% to 13% when receptacle loads are not included.[17] Comparing these percentages with LEED-NC EA Credit 1, additional thermal mass alone will provide at least 5% energy cost savings in Memphis, Salem, Denver, and Chicago (see Figure A10 in Appendix A).

Energy cost savings due to thermal mass in the structural frame. In Memphis, Salem, Denver, and Chicago, significant energy cost savings are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code: 6% to 11% when receptacle loads are not included (see Figure A8 in Appendix A). This energy cost savings is due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building.

Internal loads near center core. We analyzed the building with precast concrete walls and reinforced concrete frames in two ways: first, with internal loads distributed uniformly across the floor area, and second, with the internal loads weighted more heavily toward the interior zone. The second case has more energy use for all cases. This means the thermal mass in or near the building envelope helps offset internal loads more than thermal mass in the core. This analysis was done using VisualDOE. Energy-10 was not used because it cannot model more than two zones.

Walls exceeding energy code requirements. VisualDOE shows significant energy cost savings for precast concrete walls exceeding code. The amount of added insulation chosen to make the walls exceed code is not unusual. Even more insulation could have been used, but using a low value shows how even modest improvements can result in significant energy savings. For example, in Denver and Chicago, the added insulation in the concrete wall exceeding code is about the same as the amount of insulation in the EIFS and curtains walls meeting code. This shows that the amount of added insulation is realistic and that concrete with insulation saves energy. When receptacle loads are excluded, energy cost savings are in the range of 10% to 27% for all cities except Miami, where the energy cost savings are about 5%.

LEED EA Credit 1. In the three cities representing cool and cold climates, reinforced concrete frame buildings with precast concrete walls that exceed code will most likely qualify for points under LEED-NC EA Credit 1. In the cold climate category (Denver and Chicago), these

[17]In LEED-NC v2.1 EA Credit 1, receptacle loads are not considered in the cost savings calculations.

buildings will likely qualify for 2 points, that is, at least 20% energy cost savings. In the cool climate category (Salem), these buildings will likely qualify for 3 points, that is, at least 25% energy cost savings. In mild climates, such as Memphis, these buildings will likely qualify for 1 point (see Figure A10 in Appendix A). These results are particularly significant because commercial buildings such as the ones modeled in this study have a relatively large window area (0.4 window-to-wall ratio) and very large associated energy loads.

SUMMARY AND CONCLUSIONS

This project provides in-depth information on energy savings in mid-rise commercial buildings from additional thermal mass and for exceeding building envelope thermal performance requirements. It shows how to model the thermal properties of concrete to accurately obtain LEED-NC v2.1 EA Credit 1 points. Using energy simulation software, in most scenarios, the effect of thermal mass in concrete frame buildings has been shown to lower energy *use*, and the overall effect of thermal mass in concrete framed buildings is to lower energy *cost* relative to the baseline steel framed EIFS buildings.

In all cities except Miami, reinforced concrete frame buildings with precast concrete walls and building envelopes that exceed code will most likely qualify for points under EA Credit 1. In the cold climate category (Denver and Chicago), these buildings will likely qualify for 2 points, that is, at least 20% energy cost savings. In the cool climate category (Salem), these buildings will likely qualify for 3 points, that is, at least 25% energy cost savings. In the mild climate category (Memphis), these buildings will likely qualify for 1 point, that is, at least 15% cost savings.

In Memphis, Salem, Denver, and Chicago, significant energy cost savings are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code: 6% to 11% when receptacle loads are not included. This energy cost savings is due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building.

The results in this report are for the buildings modeled in the stated cities. Actual energy use and cost will vary depending on climate, building type and occupancy, orientation, actual building materials, and fenestration amount and type.

REFERENCES

ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 2004, www.ashrae.org.

ANSI/ASHRAE/IESNA Standard 90.1-2001, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 2001, www.ashrae.org.

ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 1999, www.ashrae.org.

ASHRAE/IESNA Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 1989, www.ashrae.org.

ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, American Society of Heating Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 1989.

2001 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, USA, 2001, www.ashrae.org.

Architectural Energy Corporation, *VisualDOE 4.0 User Manual*, Architectural Energy Corporation, San Francisco, CA, USA, 2004.

LEED Green Building Rating System for New Construction and Major Renovations (LEED-NC) Version 2.1, United Stated Green Building Council, Washington, DC USA, 2002, www.usgbc.org.

2004 Supplement to the International Energy Conservation Code, International Code Council, Inc., Country Club Hills, IL, USA, 2001, www.iccsafe.org.

2003 International Energy Conservation Code, International Code Council, Inc., Country Club Hills, IL, USA, 2003, www.iccsafe.org.

Winkelmann, F., "Underground Surfaces: How to get a Better Underground Surface Heat Transfer Calculation in DOE-2.1E," Building Energy Simulation Users News, Vol. 23, No. 6, November/December 2002.

Winkelmann, F., "DOE2.1E-119," U.S. Department of Energy, Energy Science and Technology Software Center, Oak Ridge, TN, USA, 2002.

Winkelmann, F., et al., *DOE-2 Supplement, Version 2.1E*, Regents of the University of California, Lawrence Berkeley Laboratory, Berkeley, CA, USA, 1993.

ACKNOWLEDGEMENTS

The research reported in this paper (PCA R&D Serial No. 2880) was conducted by CTLGroup with the sponsorship of the Portland Cement Association (PCA Project Index No. 04-08). The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the views of the Portland Cement Association.

APPENDIX A – VisualDOE DATA PLOTS

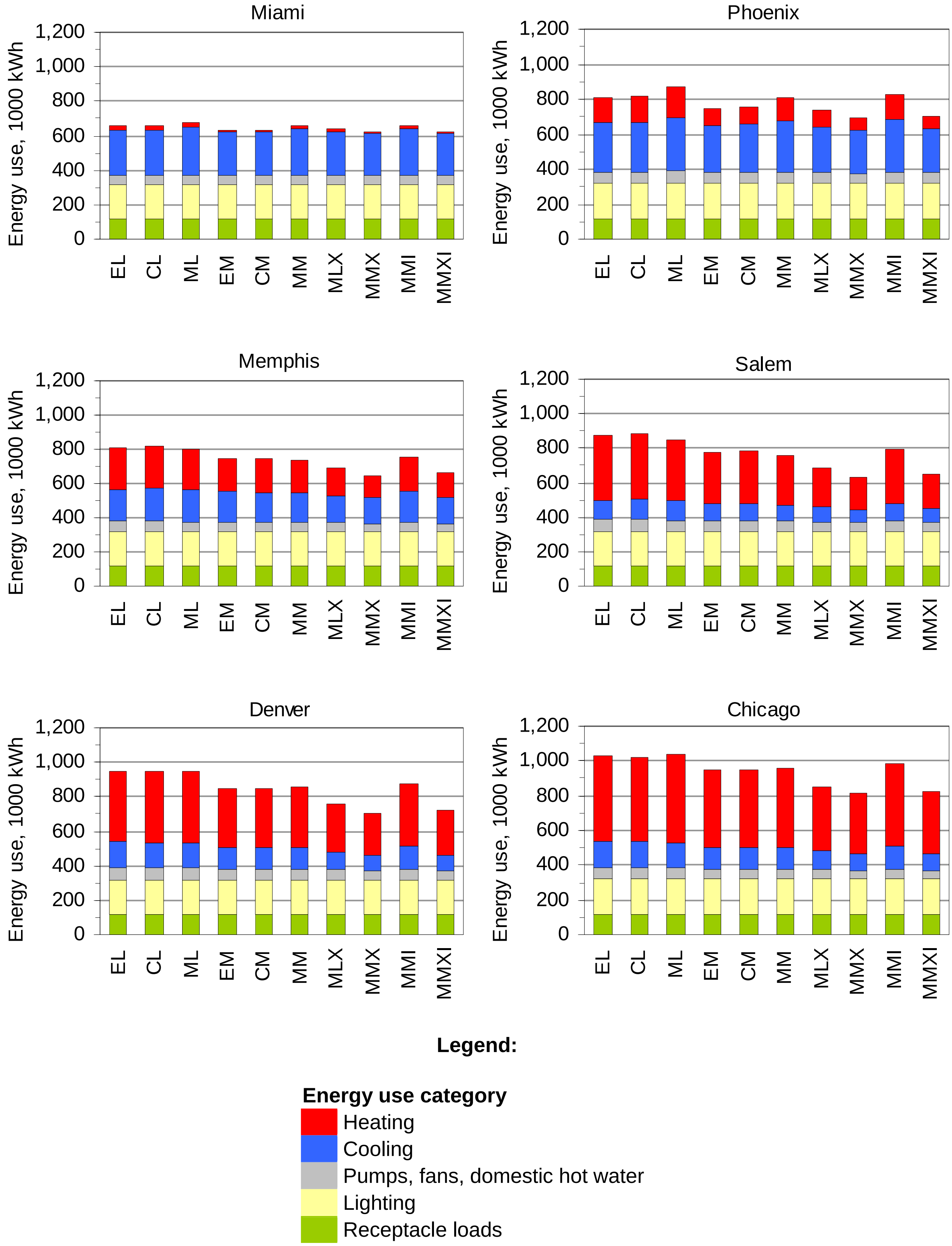

Figure A1. Yearly building energy use by category in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

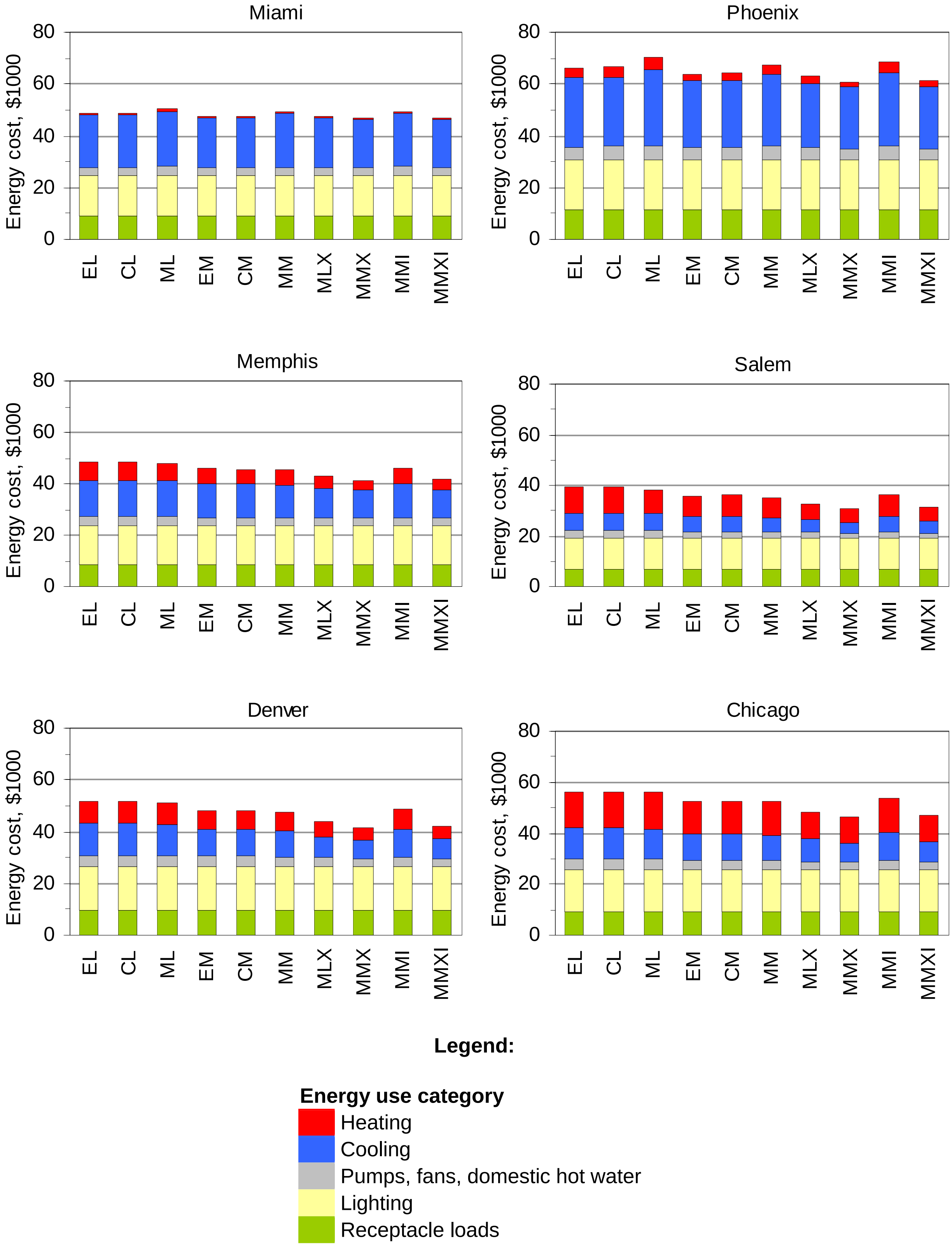

Figure A2. Yearly building energy cost by category in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

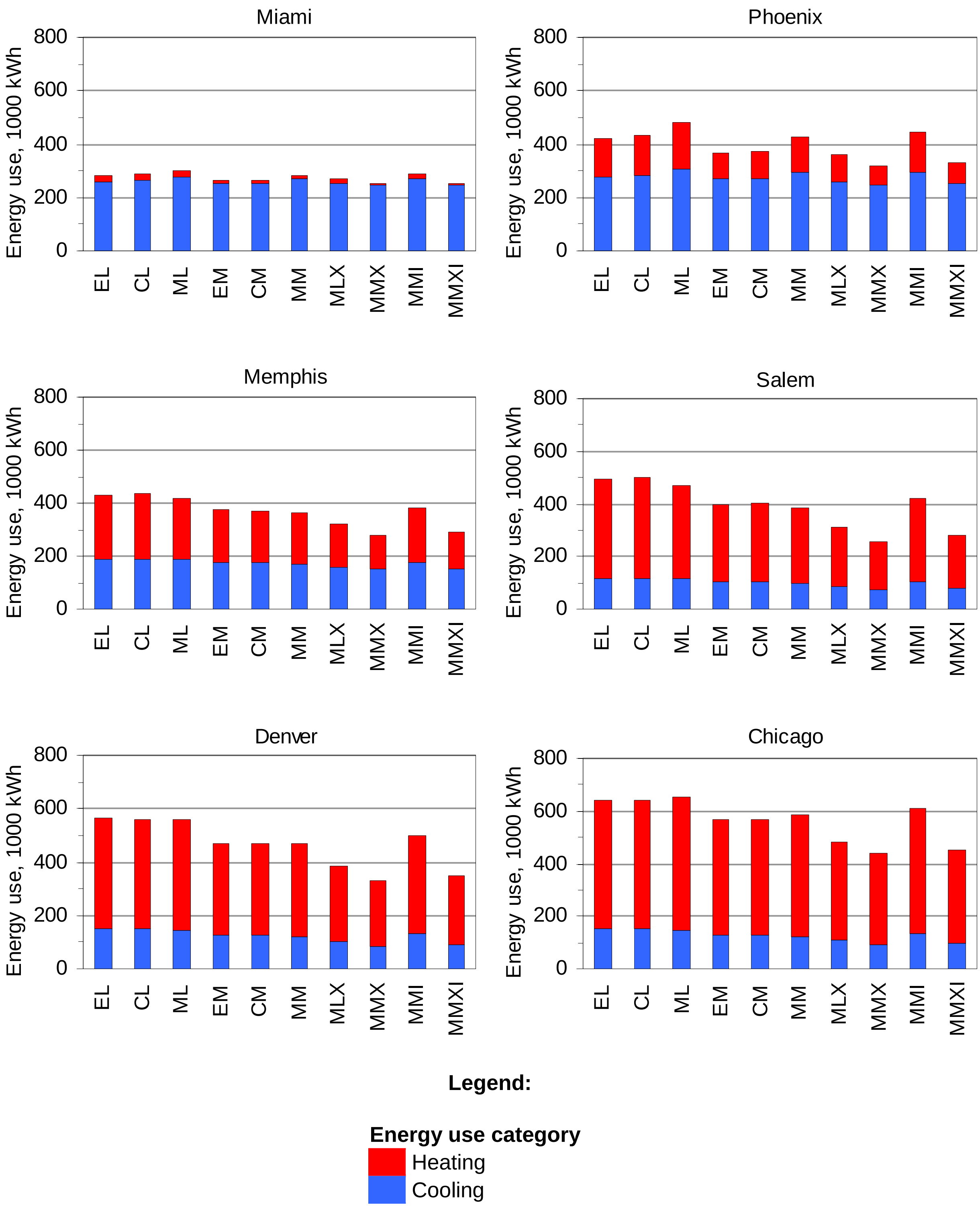

Figure A3. Yearly heating and cooling energy in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

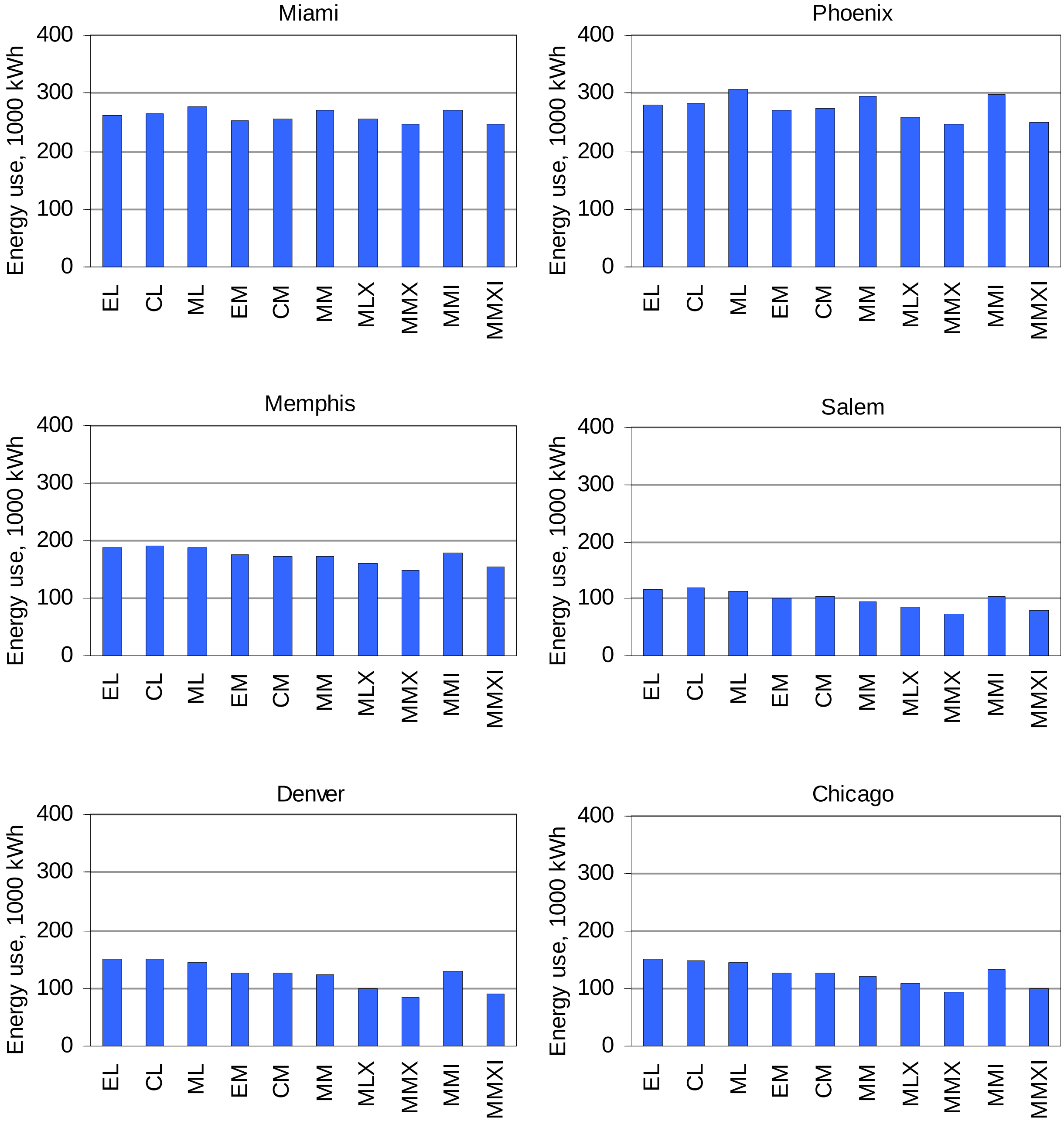

Figure A4. Yearly cooling energy in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

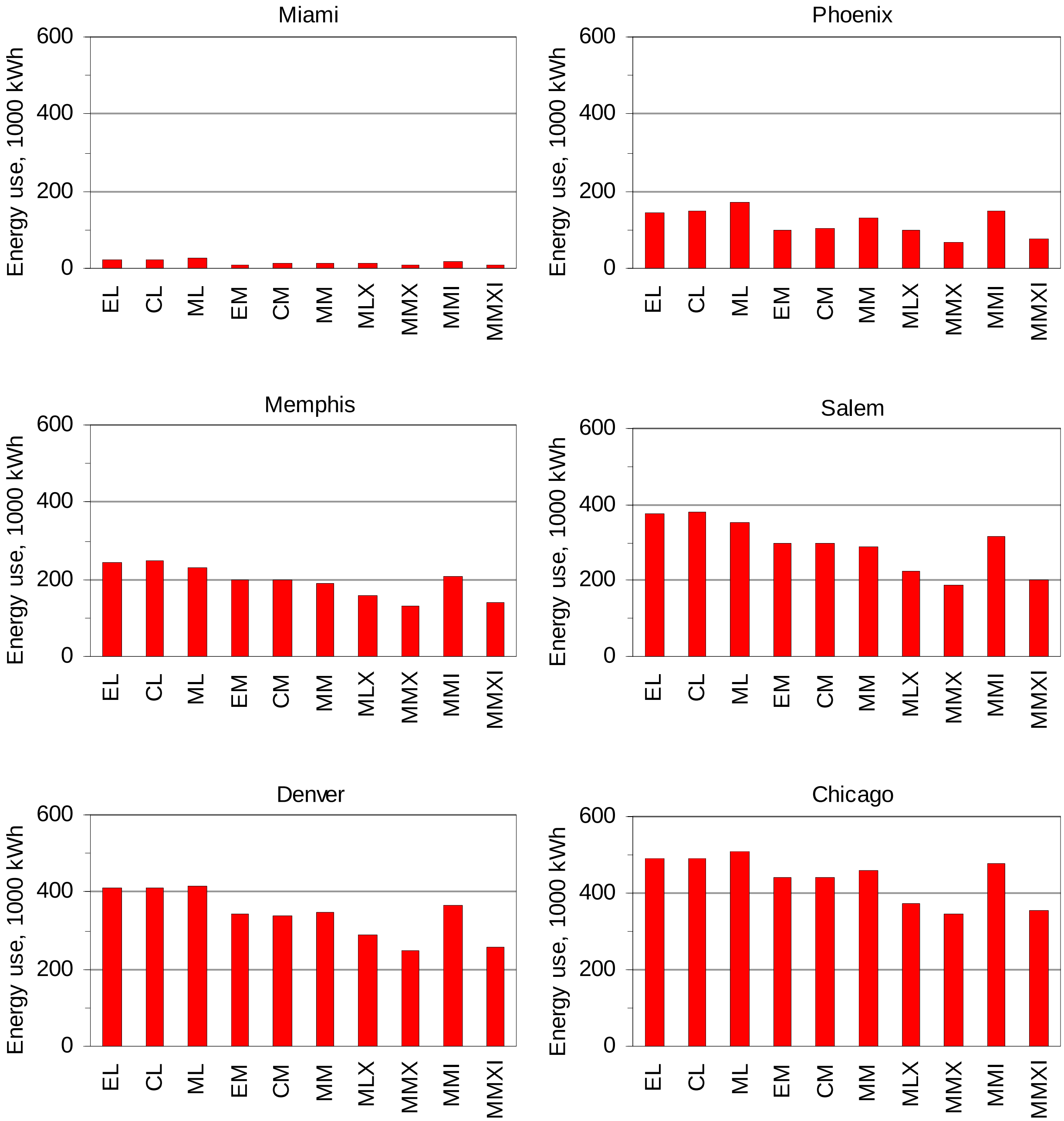

Figure A5. Yearly heating energy in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

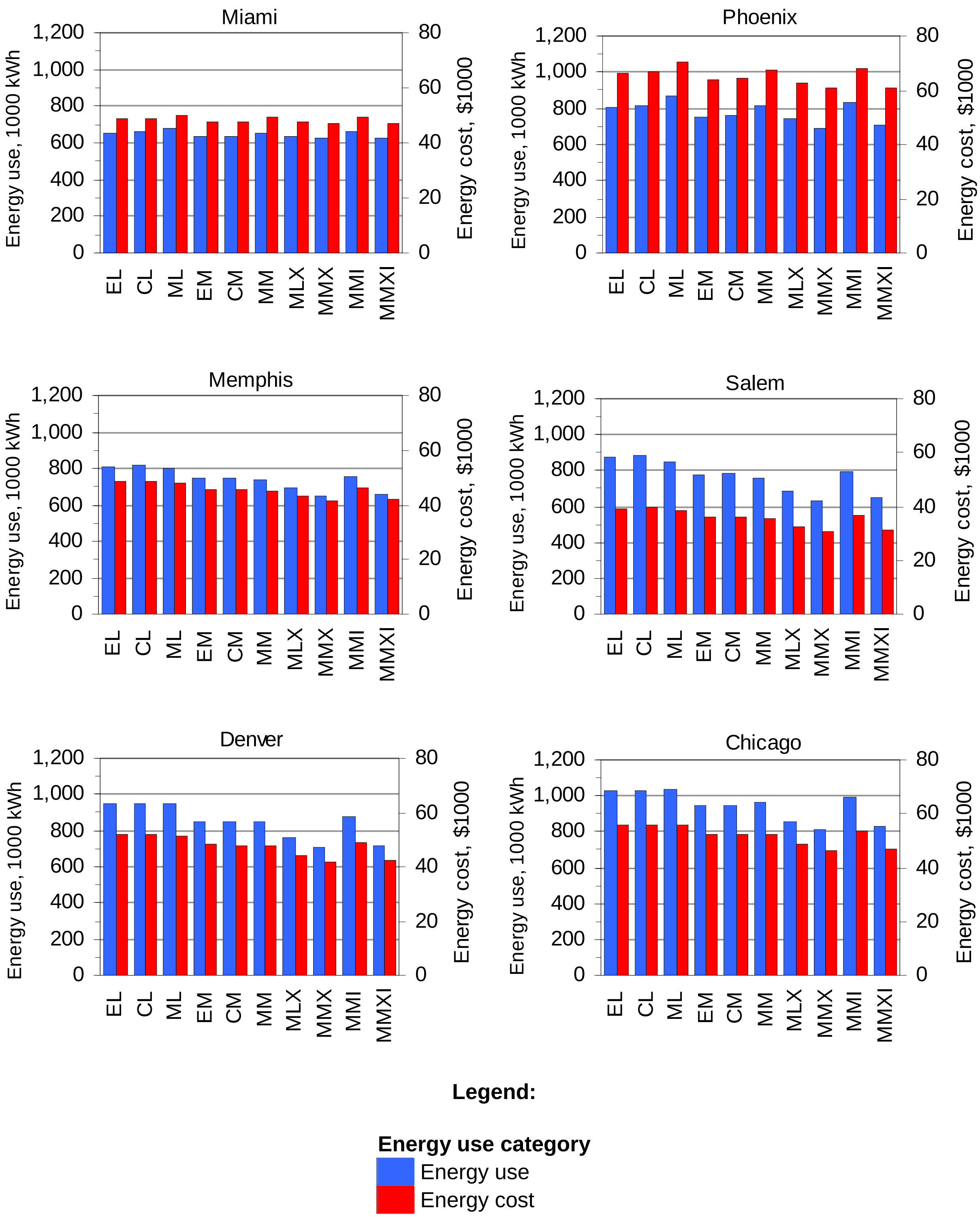

Figure A6. Yearly energy use and cost in six cities from VisualDOE. The abbreviated scenario names EL through MMXI are described in the text.

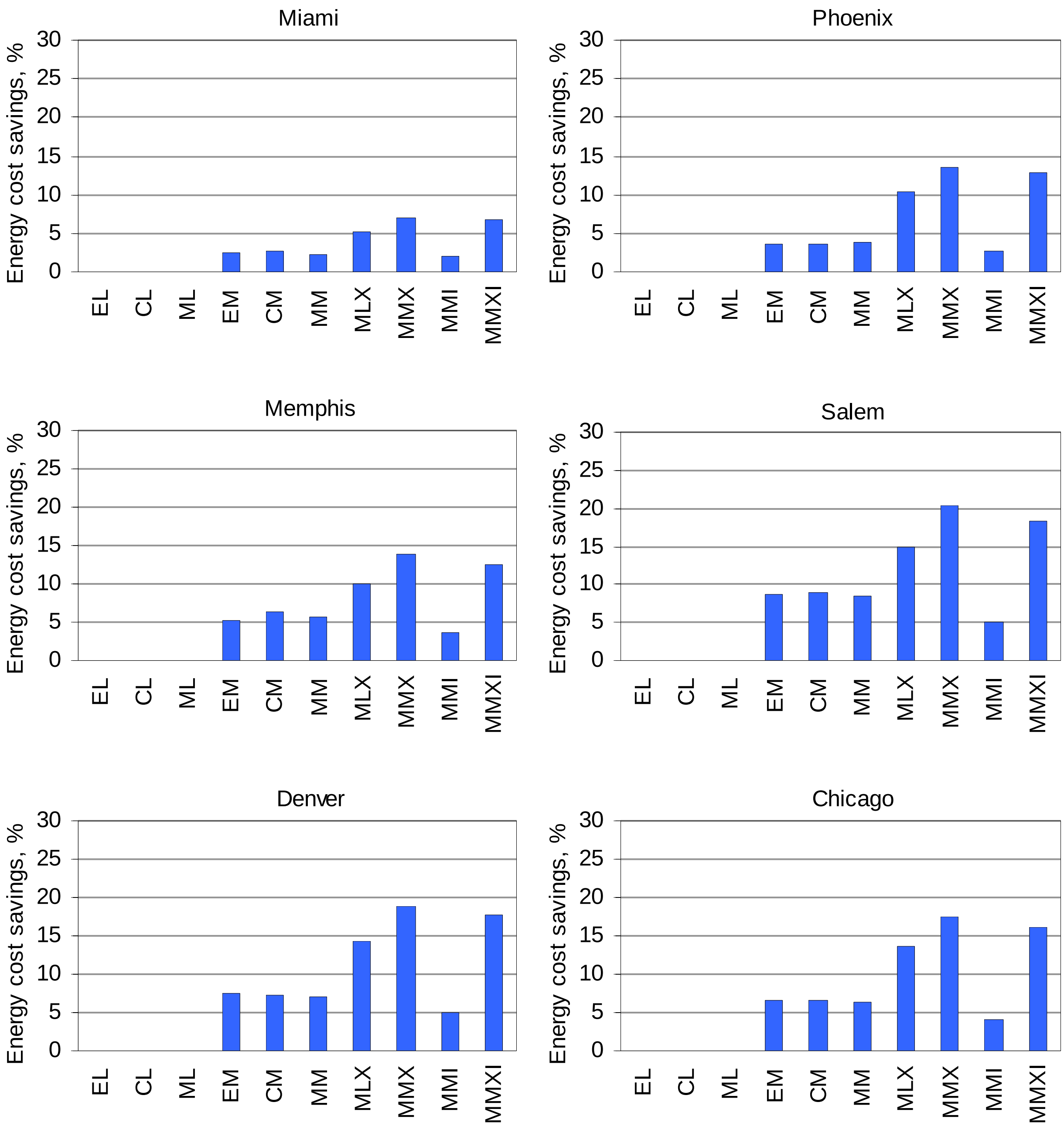

Figure A7. Energy cost savings (from VisualDOE) as a percent of base case: EM compared to EL, CM compared to CL, and MM to MMXI compared to ML. The abbreviated scenario names EL through MMXI are described in the text.

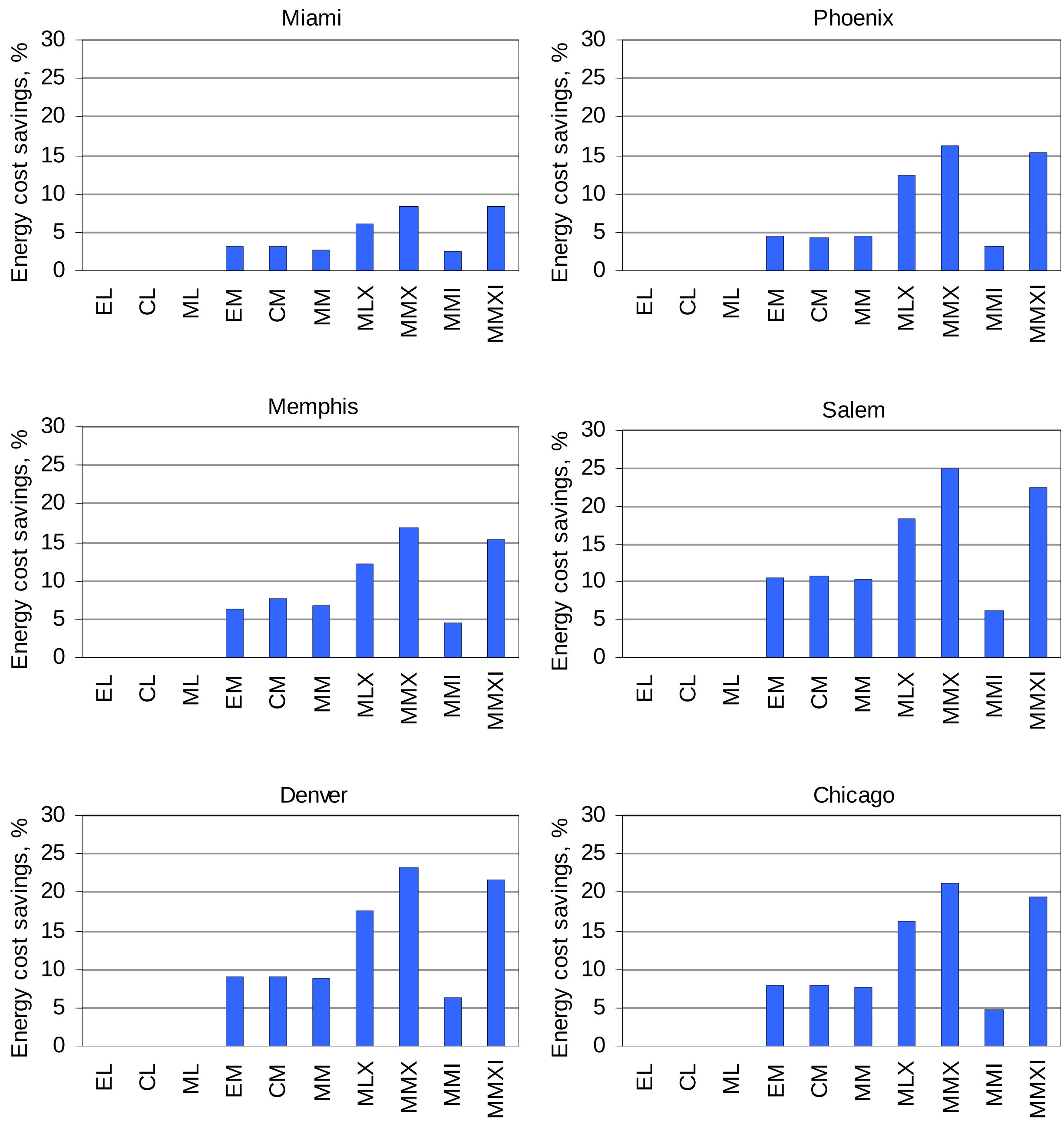

Figure A8. Energy cost savings (from VisualDOE) as a percent of base case excluding receptacle loads: EM compared to EL, CM compared to CL, and MM to MMXI compared to ML. The abbreviated scenario names EL through MMXI are described in the text.

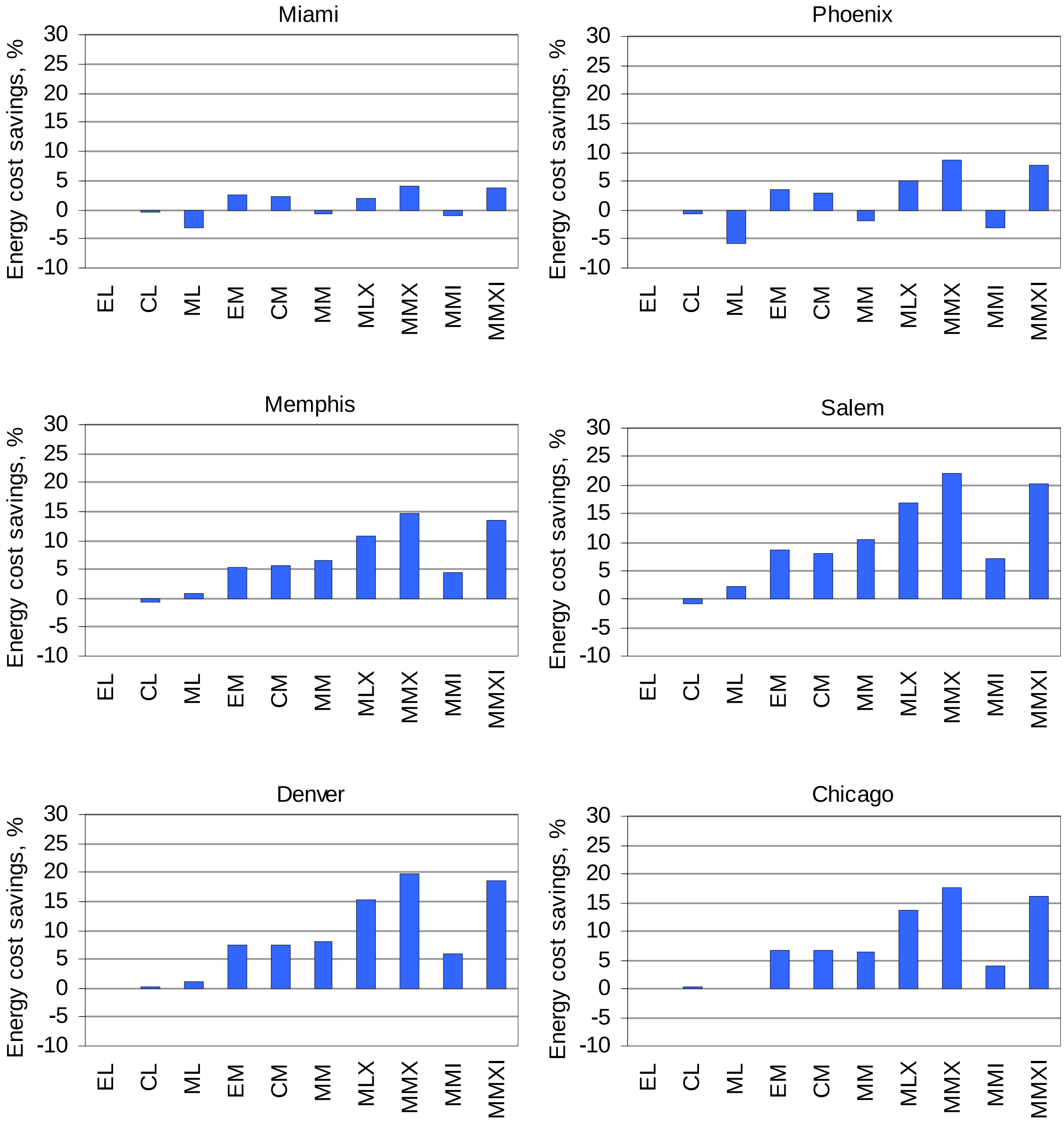

Figure A9. Energy cost savings (from VisualDOE) as a percent of baseline building (EL). The abbreviated scenario names EL through MMXI are described in the text.

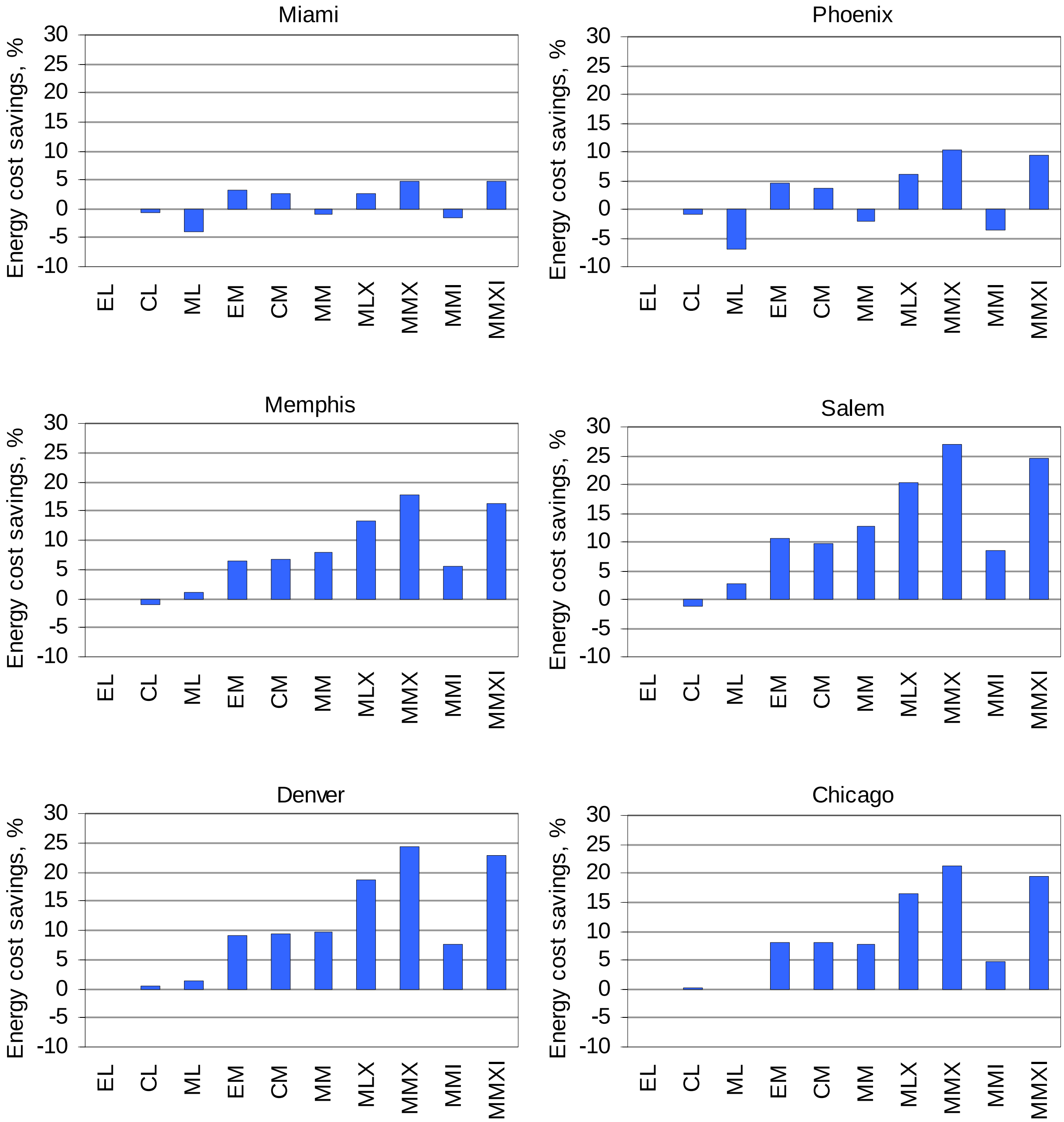

Figure A10. Energy cost savings (from VisualDOE) as a percent of baseline building (EL) excluding receptacle loads. The abbreviated scenario names EL through MMXI are described in the text.

APPENDIX B – VISUALDOE DATA TABLES

Table B1. VisualDOE Annual Electrical and Fuel End-Uses

City	Scenario	Electrical, kWh						Fuel, kWh		Total, kWh
		Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	
Miami	EL	202,836	117,026	308	261,596	1,850	37,279	21,717	12,485	655,096
	CL	202,836	117,026	324	263,452	1,977	37,536	22,889	12,485	658,525
	ML	202,836	117,026	351	277,954	1,923	39,836	24,882	12,485	677,293
	EM	202,836	117,026	157	253,021	1,080	35,909	11,049	12,485	633,563
	CM	202,836	117,026	162	254,521	1,128	36,106	11,400	12,485	635,664
	MM	202,836	117,026	215	269,415	1,392	38,687	15,152	12,485	657,208
	MLX	202,836	117,026	194	254,229	1,360	36,250	13,598	12,485	637,978
	MMX	202,836	117,026	97	247,160	834	35,057	6,799	12,485	622,294
	MMI	202,836	117,054	245	270,291	1,513	38,626	17,203	12,485	660,253
	MMXI	202,836	117,054	111	247,522	957	34,928	7,766	12,485	623,659
Phoenix	EL	202,836	117,026	1,992	279,010	6,094	44,456	142,169	13,833	807,416
	CL	202,836	117,026	2,057	281,515	6,276	44,848	146,946	13,833	815,337
	ML	202,836	117,026	2,363	308,055	6,365	47,941	169,395	13,833	867,814
	EM	202,836	117,026	1,388	269,712	4,993	42,274	98,032	13,833	750,094
	CM	202,836	117,026	1,424	273,406	5,064	42,771	100,641	13,833	757,001
	MM	202,836	117,026	1,833	293,520	5,647	46,270	130,153	13,833	811,118
	MLX	202,836	117,026	1,390	259,990	5,194	41,372	98,150	13,833	739,790
	MMX	202,836	117,026	958	247,899	4,289	39,644	67,289	13,833	693,774
	MMI	202,836	117,054	2,041	297,725	5,870	46,308	144,748	13,833	830,415
	MMXI	202,836	117,054	1,093	250,308	4,718	39,580	76,726	13,833	706,148
Memphis	EL	202,836	117,026	3,294	188,090	7,442	33,274	240,787	17,614	810,363
	CL	202,836	117,026	3,356	190,477	7,668	33,729	245,330	17,614	818,035
	ML	202,836	117,026	3,140	188,640	7,160	31,966	228,976	17,614	797,358
	EM	202,836	117,026	2,682	176,682	6,103	31,030	193,896	17,614	747,868
	CM	202,836	117,026	2,708	172,837	6,178	31,503	195,771	17,614	746,473
	MM	202,836	117,026	2,607	172,058	5,986	30,074	187,888	17,614	736,088
	MLX	202,836	117,026	2,180	159,655	5,914	26,739	157,027	17,614	688,991
	MMX	202,836	117,026	1,804	148,835	5,050	25,231	128,365	17,614	646,761
	MMI	202,836	117,054	2,831	177,644	6,590	30,011	203,714	17,614	758,293
	MMXI	202,836	117,054	1,939	153,244	5,485	25,149	137,861	17,614	661,181
Salem	EL	202,836	117,026	5,139	116,279	11,324	31,944	370,794	21,248	876,589
	CL	202,836	117,026	5,226	118,852	11,420	32,628	377,095	21,248	886,330
	ML	202,836	117,026	4,857	114,111	10,921	29,926	350,015	21,248	850,939
	EM	202,836	117,026	4,090	100,783	9,540	28,580	291,840	21,248	775,943
	CM	202,836	117,026	4,134	102,680	9,645	29,180	295,035	21,248	781,783
	MM	202,836	117,026	3,968	95,863	9,230	26,993	282,784	21,248	759,948
	MLX	202,836	117,026	3,145	86,201	8,977	22,072	223,555	21,248	685,059
	MMX	202,836	117,026	2,596	72,936	7,556	20,093	183,111	21,248	627,401
	MMI	202,836	117,054	4,373	103,421	9,946	26,976	311,095	21,248	796,949
	MMXI	202,836	117,054	2,810	78,578	8,248	20,027	198,116	21,248	648,917
Denver	EL	202,836	117,026	5,498	151,290	11,137	33,542	406,197	22,098	949,623
	CL	202,836	117,026	5,460	150,206	11,048	33,328	403,354	22,098	945,355
	ML	202,836	117,026	5,531	145,669	10,944	32,354	408,453	22,098	944,911
	EM	202,836	117,026	4,610	127,593	9,463	30,266	336,153	22,098	850,044
	CM	202,836	117,026	4,594	127,050	9,422	30,128	334,980	22,098	848,134
	MM	202,836	117,026	4,718	122,902	9,406	29,296	344,505	22,098	852,787
	MLX	202,836	117,026	3,906	99,605	9,132	23,801	282,960	22,098	761,364
	MMX	202,836	117,026	3,398	84,442	7,975	21,778	243,777	22,098	703,329
	MMI	202,836	117,054	4,975	129,909	9,875	29,294	362,324	22,098	878,364
	MMXI	202,836	117,054	3,545	88,964	8,365	21,739	254,034	22,098	718,635
Chicago	EL	202,836	117,026	6,500	150,489	10,531	30,633	486,674	22,215	1,026,904
	CL	202,836	117,026	6,475	149,938	10,452	30,525	485,062	22,215	1,024,529
	ML	202,836	117,026	6,667	146,302	10,461	29,826	500,184	22,215	1,035,517
	EM	202,836	117,026	5,880	126,281	8,875	28,104	437,233	22,215	948,450
	CM	202,836	117,026	5,870	125,966	8,843	28,035	436,441	22,215	947,232
	MM	202,836	117,026	6,102	122,715	8,873	27,467	455,169	22,215	962,402
	MLX	202,836	117,026	4,979	108,728	8,957	22,403	367,335	22,215	854,479
	MMX	202,836	117,026	4,713	92,627	7,927	20,748	342,864	22,215	810,956
	MMI	202,836	117,054	6,338	132,252	9,331	27,441	471,551	22,215	989,018
	MMXI	202,836	117,054	4,831	99,044	8,237	20,719	350,894	22,215	825,830

Table B2. VisualDOE Annual Electrical and Fuel Cost

City	Scenario	Electrical, $						Fuel, $		Total, $
		Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	
Miami	EL	15,497	8,941	24	19,986	141	2,848	808	465	48,710
	CL	15,497	8,941	25	20,128	151	2,868	852	465	48,926
	ML	15,497	8,941	27	21,236	147	3,043	926	465	50,281
	EM	15,497	8,941	12	19,331	83	2,743	411	465	47,482
	CM	15,497	8,941	12	19,445	86	2,758	424	465	47,629
	MM	15,497	8,941	16	20,583	106	2,956	564	465	49,128
	MLX	15,497	8,941	15	19,423	104	2,770	506	465	47,720
	MMX	15,497	8,941	7	18,883	64	2,678	253	465	46,788
	MMI	15,497	8,943	19	20,650	116	2,951	640	465	49,280
	MMXI	15,497	8,943	8	18,911	73	2,668	289	465	46,854
Phoenix	EL	19,371	11,176	190	26,645	582	4,246	3,760	366	66,335
	CL	19,371	11,176	196	26,885	599	4,283	3,886	366	66,762
	ML	19,371	11,176	226	29,419	608	4,578	4,480	366	70,223
	EM	19,371	11,176	133	25,757	477	4,037	2,592	366	63,909
	CM	19,371	11,176	136	26,110	484	4,085	2,661	366	64,388
	MM	19,371	11,176	175	28,031	539	4,419	3,442	366	67,519
	MLX	19,371	11,176	133	24,829	496	3,951	2,595	366	62,917
	MMX	19,371	11,176	91	23,674	410	3,786	1,779	366	60,653
	MMI	19,371	11,179	195	28,433	561	4,422	3,828	366	68,354
	MMXI	19,371	11,179	104	23,904	451	3,780	2,029	366	61,183
Memphis	EL	14,990	8,648	243	13,900	550	2,459	7,090	519	48,399
	CL	14,990	8,648	248	14,076	567	2,493	7,224	519	48,764
	ML	14,990	8,648	232	13,940	529	2,362	6,743	519	47,963
	EM	14,990	8,648	198	13,057	451	2,293	5,710	519	45,865
	CM	14,990	8,648	200	12,773	457	2,328	5,765	519	45,679
	MM	14,990	8,648	193	12,715	442	2,222	5,533	519	45,262
	MLX	14,990	8,648	161	11,799	437	1,976	4,624	519	43,153
	MMX	14,990	8,648	133	10,999	373	1,865	3,780	519	41,306
	MMI	14,990	8,650	209	13,128	487	2,218	5,999	519	46,199
	MMXI	14,990	8,650	143	11,325	405	1,859	4,060	519	41,950
Salem	EL	12,028	6,940	305	6,895	672	1,894	9,995	573	39,302
	CL	12,028	6,940	310	7,048	677	1,935	10,165	573	39,675
	ML	12,028	6,940	288	6,767	648	1,775	9,435	573	38,453
	EM	12,028	6,940	243	5,976	566	1,695	7,867	573	35,887
	CM	12,028	6,940	245	6,089	572	1,730	7,953	573	36,130
	MM	12,028	6,940	235	5,685	547	1,601	7,623	573	35,231
	MLX	12,028	6,940	186	5,112	532	1,309	6,026	573	32,706
	MMX	12,028	6,940	154	4,325	448	1,192	4,936	573	30,595
	MMI	12,028	6,941	259	6,133	590	1,600	8,386	573	36,510
	MMXI	12,028	6,941	167	4,660	489	1,188	5,340	573	31,386
Denver	EL	16,896	9,748	458	12,602	928	2,794	8,080	440	51,947
	CL	16,896	9,748	455	12,512	920	2,776	8,024	440	51,771
	ML	16,896	9,748	461	12,134	912	2,695	8,125	440	51,411
	EM	16,896	9,748	384	10,628	788	2,521	6,687	440	48,093
	CM	16,896	9,748	383	10,583	785	2,510	6,664	440	48,008
	MM	16,896	9,748	393	10,238	784	2,440	6,853	440	47,792
	MLX	16,896	9,748	325	8,297	761	1,983	5,629	440	44,079
	MMX	16,896	9,748	283	7,034	664	1,814	4,849	440	41,729
	MMI	16,896	9,751	414	10,821	823	2,440	7,208	440	48,793
	MMXI	16,896	9,751	295	7,411	697	1,811	5,053	440	42,354
Chicago	EL	16,369	9,444	525	12,144	850	2,472	13,667	624	56,094
	CL	16,369	9,444	523	12,100	843	2,463	13,621	624	55,988
	ML	16,369	9,444	538	11,807	844	2,407	14,046	624	56,079
	EM	16,369	9,444	475	10,191	716	2,268	12,278	624	52,365
	CM	16,369	9,444	474	10,165	714	2,262	12,256	624	52,308
	MM	16,369	9,444	492	9,903	716	2,217	12,782	624	52,547
	MLX	16,369	9,444	402	8,774	723	1,808	10,315	624	48,459
	MMX	16,369	9,444	380	7,475	640	1,674	9,628	624	46,234
	MMI	16,369	9,446	511	10,673	753	2,214	13,242	624	53,833
	MMXI	16,369	9,446	390	7,993	665	1,672	9,854	624	47,012

Table B3. VisualDOE Percent Cost Savings

City	Scenario	Cost savings: Compared to similar building, %	Cost savings: Compared to similar building, excluding receptacle loads, %	Cost savings: Compared to EL, %	Cost savings: Compare to EL excluding receptacle loads, %
Miami	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.4	-0.5
	ML	0.0	0.0	-3.2	-4.0
	EM	2.5	3.1	2.5	3.1
	CM	2.6	3.2	2.2	2.7
	MM	2.3	2.8	-0.9	-1.1
	MLX	5.1	6.2	2.0	2.5
	MMX	6.9	8.5	3.9	4.8
	MMI	2.0	2.4	-1.2	-1.4
	MMXI	6.8	8.3	3.8	4.7
Phoenix	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.6	-0.8
	ML	0.0	0.0	-5.9	-7.0
	EM	3.7	4.4	3.7	4.4
	CM	3.6	4.3	2.9	3.5
	MM	3.9	4.6	-1.8	-2.1
	MLX	10.4	12.4	5.2	6.2
	MMX	13.6	16.2	8.6	10.3
	MMI	2.7	3.2	-3.0	-3.7
	MMXI	12.9	15.3	7.8	9.3
Memphis	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.8	-0.9
	ML	0.0	0.0	0.9	1.1
	EM	5.2	6.4	5.2	6.4
	CM	6.3	7.7	5.6	6.8
	MM	5.6	6.9	6.5	7.9
	MLX	10.0	12.2	10.8	13.2
	MMX	13.9	16.9	14.7	17.8
	MMI	3.7	4.5	4.5	5.5
	MMXI	12.5	15.3	13.3	16.2
Salem	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-1.0	-1.2
	ML	0.0	0.0	2.2	2.6
	EM	8.7	10.6	8.7	10.6
	CM	8.9	10.8	8.1	9.8
	MM	8.4	10.2	10.4	12.6
	MLX	14.9	18.2	16.8	20.4
	MMX	20.4	24.9	22.2	26.9
	MMI	5.1	6.2	7.1	8.6
	MMXI	18.4	22.4	20.1	24.5
Denver	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	0.3	0.4
	ML	0.0	0.0	1.0	1.3
	EM	7.4	9.1	7.4	9.1
	CM	7.3	9.0	7.6	9.3
	MM	7.0	8.7	8.0	9.8
	MLX	14.3	17.6	15.1	18.6
	MMX	18.8	23.2	19.7	24.2
	MMI	5.1	6.3	6.1	7.5
	MMXI	17.6	21.7	18.5	22.7
Chicago	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	0.2	0.2
	ML	0.0	0.0	0.0	0.0
	EM	6.6	8.0	6.6	8.0
	CM	6.6	7.9	6.7	8.1
	MM	6.3	7.6	6.3	7.6
	MLX	13.6	16.3	13.6	16.4
	MMX	17.6	21.1	17.6	21.1
	MMI	4.0	4.8	4.0	4.9
	MMXI	16.2	19.4	16.2	19.5

APPENDIX C – ENERGY-10 DATA PLOTS

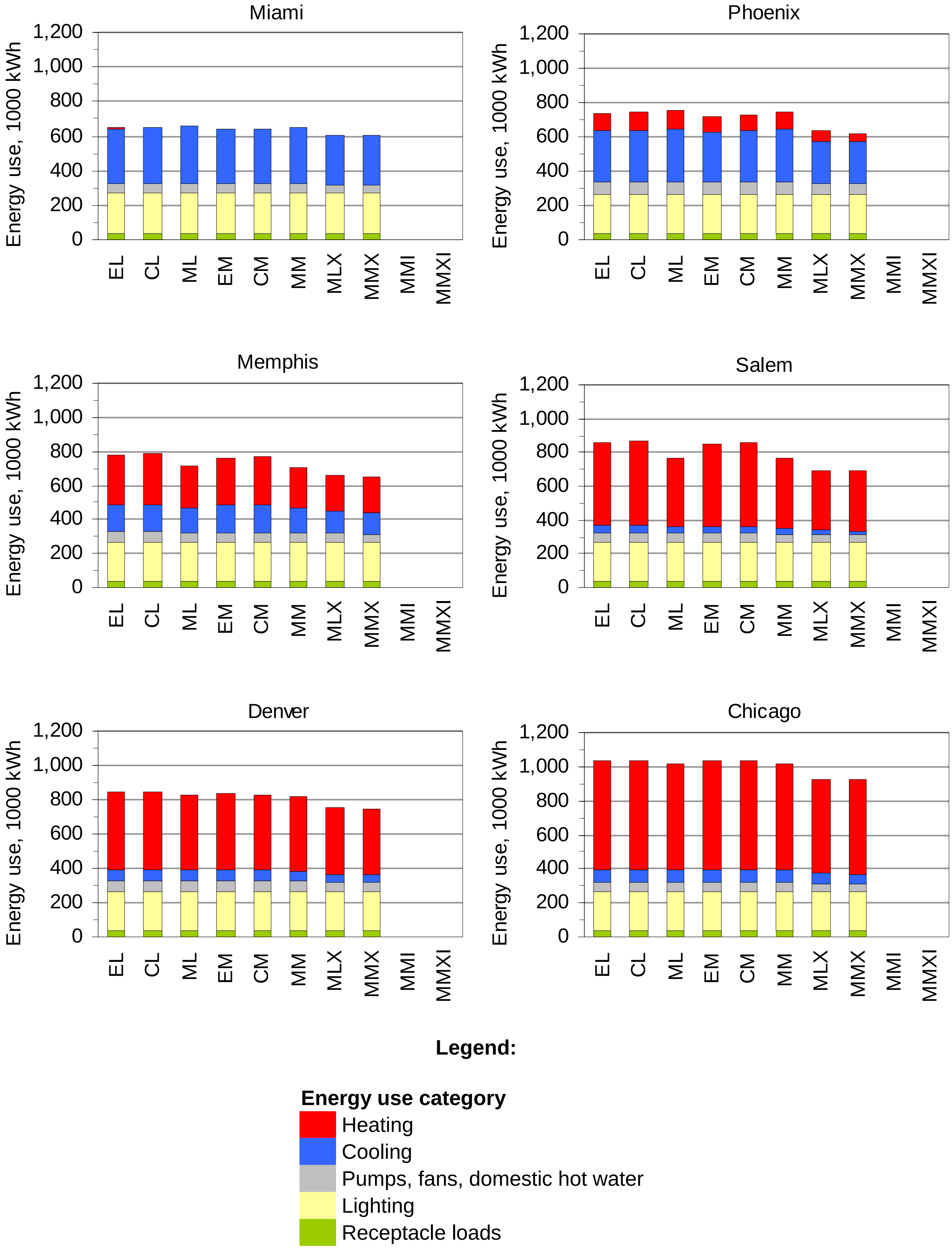

Figure C1. Yearly building energy use by category in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

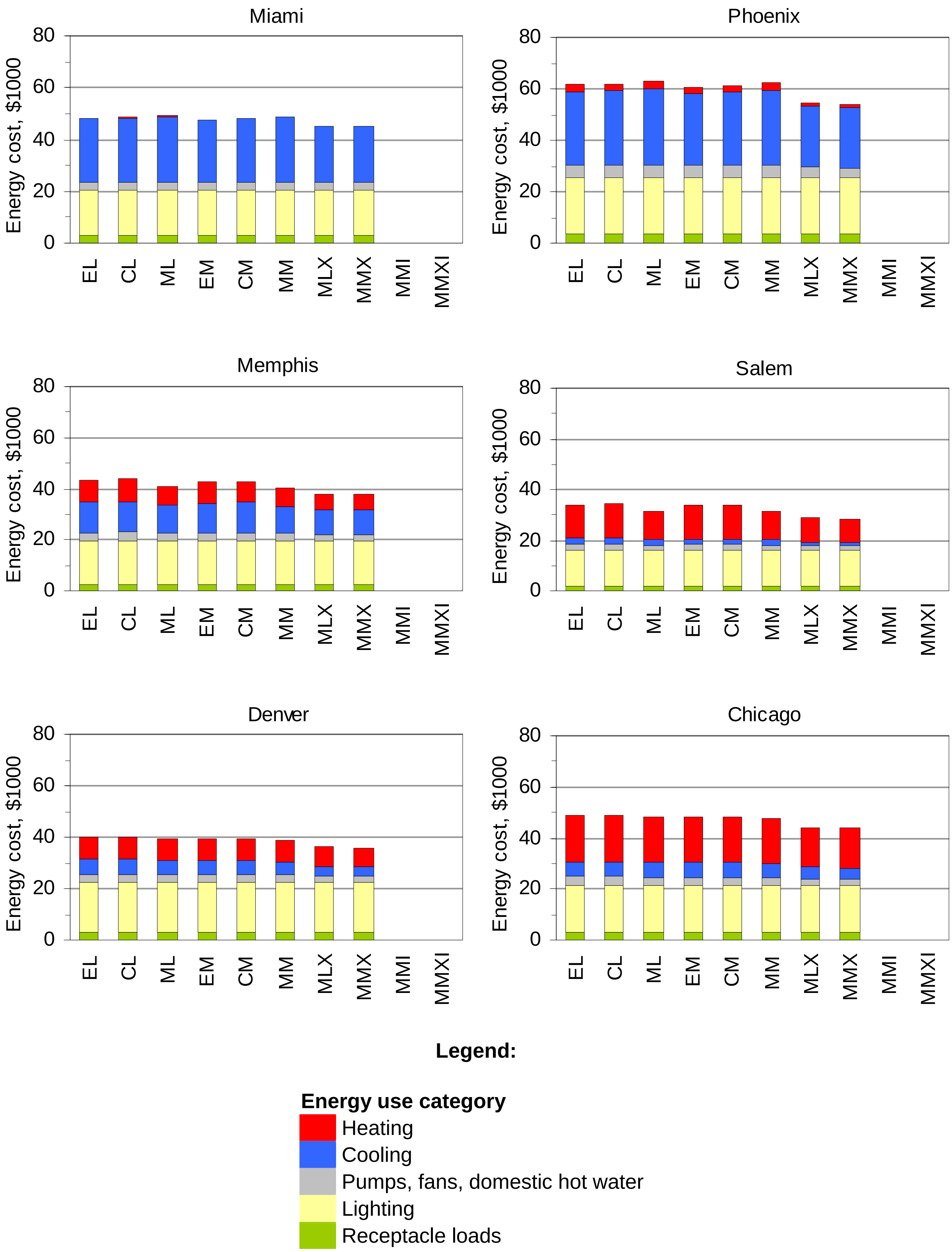

Figure C2. Yearly building energy cost by category in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

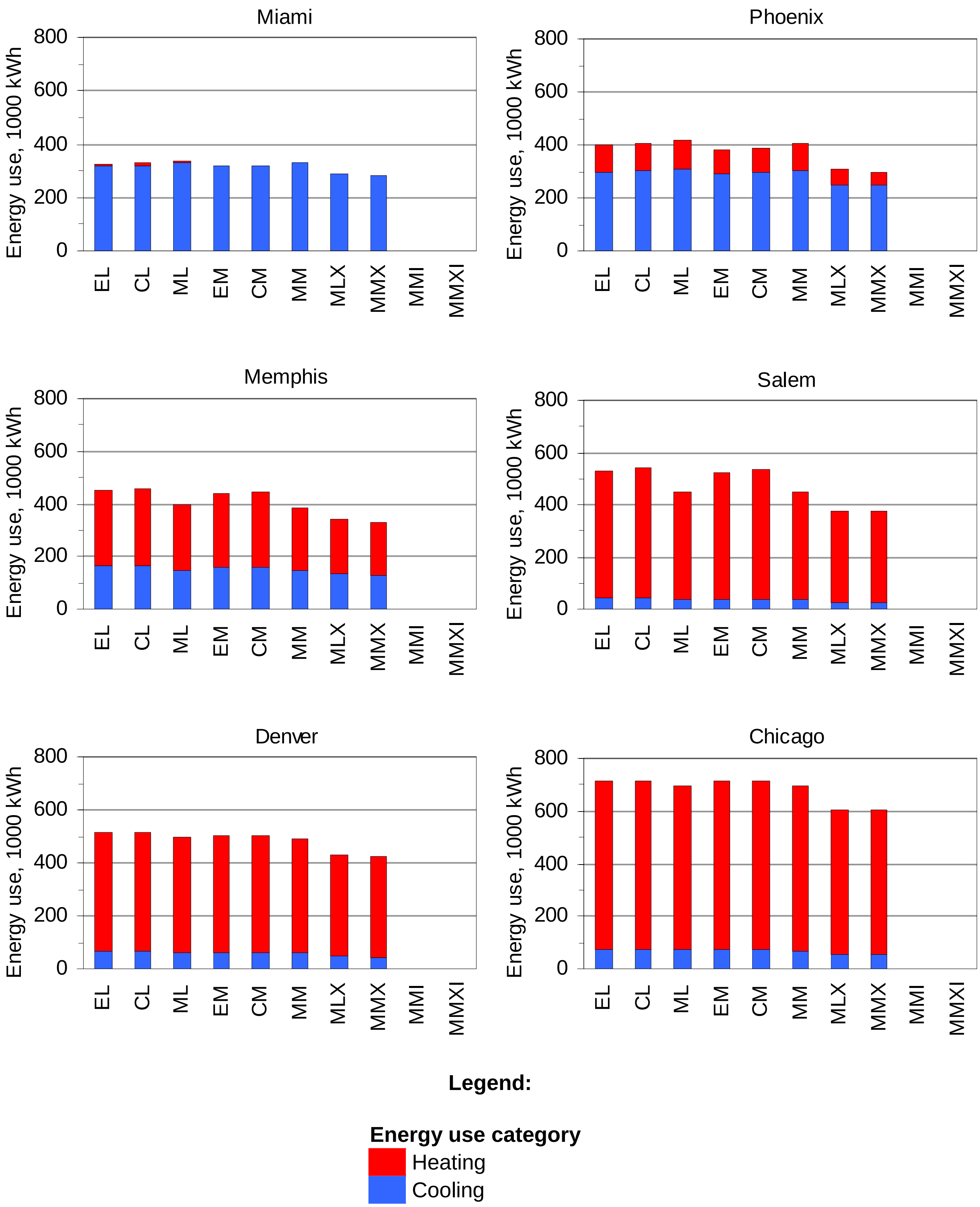

Figure C3. Yearly heating and cooling energy in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

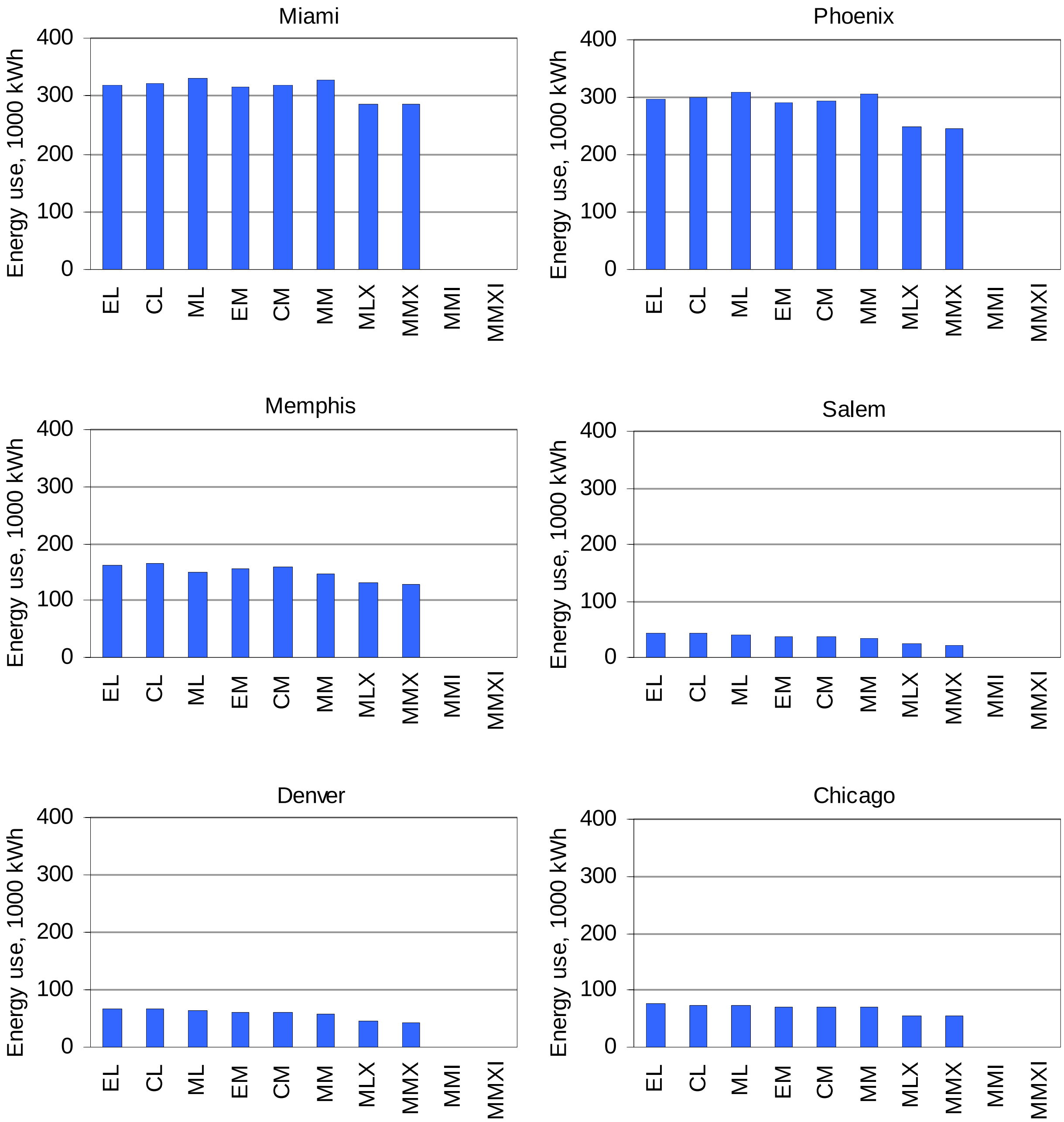

Figure C4. Yearly cooling energy in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

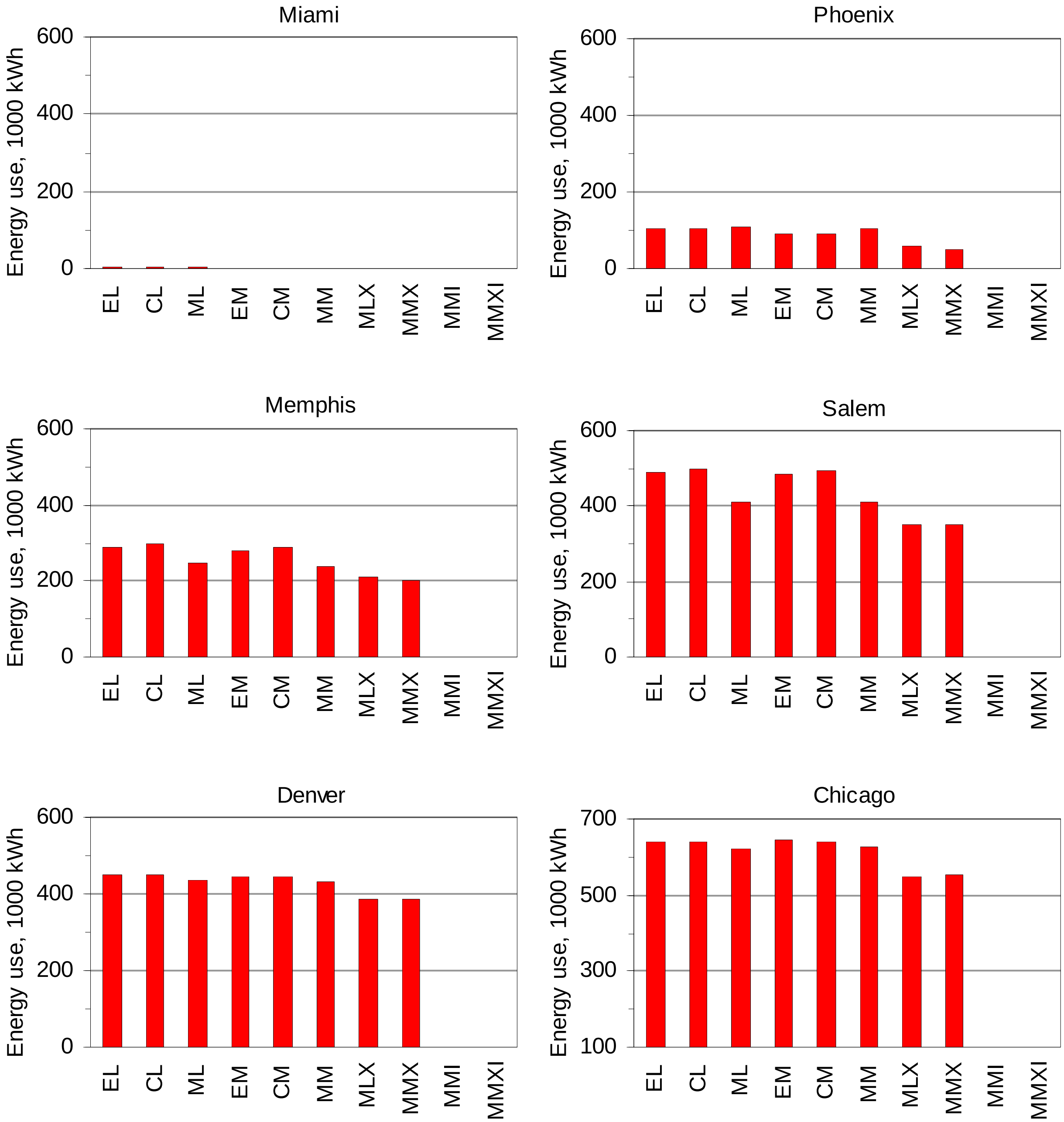

Figure C5. Yearly heating energy in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

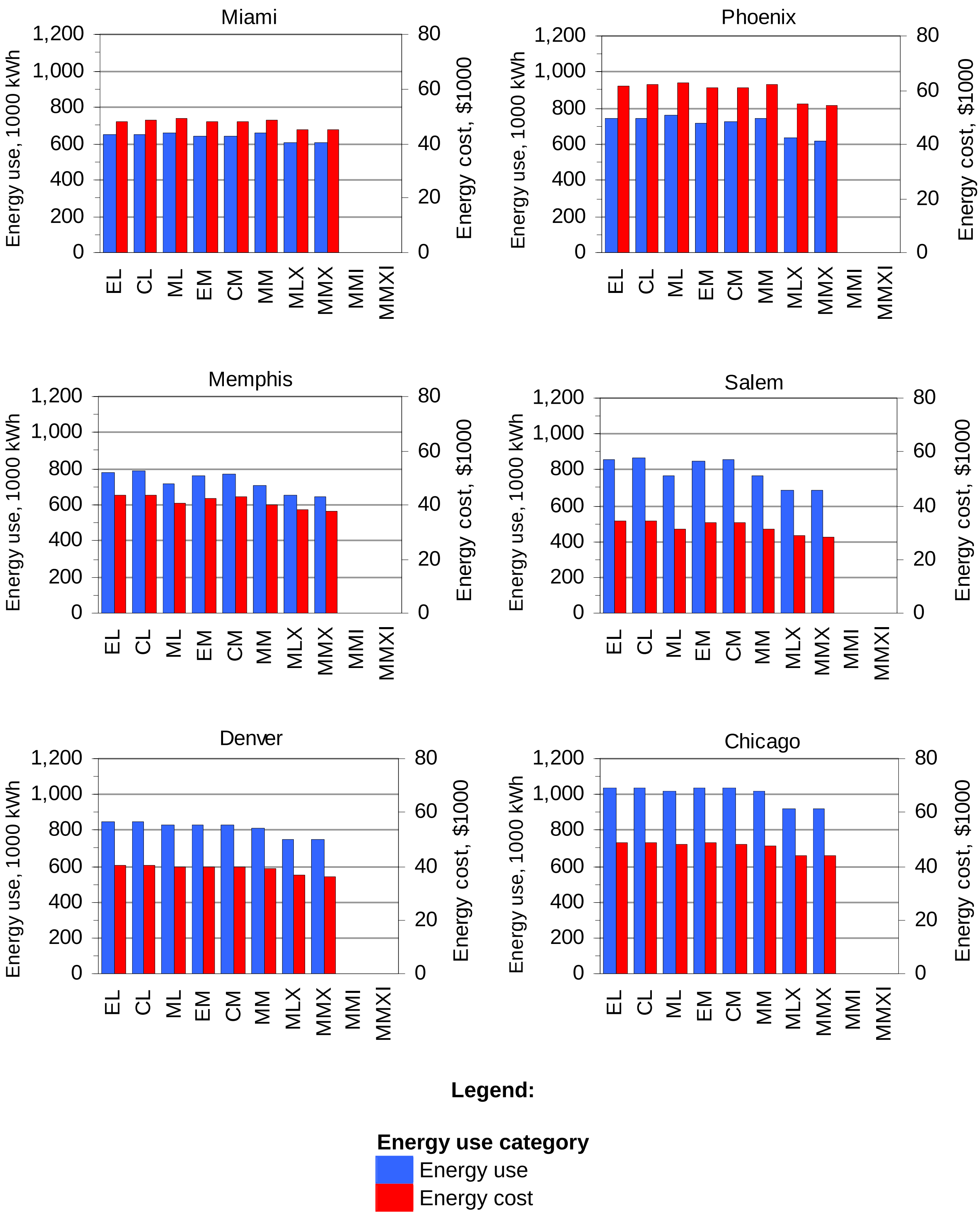

Figure C6. Yearly energy use and cost in six cities from Energy-10. The abbreviated scenario names EL through MMXI are described in the text.

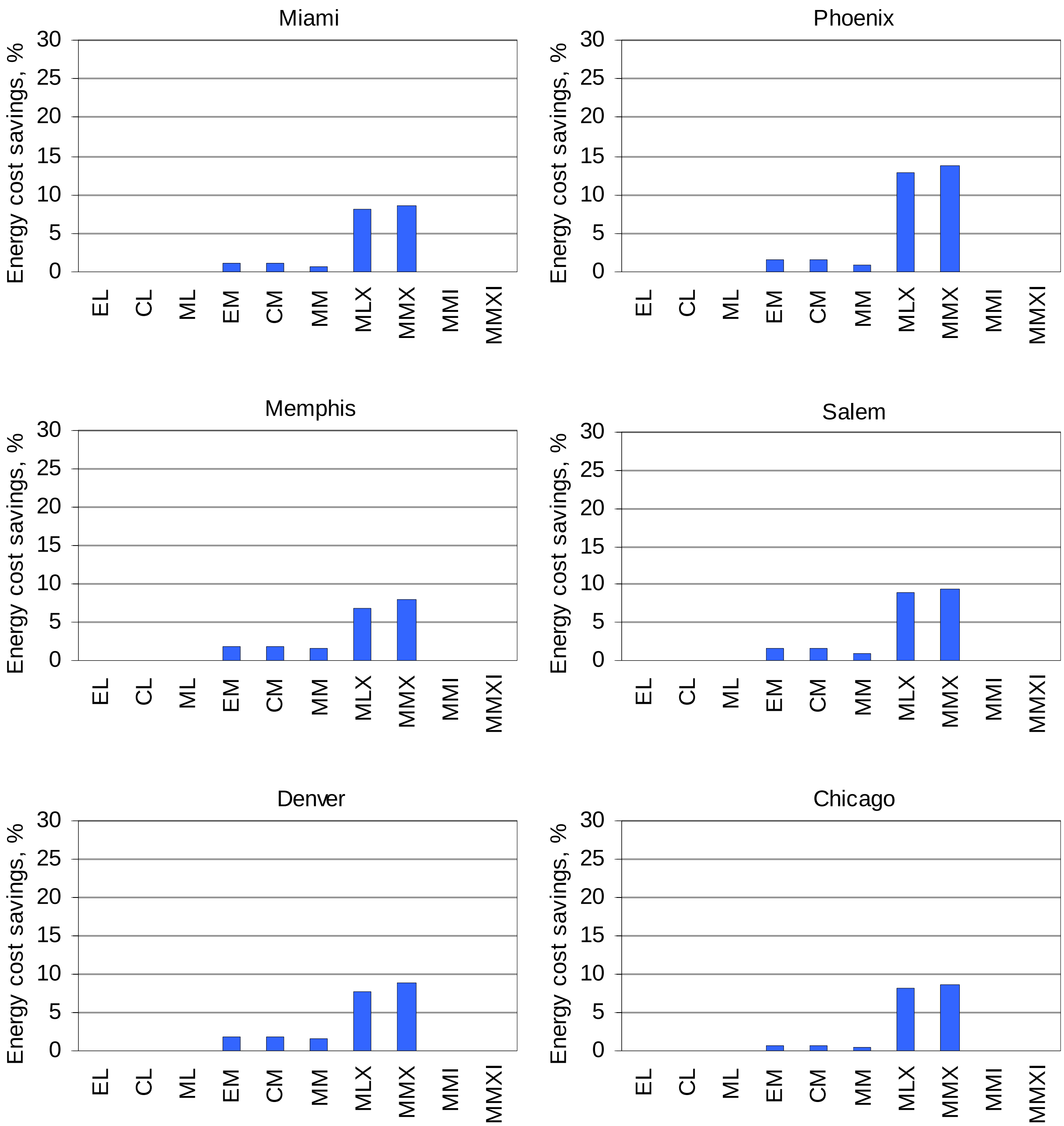

Figure C7. Energy cost savings (from Energy-10) as a percent of base case: EM compared to EL, CM compared to CL, and MM to MMXI compared to ML. The abbreviated scenario names EL through MMXI are described in the text.

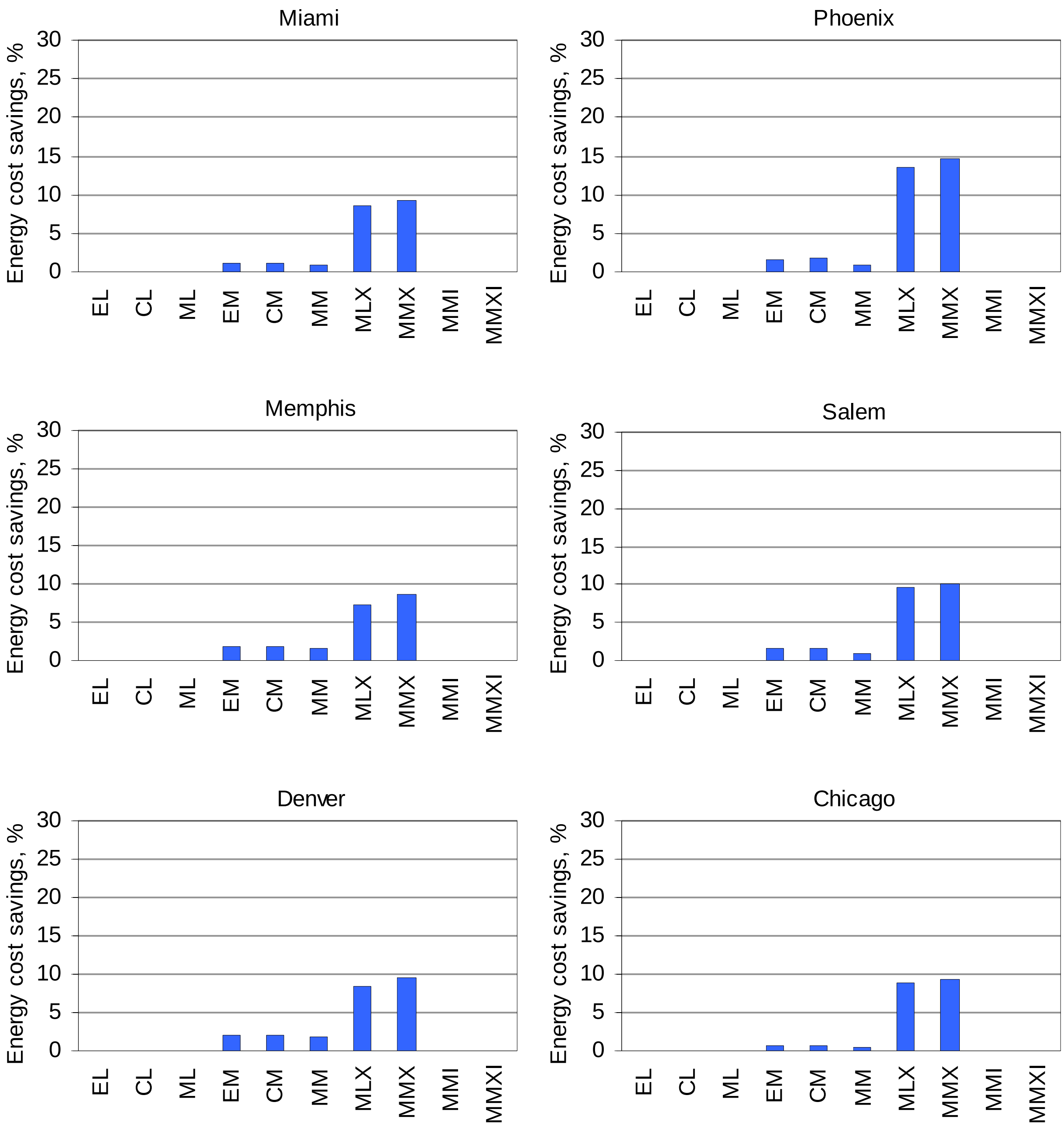

Figure C8. Energy cost savings (from Energy-10) as a percent of base case excluding receptacle loads: EM compared to EL, CM compared to CL, and MM to MMXI compared to ML. The abbreviated scenario names EL through MMXI are described in the text.

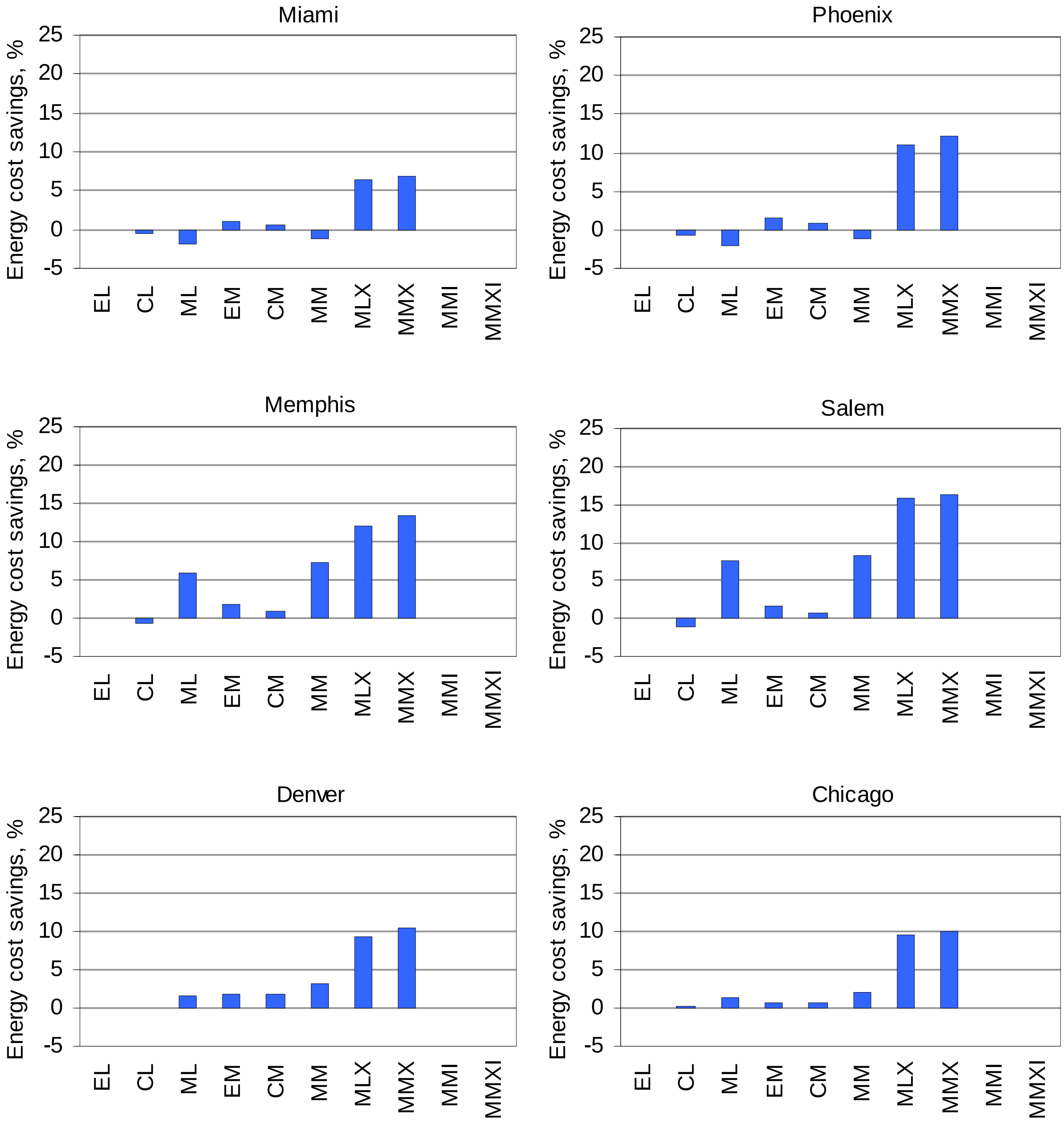

Figure C9. Energy cost savings (from Energy-10) as a percent of baseline building (EL). The abbreviated scenario names EL through MMXI are described in the text.

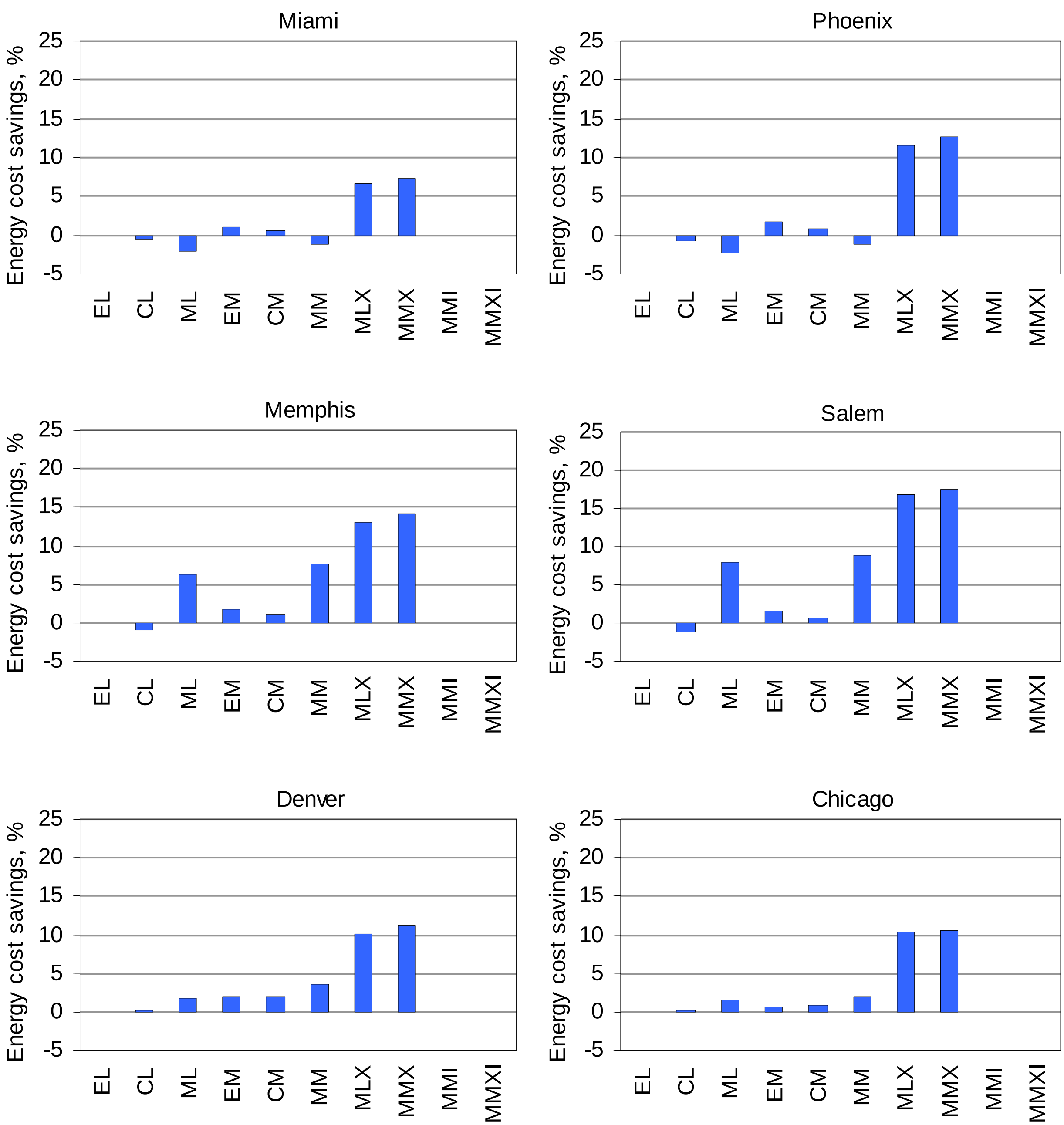

Figure C10. Energy cost savings (from Energy-10) as a percent of baseline building (EL) excluding receptacle loads. The abbreviated scenario names EL through MMXI are described in the text.

APPENDIX D – ENERGY-10 DATA TABLES

Table D1. Energy-10 Annual Electrical ad Fuel End-Uses

City	Scenario	Electrical, kWh						Fuel, kWh		Total, kWh
		Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	
Miami	EL	229,972	36,217	-	319,127	-	31,001	6,379	26,019	648,715
	CL	229,972	36,217	-	321,603	-	31,900	6,644	26,019	652,355
	ML	229,972	36,217	-	330,602	-	31,785	5,748	26,019	660,343
	EM	229,972	36,217	-	315,869	-	29,724	1,849	26,019	639,650
	CM	229,972	36,217	-	317,860	-	30,553	1,931	26,019	642,552
	MM	229,972	36,217	-	328,965	-	30,508	1,862	26,019	653,544
	MLX	229,972	36,217	-	286,233	-	25,868	1,874	26,019	606,184
	MMX	229,972	36,217	-	284,720	-	24,635	254	26,019	601,818
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Phoenix	EL	229,972	36,217	-	297,563	-	44,982	104,416	26,019	739,169
	CL	229,972	36,217	-	301,141	-	46,005	105,902	26,019	745,257
	ML	229,972	36,217	-	308,878	-	45,475	110,678	26,019	757,239
	EM	229,972	36,217	-	291,888	-	43,995	91,405	26,019	719,496
	CM	229,972	36,217	-	295,339	-	44,766	92,857	26,019	725,170
	MM	229,972	36,217	-	305,891	-	44,490	102,728	26,019	745,317
	MLX	229,972	36,217	-	249,147	-	35,586	57,850	26,019	634,791
	MMX	229,972	36,217	-	245,732	-	34,368	49,130	26,019	621,439
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Memphis	EL	229,972	36,217	-	162,223	-	33,244	289,905	26,019	777,580
	CL	229,972	36,217	-	164,035	-	33,808	295,472	26,019	785,523
	ML	229,972	36,217	-	149,587	-	29,172	246,014	26,019	716,981
	EM	229,972	36,217	-	157,034	-	32,028	280,834	26,019	762,105
	CM	229,972	36,217	-	158,420	-	32,568	286,509	26,019	769,705
	MM	229,972	36,217	-	145,350	-	27,956	238,407	26,019	703,921
	MLX	229,972	36,217	-	131,609	-	24,812	208,889	26,019	657,518
	MMX	229,972	36,217	-	128,043	-	23,744	202,003	26,019	645,998
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Salem	EL	229,972	36,217	-	43,150	-	31,460	488,591	26,019	855,409
	CL	229,972	36,217	-	43,829	-	31,864	498,909	26,019	866,810
	ML	229,972	36,217	-	38,626	-	27,628	411,675	26,019	770,137
	EM	229,972	36,217	-	37,370	-	29,729	485,453	26,019	844,761
	CM	229,972	36,217	-	37,732	-	30,110	495,635	26,019	855,685
	MM	229,972	36,217	-	34,648	-	26,179	412,979	26,019	766,014
	MLX	229,972	36,217	-	25,619	-	21,057	350,836	26,019	689,720
	MMX	229,972	36,217	-	22,636	-	20,032	352,862	26,019	687,738
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Denver	EL	229,972	36,217	-	65,945	-	36,641	451,999	26,019	846,793
	CL	229,972	36,217	-	65,828	-	36,582	450,557	26,019	845,175
	ML	229,972	36,217	-	63,433	-	34,773	436,081	26,019	826,495
	EM	229,972	36,217	-	60,619	-	34,870	444,758	26,019	832,455
	CM	229,972	36,217	-	60,564	-	34,818	443,249	26,019	830,840
	MM	229,972	36,217	-	58,662	-	32,943	431,397	26,019	815,210
	MLX	229,972	36,217	-	46,151	-	26,911	387,013	26,019	752,283
	MMX	229,972	36,217	-	42,582	-	25,609	384,540	26,019	744,939
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Chicago	EL	229,972	36,217	-	74,834	-	31,339	639,867	26,019	1,038,248
	CL	229,972	36,217	-	74,759	-	31,293	638,193	26,019	1,036,453
	ML	229,972	36,217	-	73,045	-	29,970	623,765	26,019	1,018,988
	EM	229,972	36,217	-	71,182	-	29,874	643,687	26,019	1,036,951
	CM	229,972	36,217	-	71,140	-	29,829	641,930	26,019	1,035,107
	MM	229,972	36,217	-	69,938	-	28,342	628,735	26,019	1,019,223
	MLX	229,972	36,217	-	56,195	-	23,392	549,385	26,019	921,180
	MMX	229,972	36,217	-	53,741	-	22,192	553,378	26,019	921,519
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-

Table D2. Energy-10 Annual Electrical and Fuel Cost

City	Scenario	Electrical, $						Fuel, $		Total, $
		Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	
Miami	EL	17,570	2,767	-	24,381	-	2,368	237	969	48,293
	CL	17,570	2,767	-	24,570	-	2,437	247	969	48,560
	ML	17,570	2,767	-	25,258	-	2,428	214	969	49,206
	EM	17,570	2,767	-	24,132	-	2,271	69	969	47,778
	CM	17,570	2,767	-	24,285	-	2,334	72	969	47,996
	MM	17,570	2,767	-	25,133	-	2,331	69	969	48,839
	MLX	17,570	2,767	-	21,868	-	1,976	70	969	45,220
	MMX	17,570	2,767	-	21,753	-	1,882	9	969	44,950
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Phoenix	EL	21,962	3,459	-	28,417	-	4,296	2,761	688	61,583
	CL	21,962	3,459	-	28,759	-	4,393	2,800	688	62,062
	ML	21,962	3,459	-	29,498	-	4,343	2,927	688	62,877
	EM	21,962	3,459	-	27,875	-	4,202	2,417	688	60,603
	CM	21,962	3,459	-	28,205	-	4,275	2,456	688	61,045
	MM	21,962	3,459	-	29,213	-	4,249	2,717	688	62,287
	MLX	21,962	3,459	-	23,794	-	3,398	1,530	688	54,831
	MMX	21,962	3,459	-	23,467	-	3,282	1,299	688	54,158
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Memphis	EL	16,995	2,676	-	11,988	-	2,457	8,537	766	43,419
	CL	16,995	2,676	-	12,122	-	2,498	8,701	766	43,759
	ML	16,995	2,676	-	11,054	-	2,156	7,244	766	40,892
	EM	16,995	2,676	-	11,605	-	2,367	8,270	766	42,679
	CM	16,995	2,676	-	11,707	-	2,407	8,437	766	42,988
	MM	16,995	2,676	-	10,741	-	2,066	7,020	766	40,265
	MLX	16,995	2,676	-	9,726	-	1,834	6,151	766	38,148
	MMX	16,995	2,676	-	9,462	-	1,755	5,948	766	37,603
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Salem	EL	13,637	2,148	-	2,559	-	1,866	13,170	701	34,081
	CL	13,637	2,148	-	2,599	-	1,890	13,449	701	34,424
	ML	13,637	2,148	-	2,291	-	1,638	11,097	701	31,512
	EM	13,637	2,148	-	2,216	-	1,763	13,086	701	33,551
	CM	13,637	2,148	-	2,238	-	1,786	13,360	701	33,870
	MM	13,637	2,148	-	2,055	-	1,552	11,132	701	31,226
	MLX	13,637	2,148	-	1,519	-	1,249	9,457	701	28,711
	MMX	13,637	2,148	-	1,342	-	1,188	9,512	701	28,528
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Denver	EL	19,157	3,017	-	5,493	-	3,052	8,992	518	40,228
	CL	19,157	3,017	-	5,483	-	3,047	8,963	518	40,185
	ML	19,157	3,017	-	5,284	-	2,897	8,675	518	39,547
	EM	19,157	3,017	-	5,050	-	2,905	8,847	518	39,493
	CM	19,157	3,017	-	5,045	-	2,900	8,817	518	39,454
	MM	19,157	3,017	-	4,887	-	2,744	8,582	518	38,904
	MLX	19,157	3,017	-	3,844	-	2,242	7,699	518	36,476
	MMX	19,157	3,017	-	3,547	-	2,133	7,650	518	36,021
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
Chicago	EL	18,559	2,923	-	6,039	-	2,529	17,969	731	48,749
	CL	18,559	2,923	-	6,033	-	2,525	17,922	731	48,692
	ML	18,559	2,923	-	5,895	-	2,419	17,517	731	48,042
	EM	18,559	2,923	-	5,744	-	2,411	18,076	731	48,443
	CM	18,559	2,923	-	5,741	-	2,407	18,027	731	48,387
	MM	18,559	2,923	-	5,644	-	2,287	17,656	731	47,799
	MLX	18,559	2,923	-	4,535	-	1,888	15,428	731	44,063
	MMX	18,559	2,923	-	4,337	-	1,791	15,540	731	43,880
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-

Table D3. Energy-10 Percent Cost Savings

City	Scenario	Cost savings			
		Compared to similar building, %	Compared to similar building, excluding receptacle loads, %	Compared to EL, %	Compare to EL excluding receptacle loads, %
Miami	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.6	-0.6
	ML	0.0	0.0	-1.9	-2.0
	EM	1.1	1.1	1.1	1.1
	CM	1.2	1.2	0.6	0.7
	MM	0.7	0.8	-1.1	-1.2
	MLX	8.1	8.6	6.4	6.7
	MMX	8.6	9.2	6.9	7.3
	MMI	-	-	-	-
	MMXI	-	-	-	-
Phoenix	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.8	-0.8
	ML	0.0	0.0	-2.1	-2.2
	EM	1.6	1.7	1.6	1.7
	CM	1.6	1.7	0.9	0.9
	MM	0.9	1.0	-1.1	-1.2
	MLX	12.8	13.5	11.0	11.6
	MMX	13.9	14.7	12.1	12.8
	MMI	-	-	-	-
	MMXI	-	-	-	-
Memphis	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-0.8	-0.8
	ML	0.0	0.0	5.8	6.2
	EM	1.7	1.8	1.7	1.8
	CM	1.8	1.9	1.0	1.1
	MM	1.5	1.6	7.3	7.7
	MLX	6.7	7.2	12.1	12.9
	MMX	8.0	8.6	13.4	14.3
	MMI	-	-	-	-
	MMXI	-	-	-	-
Salem	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	-1.0	-1.1
	ML	0.0	0.0	7.5	8.0
	EM	1.6	1.7	1.6	1.7
	CM	1.6	1.7	0.6	0.7
	MM	0.9	1.0	8.4	8.9
	MLX	8.9	9.5	15.8	16.8
	MMX	9.5	10.2	16.3	17.4
	MMI	-	-	-	-
	MMXI	-	-	-	-
Denver	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	0.1	0.1
	ML	0.0	0.0	1.7	1.8
	EM	1.8	2.0	1.8	2.0
	CM	1.8	2.0	1.9	2.1
	MM	1.6	1.8	3.3	3.6
	MLX	7.8	8.4	9.3	10.1
	MMX	8.9	9.7	10.5	11.3
	MMI	-	-	-	-
	MMXI	-	-	-	-
Chicago	EL	0.0	0.0	0.0	0.0
	CL	0.0	0.0	0.1	0.1
	ML	0.0	0.0	1.5	1.5
	EM	0.6	0.7	0.6	0.7
	CM	0.6	0.7	0.7	0.8
	MM	0.5	0.5	1.9	2.1
	MLX	8.3	8.8	9.6	10.2
	MMX	8.7	9.2	10.0	10.6
	MMI	-	-	-	-
	MMXI	-	-	-	-