

**Research & Development Information** 

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# Modeling Energy Performance of Concrete Buildings for LEED-NC, v. 2.2 Energy and Atmosphere Credit 1

by Medgar L. Marceau and Martha G. VanGeem

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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 points for optimizing 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 rather than with concrete.

This report 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 version 2.2 points. The LEED Energy & Atmosphere (EA) Credit 1 on optimizing energy performance provides up to 10 points for energy savings beyond *ASHRAE/IESNA Standard 90.1-2004*. A total of 26 points are 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 several five-story prototype buildings with plan dimensions of 105 by 105 sq ft and a window-to-wall ratio is 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 cities representing the range of climates in the US: Miami, Phoenix, Memphis, Salem, Denver, and Chicago. These cities and the building floor plans 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 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls exceeding *ASHRAE 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2004*, reinforced concrete frame, and high internal load equipment placed near the central core of the building, and
- Precast concrete walls exceeding *ASHRAE 90.1-2004*, 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 *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 and Phoenix, reinforced concrete frame buildings with 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 3 points, that is, at least 17.5% energy cost savings. In the cool climate category (Salem), these buildings will most likely qualify for 4 points, that is, at least 21% energy cost savings. In the mild climate category (Memphis), these buildings will most likely qualify for 2 points, that is, at least 14% energy cost savings.

In Memphis, Salem, Denver, and Chicago, significant energy cost savings of 6 to 9% are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code. This energy cost savings is due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building.

According to the minimum code requirements, 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.

### REFERENCE

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

by Medgar L. Marceau and Martha G. VanGeem<sup>1</sup>

### 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 2.2 of LEED for new construction and major renovation (LEED-NC)<sup>2</sup>.

LEED-NC has gained widespread acceptance across the US. 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 90.1-2004*<sup>3</sup>. 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 effect.

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.

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<sup>2.</sup> Leadership in Energy and Environmental Design for New Construction and Major Renovations, Version 2.2, United States Green Building Council, October 2005, <u>www.usgbc.org</u>.

<sup>3.</sup> ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-rise Residential Buildings, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 2004, www.ashrae.org.

### 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 90.1-2004*. The modeling conforms to the requirements of Informative Appendix G: Performance Rating Method in *ASHRAE 90.1-2004*.

The building performance rating method in Informative Appendix G 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:

Percent improvement =  $100 \times (baseline building performance - proposed building performance).$ baseline building performance

Table 1 shows the number of points available under EA Credit 1 for achieving energy cost savings beyond *ASHRAE Standard* 90.1-2004.

Energy cost savings beyond	Deinte		
New buildings	Existing buildings	Points	
10.5%	3.5%	1	
14.0%	7.0%	2	
17.5%	10.5%	3	
21.0%	14.0%	4	
24.5%	17.5%	5	
28.0%	21.0%	6	
31.5%	24.5%	7	
35.0%	28.0%	8	
38.5%	31.5%	9	
42.0%	35.0%	10	

 Table 1. Points for Optimizing Energy Performance in LEED-NC v2.2 Energy and Atmosphere

 Credit 1

### **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.

All the buildings in this study are five-story commercial buildings with plan dimensions 105 by 105 ft. More detail is provided below in the section called Building Description. The baseline building generally conforms to the requirements of Informative Appendix G. It consists of an exterior insulation finishing system (EIFS) with steel stud walls<sup>4</sup>, 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 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls exceeding *ASHRAE 90.1-2004* with either structural steel or reinforced concrete frame,
- Precast concrete walls meeting *ASHRAE 90.1-2004*, reinforced concrete frame, and high internal load equipment placed near the central core of the building, and
- Precast concrete walls exceeding *ASHRAE 90.1-2004*, reinforced concrete frame, and high internal load equipment placed near the central core of the building.

The first letter of the abbreviated building designation 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 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 modestly exceed code. Buildings MMI and MMXI are like MM and MMX, respectively, except that high internal loads are assumed to be clustered near the central core of the building, where most of the interior concrete is located.

<sup>4.</sup> Steel studs are light gauge cold formed steel framing (American Iron and Steel Institute, www.steel.org).

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
СМ	curtain wall reinforced concr		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

Table 2. Buildings Modeled

\*See text for an explanation of the designations.

### **Energy Modeling**

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

VisualDOE<sup>5</sup> is a graphic interface to the DOE-2 program modules.<sup>6</sup> 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 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.<sup>7</sup> Energy use and demand in response to thermal mass effect are accurately predicted because the program performs hourly simulation.

<sup>5.</sup> VisualDOE, version 4.0.0, Architectural Energy Corporation, San Francisco, CA, 2004.

<sup>6.</sup> 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).

<sup>7.</sup> 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.

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 consistency check in the results. However, Energy-10 is not intended for buildings like the ones in this project, nor does it meet the requirements<sup>8</sup> 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 *ASHRAE 90.1-2004* and *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 5B, 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 105 by 105 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.

**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 35 by 35 ft. VisualDOE automatically includes partition walls between adjacent zones. The user can accept the default wall construction or input a new wall.

<sup>8.</sup> The requirements are listed in Informative Appendix G, section G2.2, page 169. Energy-10 does not meet the requirements because it can only model two zones.



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 ten windows each 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 building and window orientation. However, the analyses in this report are not orientation specific since the buildings modeled are symmetrical in plan and have equal amounts of glazing on each orientation. Therefore, the buildings do not need to be modeled in four perpendicular orientations (as required in Informative Appendix G) to eliminate the effect of 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,  $\frac{5}{16}$ -in. gypsum wallboard, board insulation, and built-up waterproofing membrane. The overall roof U-value is 0.062 Btu/h·ft<sup>2</sup>·°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-inplace concrete slab-on-ground. According to *ASHRAE 90.1-2004*, 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<sup>9</sup> of 1.0 h·ft<sup>2</sup>.°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<sup>2</sup>.°F/Btu for the fictitious insulation. The inside airfilm 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 oversizing ration is 1.15. Heating is provided by a hot water natural gas boiler with a thermal efficiency is 0.8. The heating over-sizing ratio is 1.25. 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 based on ASHRAE 90.1-1989 schedules and VisualDOE defaults.

**Equipment and lighting.** Equipment power density (also called plug or receptacle load) is 0.75 watt/ft<sup>2</sup>. It includes all plug or receptacle loads and two average-efficiency<sup>10</sup> elevators. Lighting power density is 1.0 watt/ft<sup>2</sup>. There is no daylight control. The energy for exterior lighting is not considered. Natural gas water heaters supply domestic hot water.

10. Using the Otis Energy Expense Calculator assuming two 8-person capacity cars, the resulting energy use is less than 1% of the total equipment power density

(http://www.aobr.on.com.br/Rac\_energia/New\_Zealand/internet\_pages/Info\_Calc.asp).

<sup>9.</sup> The thermal resistance of soil is taken from Winkelmann (2002), section A6, page 99, rather than from *ASHRAE* 90.1-2004.

#### 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
ighting 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 *ASHRAE-90.1-2004*. It is also within the normal range for office buildings, that is 0.1 to 0.6 ach.<sup>11</sup> 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.<sup>12</sup>

**Occupancy.** The occupancy is 275 sq ft/person.<sup>13</sup> The thermostat throttling range is 4 °F. The operating hours are based on *ASHRAE 90.1-1989*.<sup>14</sup> 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<sup>3</sup>, conductivity of 1.333 Btu/h·ft·°F, and specific heat of 0.22 Btu/lb·°F. Buildings ML, EM, CM, MM, MLX, 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. 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 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.

**Interior partition walls.** The interior partition walls of the steel frame buildings consist of non-structural steel studs and gypsum wallboard. Lateral resistance is provided by the structural frame. The interior partition walls of the concrete frame buildings are structural reinforced concrete. In this case, lateral resistance is provided by the partition walls, that is, the partition walls also act as shear walls. The thickness of the concrete partition walls is discussed in the section, "Modeling Thermal Mass".

<sup>11. 2001</sup> ASHRAE Fundamentals Handbook IP, page 27.23 (ASHRAE, 2001).

<sup>12.</sup> 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, 2001, <u>www.ashrae.org</u>.

<sup>13.</sup> ASHRAE Standard 90.1-1989, Table 13.2, page 110.

<sup>14.</sup> ASHRAE Standard 90.1-1989, Table 13.3, page 111.

Lootion	Maximum code-	Insulation and resulting wall U-factor to meet code					
Location	U-factor*	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				

Table 4. Thermal Performance Requirements in ASHRAE 90.1-2004 for EIFS and Curtain Walls

\*These U-factors, in units of Btu/h-ft<sup>2</sup>·°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.

Leastion	Maximum code-	Insulation and resulting wall U-factor to meet cod					
Location	U-factor*	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 1/2 in. air space	0.113				

Table 5. Thermal Performance Requirements in ASHRAE 90.1-2004 for Concrete Walls

\*These U-factors, in units of Btu/h·ft<sup>2</sup>·°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.

**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.

**Roofs.** The code requires a U-factor no more than 0.063 Btu/h·ft<sup>2.</sup>°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<sup>2.</sup>°F (including air films). In addition, Table 9 shows the properties of the selected roofs used to exceed the requirements.

Lover	Location						
	Miami &	Memphis &	Denver &	All cities: exceeding			
Thermal resistance, h-ft <sup>2</sup> -°F/Btu	Phoenix	Salem	Chicago	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 <sup>2</sup> ·°F	0.405	0.130	0.113	0.086			

Table 6. Concrete Wall Assembly Used to Meet Requirements in ASHRAE Standard 90.1-2004

\*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 90.1-2004, Table A9.2B, 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 90.1-2004

	Code-r	equired	Selected windows					
Location	Maximum U-factor*	Maximum SHGC**	U-factor*	SHGC <sup>†</sup>	VLT <sup>††</sup>	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<sup>2</sup>·°F.

\*\*Solar heat gain coefficient (SHGC) requirement in a non-north orientation.

<sup>†</sup>Solar heat gain coefficient at a 60° angle of incidence.

<sup>+†</sup>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 <sup>†</sup>	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<sup>2</sup>·°F.

\*\*Solar heat gain coefficient at a 60° angle of incidence.

<sup>†</sup>Visible light transmittance (VLT) is not a code requirement.

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

Table 9. Selected Roof Insulation that Exceeds Requirements in ASHRAE Standard 90.1-2004
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\*U-factor in units of Btu/h·ft<sup>2</sup>·°F.

**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 **Error! Not a valid bookmark self-reference.** The limits are based on the 1% cooling design wet-bulb temperature.

#### Table 10. Control Condition for Economizer in Various Locations

Location	1% wet-bulb	Shutoff dry bulb temperature, °F			
Location	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		

**Energy costs.** The energy costs for each city are show in **Error! Not a valid bookmark self**reference.

#### Table 11. Energy Costs

Location	Electricity*	Electricity	Natural gas**	Natural gas	
Location	¢/kWh	\$/kWh	\$/thousand cu ft	\$/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: <u>http://www.eia.doe.gov/emeu/states/\_states.html.</u> 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* and *precalculated weighting factors*. By default, VisualDOE uses the custom weighting factor method<sup>15</sup>. 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.<sup>16</sup> 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 partition walls.** Buildings modeled with VisualDOE also contain interior partitions by default. If the partition walls 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  $(5,447 \text{ ft}^3)$  is distributed over the VisualDOE default partition wall area (19,604 ft<sup>2</sup> 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<sup>3</sup> and heavy represents a density of 80 lb/ft<sup>3</sup>. 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<sup>2</sup>. 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<sup>2</sup> covering 85% of the floor. This scenario is the most common for office buildings.

<sup>15 .</sup> 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.

<sup>16.</sup> See page III.A.4 of the DOE-2 Supplement (Winkelmann and others 1993).

Construction Editor		X
Name       Precast concrete, Chi & Den-         Description       CTL 312036, PCA 04-08         Type       Wall         Roughness       3 - Textured         Inside Surface       Non Refl. Wall         Enter U-factor       O.9         Outside       0.9         Enter U-factor       O.9         Sketch of Construction       Clear Construction         Iffer exterior       Construction	Materials Classes Interior Finishes Concrete Masonry Air Layers Edit Material Choices Heavy Wt. Undried Aggregate 4 in. Earth (Soil) Heavy Wt. Concrete 12 in. Normal weight, 12 in 312036 Normal weight, 6 in 312036 Sketch of Selected Material Sketch of Selected Material	Copy Sketch OK
Construction Details	Material Details	
Property         Value           Ufactor (Btu/h-ft²-°F)         0.1130529           HC (Btu/ft²-°F)         16.367           Roughness         3           Absorp         0.7	Property     Value       Thickness (inch)     6       Conductivity (Btu/h-ft-*F)     1.333       Density (lb/ft*)     145       Specific Heat (Btu/lb-*F)     0.22	

Figure 3. Screen shot of VisualDOE construction editor shows that layers of materials are assembled into constructions in order: 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 use versus cost are similar using both software. Summary charts and tabulated data from VisualDOE are presented in Appendices A and B, respectively; and summary charts and tabulated data from Energy-10 are presented in Appendices C and D, respectively. For each city, 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 equipment 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, 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 of 6 to 11% are indicated for the three concrete frame and walls will provide at least 5% energy cost savings in Memphis, Salem, Denver, and Chicago (see Figure A8 in Appendix A).

**Energy cost savings due to thermal mass in the structural frame.** In Memphis, Salem, Denver, and Chicago, energy cost savings of 6 to 9% are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code (see Figure A7 in Appendix A). The exterior wall construction is identical in each pair of comparisons, that is the exterior walls of CL and CM are identical, as are EL and EM, and ML and MM. So the energy cost savings are due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building.

**Thermal mass in the walls.** Due to thermal mass effects, *ASHRAE 90.1-2004* does not require mass walls to have as high an R-value as low-mass walls (for example, see Tables 4 and 5). Comparing buildings with the same structural frame but different walls shows small differences in energy costs savings. These results indicate that the reduced R-values for mass walls allowed in energy codes are justified.

**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 (this is the usual way to simulate a building), and second, with the internal loads weighted more heavily towards 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 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. Energy cost savings are in the range of 9 to 23% for all cities except Miami, where the energy cost savings are about 5%.

**LEED EA Credit 1.** In the four cities representing mild, cool, and cold climates, reinforced concrete frame buildings with 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 buildings will likely qualify for 3 points, that is, at least 17.5% energy cost savings. In the cool climate category (Salem), these buildings will likely qualify for 4 points, that is, at least 21% energy cost savings. In mild climates, such as Memphis, these buildings will likely qualify for 2 points, that is, at least 14.5% energy cost savings (see Figure A8 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.

**Sensitivity analysis.** A sensitivity analysis was also performed using VisualDOE to determine how energy use and costs vary with concrete floor thickness. The sensitivity analysis considered:

- floor thicknesses of 7.5, 9, 10.5, and 12 in.,
- building types CM, MM, and MMX, and
- cities Phoenix, Salem, and Denver.

These cities represent climates where (i) thermal mass is demonstrably effective in saving energy costs (Salem and Denver) and (ii) a wide daily temperature swing normally shows positive benefits for thermal mass but because of the energy code requirements and energy cost structure, results are not as dramatic (Phoenix). The results, which are presented in Appendix E, show that regardless of building type or location, increasing the floor thickness in increments of 1.5 in., from 7.5 in to 12 in., increases the energy cost savings by a small amount. For Salem and Denver, increasing the floor thickness by 1.5 in. results in incremental energy costs savings of about 0.1%. For Phoenix it is about 0.05%. These savings, though real, are not significant because they represent annual savings in the range of \$50 to \$150. This is well below the modeling resolution of any simulation program.

**Thermal mass effects and energy simulation.** Energy simulation computer programs based on DOE-2, such as VisualDOE, typically do not show as large energy savings due to building thermal mass as BLAST or EnergyPlus (Crawly and others 2005). However VisualDOE was used due to its relative user friendliness. Until very recently, there have been no user interfaces for EnergyPlus.

## 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 v2.2 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 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 3 points, that is, at least 17.5% energy cost savings. In the cool climate category (Salem), these buildings will

likely qualify for 4 points, that is, at least 21% energy cost savings. In the mild climate category (Memphis), these buildings will likely qualify for 2 points, that is, at least 14% energy cost savings.

In Memphis, Salem, Denver, and Chicago, energy cost savings of 6 to 9% are indicated for the three concrete frame buildings meeting code compared to the three steel frame buildings meeting code. This energy cost savings is due to the concrete shear walls and increased thickness of the concrete floors in the concrete frame building. The exterior wall construction is identical in each pair of comparisons.

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.

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**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.













Legend:



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 structural frame 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 baseline building (EL). The abbreviated scenario names EL through MMXI are described in the text.

# **APPENDIX B – VISUALDOE DATA TABLES**

	Electrical, kWh					Fuel,	Tatal			
City	Scenario	Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	l otal, kWh
	EL	156,023	117,026	328	247,934	1,911	34,935	23,182	12,485	593,824
	CL	156,023	117,026	345	249,832	2,039	35,198	24,384	12,485	597,331
	ML	156,023	117,026	373	264,479	1,995	37,530	26,435	12,485	616,346
	EM	156,023	117,026	176	239,666	1,132	33,632	12,397	12,485	572,537
am	CM	156,023	117,026	181	241,136	1,185	33,846	12,749	12,485	574,630
Mi	MM	156,023	117,026	238	256,378	1,492	36,436	16,734	12,485	596,812
	MLX	156,023	117,026	213	239,920	1,442	33,802	14,947	12,485	575,857
	MMX	156,023	117,026	106	233,208	882	32,657	7,444	12,485	559,831
	MMI	156,023	117,054	269	257,290	1,631	36,368	18,962	12,485	600,082
	MMXI	156,023	117,054	126	233,689	1,005	32,514	8,851	12,485	561,747
	EL	156,023	117,026	2,070	265,366	6,244	42,334	147,766	13,833	750,662
		156,023	117,026	2,134	200,204	6,430	42,740	152,450	13,033	100,917
		156,023	117,020	2,445	290,012	5 160	40,972	105 622	13,033	606.097
nix		156 023	117,020	1,495	250,055	5 233	40,203	103,023	13,033	702 780
loe	MM	156 023	117,020	1 943	281 235	5 804	40,741	137 978	13,000	758 101
P	MLX	156 023	117,020	1,345	246 774	5,004	39 161	104 890	13 833	684 568
	MMX	156.023	117,026	1,100	234,755	4,547	37,493	75,319	13,833	640.069
	MMI	156.023	117.054	2.148	285.516	6.018	44.392	152.309	13.833	777.293
	MMXI	156,023	117,054	1,205	237,459	4,914	37,441	84,610	13,833	652,539
	EL	156,023	117,026	3,451	176,718	7,617	31,282	252,276	17,614	762,006
	CL	156,023	117,026	3,507	178,971	7,829	31,742	256,291	17,614	769,002
	ML	156,023	117,026	3,308	176,923	7,337	29,956	241,168	17,614	749,355
is.	EM	156,023	117,026	2,894	164,642	6,321	29,122	209,136	17,614	702,777
h	CM	156,023	117,026	2,916	161,095	6,410	29,601	210,747	17,614	701,432
len	MM	156,023	117,026	2,830	160,068	6,285	28,145	203,890	17,614	691,880
2	MLX	156,023	117,026	2,377	147,661	6,166	24,603	171,066	17,614	642,535
	MIMX	156,023	117,026	2,049	136,844	5,387	23,183	145,774	17,614	603,899
		156,023	117,054	3,045	141 471	5,800	20,000	210,000	17,014	619 011
		156 023	117,034	5 360	108 489	11 511	20,101	386 649	21 248	836 598
	CL	156 023	117,020	5 432	110 854	11,511	30,233	392 012	21,240	845 160
	ML	156.023	117.026	5.097	105.744	11.067	28.244	367,159	21,248	811.608
	EM	156,023	117,026	4,416	92,165	9,766	27,029	315,139	21,248	742,812
em	CM	156,023	117,026	4,453	93,984	9,841	27,633	317,777	21,248	747,985
Sal	MM	156,023	117,026	4,313	87,115	9,497	25,418	307,314	21,248	727,954
	MLX	156,023	117,026	3,479	77,720	9,351	20,238	247,205	21,248	652,290
	MMX	156,023	117,026	3,021	64,126	8,164	18,343	213,063	21,248	601,013
	MMI	156,023	117,054	4,693	95,397	10,162	25,388	333,896	21,248	763,861
	MMXI	156,023	117,054	3,212	70,165	8,688	18,297	226,397	21,248	621,084
	EL	156,023	117,026	5,737	141,366	11,329	31,782	423,898	22,098	909,259
	CL	156,023	117,026	5,705	140,415	11,242	31,581	421,524	22,098	905,614
		156,023	117,026	5,779	135,720	11,137	30,592	426,829	22,098	905,203
'er		156 023	117,020	4,930	116 768	9,700	20,014	350 188	22,090	81/ 166
env	MM	156,023	117,020	5 058	112 883	9,003	27,661	369,100	22,030	819 681
ŏ	MLX	156.023	117,026	4,253	89,702	9,531	21,897	307,637	22,000	728,166
	MMX	156.023	117.026	3.821	75.130	8.383	19.985	273.934	22.098	676.399
	MMI	156,023	117,054	5,294	120,429	10,105	27,649	385,594	22,098	844,245
	MMXI	156,023	117,054	3,953	79,760	8,745	19,941	283,107	22,098	690,680
	EL	156,023	117,026	6,757	139,112	10,673	28,795	506,104	22,215	986,705
	CL	156,023	117,026	6,739	138,609	10,616	28,692	504,815	22,215	984,735
1	ML	156,023	117,026	6,936	134,786	10,618	27,978	520,348	22,215	995,929
oĉ	EM	156,023	117,026	6,241	114,105	9,039	26,371	464,019	22,215	915,039
ica	CM	156,023	117,026	6,232	113,818	9,009	26,301	463,316	22,215	913,940
Ch		156,023	117,026	0,468	07.500	9,059	25,728	482,571	22,215	929,878
		156 022	117,020	5 171	91,500 82 210	9,∠12 8.229	20,501	375 182	22,215	785 352
	MMI	156.023	117 054	6,674	120,931	9 495	25.693	496,638	22,215	954,723
	MMXI	156,023	117,054	5,277	88,598	8,535	18,923	382,604	22,215	799,229

#### Table B1. VisualDOE Annual Electrical and Fuel End-Uses

City         Scenario         Lights         Equipmen         Heating         Cooling         Pumps/ Heating         Fans         Space Neating         Heating         Total, \$           CL         11.920         8.941         26         19.097         156         2.669         98.3         465         44,3971           LL         11.920         8.941         26         19.097         156         2.867         984         465         44,564           EM         11.920         8.941         13         18.310         86         2.569         461         465         42,973           MM         11.920         8.941         16         19.330         110         2.566         466         42,973           MMX         11.920         8.941         16         19.330         110         2.682         566         466         42,921           MMX         11.920         8.943         10         17.856         77         2.486         2.779         706         465         42,921           MMM         11.920         8.943         10         17.85         2.832         566         6.0529           CL         14.900         11.176         128		Electrical. \$ Fuel. \$						el, \$			
EL         11.920         8.941         25         18.942         446         2.669         983         465         44.9371           CL         11.920         8.941         26         190.67         156         2.869         984         445         44.554           EM         11.920         8.941         13         18.310         86         2.569         461         4465         44.75           ML         11.920         8.941         16         18.303         110         2.586         566         44.943           MLX         11.920         8.941         16         18.303         110         2.582         566         44.65         44.991           MLX         11.920         8.943         11         18.657         1125         2.777         706         465         44.902           ML         11.920         8.943         10         17.844         777         2.484         3.908         66         65.527           CL         14.900         11.176         146         2.4561         4.043         3.908         66         65.277           CL         14.900         11.176         146         2.4561         4.993	City	Scenario	Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	Total, \$
E         CL         11.920         8.941         26         19.067         156         2.687         908         465         445         544           EM         11.920         8.941         13         13.010         86         2.587         441         445         442.933           MM         11.920         8.941         14         19.657         114         2.586         477         445         44.923           MLX         11.920         8.941         16         13.300         110         2.582         566         46.584         42.923           MMX         11.920         8.941         16         17.833         77         77         66         655         42.921           MLX         11.920         8.941         10         17.857         12.822         2.779         706         465         42.920           CL         14.900         11.176         143         22.342         596         4.043         3.908         366         65.527           MML         14.900         11.176         146         24.858         554         4.032         3.740         2.774         366         5.519         4.235         3.844         3.86		EL	11.920	8.941	25	18.942	146	2.669	863	465	43.971
ML         11,920         8,941         28         20,206         152         2,867         984         4455         42,767           EM         11,920         8,941         14         18,423         91         2,586         475         4455         42,787           MLX         11,920         8,941         16         19,303         110         2,586         475         4456         42,973           MLX         11,920         8,941         16         11,330         110         2,582         566         465         42,921           MLX         11,920         8,941         16         17,870         72         495         446         44,902           MMM         11,920         8,941         10         19,857         126         2,779         706         4465         42,983           EL         14,900         11,176         198         28,361         616         22,279         706         446         64,586           CM         14,900         11,176         148         24,510         494         3,845         2,783         366         65,275           MML         14,900         11,176         102         22,417 <th< td=""><td></td><td>CL</td><td>11,920</td><td>8,941</td><td>26</td><td>19,087</td><td>156</td><td>2,689</td><td>908</td><td>465</td><td>44,192</td></th<>		CL	11,920	8,941	26	19,087	156	2,689	908	465	44,192
EM         11,920         8,941         13         18,310         86         2,566         4461         4455         42,913           EM         11,920         8,941         18         19,597         114         2,784         623         4465         42,913           MLX         11,920         8,941         16         18,301         100         2,582         556         445         42,923           MMX         11,920         8,941         10         17,851         677         2,464         3,908         366         64,523           MMX         11,920         8,943         10         17,854         777         2,464         3,908         366         60,522           CL         14,900         11,176         148         24,510         494         3,845         2,733         366         55,227           MMX         14,900         11,176         148         22,567         513         3,740         2,744         366         61,924           MMX         14,900         11,176         142         25,567         4,235         3,646         65,519           MMX         14,900         11,179         205         27,267         575		ML	11,920	8,941	28	20,206	152	2,867	984	465	45,564
E         CM         11,920         8,941         14         18,423         91         2,886         475         4455         42,432           MLX         11,920         8,941         16         19,330         110         2,784         623         455         44,452           MLX         11,920         8,941         16         17,817         67         2,495         277         445         44,980           MMX         11,920         8,943         21         19,657         126         2,779         706         4465         44,614           EL         14,900         11,176         108         2,5619         615         4,043         3,906         366         60,929           CL         14,900         11,176         143         24,510         494         3,845         2,793         366         56,275           CL         14,900         11,176         1142         22,567         513         3,740         2,774         366         55,7178           ML         14,900         11,179         115         22,677         576         4,233         3,648         54,936         65,61         14,843           MMX         14,900		EM	11,920	8,941	13	18,310	86	2,569	461	465	42,767
B         MM         11,920         8,941         18         19,587         114         2,784         623         465         44,292           MMX         11,920         8,941         8         17,817         67         2,495         277         465         41,980           MMX         11,920         8,943         21         19,657         126         2,779         706         465         44,901           MMX         11,920         8,943         10         17,854         777         2,494         3,293         465         42,082           CL         14,900         11,176         143         24,510         496         4,082         4,063         3,966         65,827           MM         14,900         11,176         146         24,858         5504         4,255         3,666         55,27           MMX         14,900         11,176         142         23,567         513         3,740         2,774         366         55,497           MMX         14,900         11,176         142         2,567         756         4,239         40,28         566         65,579           MMX         14,900         11,179         105	Ĩ.	CM	11,920	8,941	14	18,423	91	2,586	475	465	42,913
MLX         11.920         8.941         16         18.330         110         2.682         556         466         42.921           MMX         11.920         8.943         21         19.657         125         2.779         706         465         44.614           MMXI         11.920         8.943         21         19.657         125         2.779         706         466         44.614           MLX         11.920         8.943         21         19.657         12.849         329         466         60.923           ML         14.900         11.176         19.8         28.202         622         4.330         4.635         366         55.654           GM         14.900         11.176         148         24.501         4.944         3.645         3.666         55.675           MMX         14.900         11.176         102         22.471         3.581         1.992         3.666         55.7178           MMX         14.900         11.176         102         22.471         3.581         1.992         51.65         5.1717           MMX         14.900         11.176         102         52.777         4.294         4.028	Mia	MM	11,920	8,941	18	19,587	114	2,784	623	465	44,452
MMX         11.920         9.843         21         19.657         125         2.779         706         465         44.614           MMXI         11.920         8.943         10         17.854         77         2.484         329         465         42.082           EL         14.900         11.176         198         25.842         506         4.052         3068         60.529           CL         14.900         11.176         233         22.620         623         4.390         4.635         366         64.526           EM         14.900         11.176         148         24.510         494         3.649         366         55.68         4.235         3.649         366         55.68         4.235         3.649         366         57.175           MMX         14.900         11.176         142         23.567         573         4.239         4.028         55.51           MMX         14.900         11.178         102         22.477         409         3.561         5.579           EL         11.530         8.648         255         13.025         563         2.312         7.429         519         44.653           MLL	_	MLX	11,920	8,941	16	18,330	110	2,582	556	465	42,921
MMI         11.920         8.943         21         19.657         125         2.779         706         465         44.614           MMX         11.920         8.943         10         17.864         77         2.484         329         465         60.983           ML         14.900         11.176         198         25.842         566         4.043         3.908         366         60.983           ML         14.900         11.176         233         28.202         623         4.390         4.032         366         56.225           CM         14.900         11.176         148         24.510         4944         3.845         2.774         366         51.924           MMX         14.900         11.176         102         22.419         434         3.581         1.992         366         54.970           MMX         14.900         11.178         116         22.677         575         4.239         4.028         366         55.91           CL         11.530         8.648         2250         13.026         579         2.346         7.547         519         44.635           ML         11.530         8.648         216		MMX	11,920	8,941	8	17,817	67	2,495	277	465	41,990
MMXI         11,920         8,943         10         17,854         77         2,484         329         465         42,023           EL         14,900         11,176         204         25,619         615         40,082         4,032         366         60,529           CL         14,900         11,176         233         28,202         623         4,390         4,635         366         56,527           CM         14,900         11,176         148         24,510         404         3,649         366         56,827           MMX         14,900         11,176         142         23,567         513         3,740         2,774         366         57,179           MMX         14,900         11,176         142         22,677         43,39         4,028         366         55,519           MMX         14,900         11,179         115         22,677         469         3,576         2,237         366         55,519           EL         11,530         8,648         216         11,910         7,747         469         3,576         2,237         366         55,519           MMX         11,530         8,648         216         11,		MMI	11,920	8,943	21	19,657	125	2,779	706	465	44,614
EL         14,900         11,176         198         25,342         556         4,043         3,908         366         60,929           ML         14,900         11,176         204         25,619         615         4,082         366         60,939           ML         14,900         11,176         143         24,858         500         3,891         2,859         366         586,857           MM         14,900         11,176         146         24,858         500         3,891         2,859         366         586,857           MMX         14,900         11,176         142         23,567         513         3,740         2,774         366         55,519           MMX         14,900         11,179         105         22,677         469         3,576         2,334         7,429         519         43,351           CL         11,530         8,648         244         13,075         542         2,214         7,429         519         43,874           ML         11,530         8,648         206         11,829         4407         2,187         6,158         519         41,823           ML         11,530         8,648         2		MMXI	11,920	8,943	10	17,854	77	2,484	329	465	42,082
CL         14.900         11.176         203         28.02         62.33         4.304         4.635         3366         64.525           EM         14.900         11.176         143         24.510         494         3.845         2.783         366         58.227           MM         14.900         11.176         146         24.858         500         3.841         2.859         366         65.827           MMX         14.900         11.176         142         23.567         573         3.740         2.747         366         57.178           MMX         14.900         11.179         102         22.479         434         3.561         2.237         366         55.579           MMX         14.900         11.179         205         27.267         575         4.239         4.028         366         55.519           MM         11.530         8.648         259         13.075         542         2.214         7.102         519         44.853           ML         11.530         8.648         215         11.095         474         2.188         6.004         519         41.804           MMM         11.530         8.648		EL	14,900	11,176	198	25,342	596	4,043	3,908	366	60,529
ML         14.900         11.176         233         28.202         623         4.390         4.635         366         64.226           CM         14.900         11.176         143         24.510         494         3.845         2.793         366         58.207           CM         14.900         11.176         146         24.858         500         3.891         2.859         366         58.095           MLX         14.900         11.176         1142         22.3567         513         3.740         2.774         366         55.519           MMX         14.900         11.179         115         22.677         749         3.576         2.234         7.429         519         44.315           CL         11.530         8.648         255         13.226         579         2.346         7.547         519         44.3874           ML         11.530         8.648         214         12.167         467         2.152         6.158         519         41.863           ML         11.530         8.648         206         11.905         474         2.188         6.206         519         41.864           MMX         11.530         8		CL	14,900	11,176	204	25,619	615	4,082	4,032	366	60,993
EM         14.900         11.176         143         24.510         494         3.845         2.793         366         58.227           GC         MM         14.900         11.176         146         24.856         554         4.235         3.640         3.66         58.693           MLX         14.900         11.176         142         23.567         513         3.740         2.774         366         51.924           MMX         14.900         11.176         1122         22.419         434         3.581         1.992         366         55.7178           MMX         14.900         11.179         205         27.267         675         4.239         4.028         366         55.719           MMX         14.300         8.648         255         13.059         563         2.312         7.429         519         44.635           ML         11.530         8.648         216         11.905         474         2.186         6.206         519         41.866           MM         11.530         8.648         215         11.905         474         2.188         5.037         519         41.283           MMX         11.530         8.		ML	14,900	11,176	233	28,202	623	4,390	4,635	366	64,526
Ge         CM         14,900         11,176         146         24,858         500         3,891         2,859         366         51,924           MLX         14,900         11,176         142         23,567         513         3,740         2,774         366         51,924           MMX         14,900         11,176         102         22,419         434         3,581         1,992         366         54,970           MMX         14,900         11,179         205         27,267         575         4,239         4,022         366         55,519           MLX         14,900         11,179         115         22,677         469         3,576         2,237         366         55,519           ML         11,530         8,648         214         12,167         467         2,152         6,158         519         41,856           CM         11,530         8,648         209         11,829         446         2,008         6,004         519         41,283           MLX         11,530         8,648         106         10,912         466         1,818         5,037         519         37,365           MMX         11,530         8,64	.×	EM	14,900	11,176	143	24,510	494	3,845	2,793	366	58,227
E         MM         14,900         11,176         142         23,567         513         3,740         2,774         366         57,178           MMX         14,900         11,176         102         22,419         434         3,581         1,992         366         64,970           MMX         14,900         11,179         115         22,677         469         3,576         2,237         366         55,519           CL         11,530         8,648         255         13,059         563         2,312         7,429         519         44,653           ML         11,530         8,648         244         13,075         542         2,214         7,102         519         43,874           ML         11,530         8,648         214         12,167         467         2,152         6,158         519         41,866           MM         11,530         8,648         215         11,905         474         2,188         6,206         519         41,684           MMX         11,530         8,648         106         10,912         456         18,18         5,037         519         39,096           MMX         11,530         8,648 <td>Den</td> <td>CM</td> <td>14,900</td> <td>11,176</td> <td>146</td> <td>24,858</td> <td>500</td> <td>3,891</td> <td>2,859</td> <td>366</td> <td>58,695</td>	Den	CM	14,900	11,176	146	24,858	500	3,891	2,859	366	58,695
MLX         14,900         11,176         142         23,867         513         3,740         2,774         366         57,178           MMX         14,900         11,179         102         22,2419         343         3,581         1,922         366         56,970           MMX         14,900         11,179         115         22,677         476         3,576         2,237         366         55,519           EL         11,530         8,648         255         13,025         579         2,346         7,429         519         44,315           CL         11,530         8,648         244         13,075         542         2,214         7,102         519         43,874           EM         11,530         8,648         209         11,829         464         2,080         6,004         519         41,684           MM         11,530         8,648         151         10,912         466         1,818         5,037         519         37,365           MMX         11,530         8,648         151         10,113         398         1,713         4,293         519         37,365           MMX         11,530         8,648         156	Ч Ч	MM	14,900	11,176	186	26,858	554	4,235	3,649	366	61,924
MMX         14,900         11,176         102         22,419         434         3,581         1,992         366         54,970           MMX         14,900         11,179         105         27,267         575         4,239         4,028         366         65,579           EL         11,530         8,648         255         13,059         563         2,312         7,429         519         44,633           ML         11,530         8,648         244         13,075         542         2,214         7,102         519         44,663           ML         11,530         8,648         215         11,905         474         2,188         6,206         519         41,866           CM         11,530         8,648         215         11,905         474         2,188         6,206         519         41,863           MMX         11,530         8,648         105         10,912         466         2,806         6,004         519         42,222           MMX         11,530         8,650         161         10,455         429         1,707         4,558         519         38,008           ML         9,252         6,940         322 <td>-</td> <td>MLX</td> <td>14,900</td> <td>11,176</td> <td>142</td> <td>23,567</td> <td>513</td> <td>3,740</td> <td>2,774</td> <td>366</td> <td>57,178</td>	-	MLX	14,900	11,176	142	23,567	513	3,740	2,774	366	57,178
MMI         14,900         11,179         205         22,267         575         4,239         4,028         396         62,738           MMX         14,900         11,179         115         22,677         469         3,576         2,2346         7,7429         519         44,353           CL         11,530         8,648         259         13,226         579         2,346         7,547         519         44,653           ML         11,530         8,648         214         12,67         467         2,152         6,158         519         41,864           EM         11,530         8,648         214         11,97         464         2,080         6,004         519         41,684           MMX         11,530         8,648         151         10,113         399.06         500         519         39.096           MMX         11,530         8,648         161         10,455         429         1,707         4,558         519         38.008           MMX         11,530         8,650         225         12,276         503         2,074         6,445         519         42,223           MMX         11,530         8,661         10,		MMX	14,900	11,176	102	22,419	434	3,581	1,992	366	54,970
MMXI         11,179         115         22,677         469         3,376         2,237         386         55,519           E         11,530         8,648         255         13,059         563         2,312         7,429         519         44,315           CL         11,530         8,648         259         13,226         579         2,346         7,547         519         44,315           ML         11,530         8,648         214         13,075         542         2,214         7,102         519         43,874           MMX         11,530         8,648         215         11,905         474         2,188         6,206         519         41,886           MMX         11,530         8,648         106         10,912         464         2,080         6,004         519         42,222           MMX         11,530         8,648         151         10,911         398         1,713         4,293         519         37,366           MMX         11,530         8,640         151         10,455         429         1,707         4,558         519         38,008           MMX         11,530         8,640         322         6,574 <td></td> <td>MMI</td> <td>14,900</td> <td>11,179</td> <td>205</td> <td>27,267</td> <td>575</td> <td>4,239</td> <td>4,028</td> <td>366</td> <td>62,758</td>		MMI	14,900	11,179	205	27,267	575	4,239	4,028	366	62,758
EL         11,530         8,648         225         13,029         563         2,312         7,429         519         44,633           ML         11,530         8,648         259         13,226         579         2,246         7,541         519         44,653           ML         11,530         8,648         214         12,075         542         2,214         7,102         519         43,874           EM         11,530         8,648         214         11,076         474         2,188         6,206         519         41,684           MMX         11,530         8,648         10,912         456         1,818         5,037         519         39,096           MMX         11,530         8,664         151         10,912         456         1,818         5,037         519         39,096           MMX         11,530         8,660         127         10,455         429         1,707         4,558         519         38,008           MMX         11,530         8,660         127         666         1,675         9,897         573         38,566           MMX         11,530         8,640         322         6,574         687		MMXI	14,900	11,179	115	22,677	469	3,576	2,237	366	55,519
CL         11,330         8,648         2249         13,226         579         2,347         7,347         319         44,653           EM         11,530         8,648         244         13,075         542         2,214         7,102         519         41,856           CM         11,530         8,648         216         11,905         474         2,188         6,206         519         41,868           CM         11,530         8,648         216         11,905         474         2,188         6,004         519         41,864           MLX         11,530         8,648         161         10,912         456         1,818         5,037         519         39,096           MMX         11,530         8,648         151         10,113         398         1,713         4,293         519         42,223           MMXI         11,530         8,660         122,76         603         2,074         6,445         519         48,008           EL         9,252         6,940         302         6,271         656         1,675         9,897         573         35,566           EM         9,252         6,940         264         5,573		EL	11,530	8,648	255	13,059	563	2,312	7,429	519	44,315
ML         11,330         6,646         244         13,073         342         2,214         7,102         319         43,874           E         ML         11,530         8,648         215         11,905         474         2,182         6,185         519         41,864           MM         11,530         8,648         209         11,829         464         2,080         6,004         519         41,283           MLX         11,530         8,648         151         10,113         398         1,713         4,293         519         37,365           MMX         11,530         8,660         225         12,276         503         2,074         6,445         519         42,222           MMX         11,530         8,660         225         6,240         322         6,574         687         1,837         10,422         573         36,671           ML         9,252         6,940         322         6,574         687         1,837         10,567         573         33,3169           CL         9,252         6,940         266         5,166         563         1,507         8,246         573         33,340           MLX			11,530	8,648	259	13,226	579	2,346	7,547	519	44,653
B         E         I         1,330         6,046         214         12,107         407         2,188         6,206         519         41,684           MM         11,530         8,648         209         11,829         464         2,080         6,004         519         41,683           MLX         11,530         8,648         100,912         456         1,818         5,037         519         39,986           MMX         11,530         8,648         176         10,912         456         1,818         5,037         519         39,096           MMX         11,530         8,660         161         10,113         398         1,713         4,293         519         37,365           MMX         11,530         8,660         161         10,413         4293         1,707         4,558         519         38,008           E         9,252         6,940         302         6,271         656         1,675         9,897         573         35,566           E         9,252         6,940         264         5,573         584         1,639         8,566         573         33,340           MLX         9,252         6,940         <			11,530	0,040	244	13,075	342	2,214	7,102	519	43,874
E         CM         11,330         8,046         213         11,322         474         2,186         0,200         519         41,283           MLX         11,530         8,648         176         10,912         456         1,818         5,007         519         39,066           MMX         11,530         8,648         151         10,113         398         1,713         4,293         519         37,365           MMX         11,530         8,650         222         12,276         503         2,074         6,445         519         42,222           MMX1         11,530         8,650         222         6,574         687         1,837         10,567         573         36,751           ML         9,252         6,940         302         6,271         656         1,675         9,897         573         33,590           ML         9,252         6,940         264         5,573         584         1639         8,566         573         33,390           MM         9,252         6,940         206         5,667         603         1,507         8,284         573         32,541           MLX         9,252         6,941	his		11,530	0,040	214	12,107	407	2,132	0,100	519	41,000
■         Mim         11,350         3,046         205         11,829         404         2000         0,004         319         41,239           MIX         11,530         8,648         151         10,113         398         1,713         4,293         519         39,096           MMX         11,530         8,648         151         10,113         398         1,713         4,293         519         37,365           MMI         11,530         8,650         161         10,455         429         1,707         4,558         519         38,008           EL         9,252         6,940         322         6,574         687         1,837         10,657         573         36,713           MLX         9,252         6,940         262         5,465         579         1,603         8,495         573         33,169           MLX         9,252         6,940         264         5,573         584         1,639         8,566         573         32,541           MLX         9,252         6,940         266         5,166         563         1,507         8,284         573         32,842           MLX         9,252         6,940	du		11,550	0,040	210	11,905	474	2,100	6,200	519	41,004
MLA         11,330         6,648         170         10,312         4,30         1,713         4,293         519         33,365           MMI         11,530         8,660         225         12,276         503         2,074         6,445         519         42,293           MMXI         11,530         8,650         161         10,455         429         1,707         4,558         519         38,008           MMXI         11,530         8,650         161         10,455         429         1,707         4,558         519         38,008           ML         9,252         6,940         322         6,574         687         1,837         10,567         573         36,471           ML         9,252         6,940         264         5,573         584         1,639         8,496         573         33,189           MMX         9,252         6,940         266         5,166         563         1,507         8,284         573         32,541           MLX         9,252         6,940         179         3,803         444         1,008         6,103         573         28,062           MMX         9,252         6,941         190	Me		11,530	0,040	209	10,029	404	2,000	5.027	519	20,006
MMX         11,530         6,650         125         12,176         530         1,713         4,233         531         51,233           MMXI         11,530         8,650         161         10,455         429         1,707         4,558         519         38,008           EL         9,252         6,940         318         6,433         663         1,796         10,422         573         36,751           ML         9,252         6,940         302         6,271         656         1,675         9,897         573         35,566           EM         9,252         6,940         262         5,465         579         1,603         8,495         573         33,390           MM         9,252         6,940         266         5,166         563         1,507         8,284         573         33,390           MMX         9,252         6,940         206         4,609         555         1,200         6,664         573         29,998           MMX         9,252         6,941         179         3,803         444         1,088         5,743         28,060           MMX1         9,252         6,941         190         4,161	_		11,530	0,040 8,648	170	10,912	308	1,010	3,037	519	39,090
MMXI         11,530         8,650         12,120         333         14,220           MMXI         11,530         8,650         161         10,455         429         1,707         4,558         519         98,020           EL         9,252         6,940         318         6,433         683         1,796         10,422         573         36,417           CL         9,252         6,940         302         6,574         687         1,837         10,567         573         35,566           EM         9,252         6,940         262         5,465         579         1,603         8,495         573         33,169           MM         9,252         6,940         266         5,166         563         1,507         8,284         573         32,541           MLX         9,252         6,940         179         3,803         484         1,088         5,743         573         28,902           MMXI         9,252         6,941         179         3,803         484         1,085         6,103         573         28,902           MMXI         9,252         6,941         190         4,161         515         1,085         6,103		MMI	11,530	8 650	225	12 276	503	2 074	6 4 4 5	519	42 222
Minku         11,333         31		MMXI	11,530	8,650	161	10 455	429	1 707	4 558	510	38 008
LL         0.252         0.940         0.022         0.674         0.032         0.674         0.032         0.674         0.032         0.674         0.032         0.674         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.072         0.032         0.		FI	9 252	6 940	318	6 433	683	1,707	10 422	573	36 417
Bit         0.252         6.940         302         6.271         666         1.675         9.897         573         35.566           EM         9.252         6.940         262         5.465         579         1.603         8.495         573         33.169           CM         9.252         6.940         264         5.573         584         1.639         8.566         573         33.319           MM         9.252         6.940         266         5.166         563         1.507         8.284         573         32.541           MLX         9.252         6.940         206         4.609         555         1.200         6.664         573         28.998           MMX         9.252         6.941         278         5.657         603         1.506         9.000         573         33.8109           MMXI         9.252         6.941         278         5.657         603         1.506         9.103         573         28.802           MMXI         9.252         6.941         278         5.657         603         1.506         9.103         573         28.802           CL         12.997         9.748         475 <td< td=""><td></td><td>CI</td><td>9,252</td><td>6,940</td><td>322</td><td>6,574</td><td>687</td><td>1,837</td><td>10,122</td><td>573</td><td>36,751</td></td<>		CI	9,252	6,940	322	6,574	687	1,837	10,122	573	36,751
Em         9,252         6,940         262         5,465         579         1,603         8,495         573         33,169           CM         9,252         6,940         264         5,573         584         1,639         8,566         573         33,390           MM         9,252         6,940         256         5,166         563         1,507         8,284         573         32,541           MLX         9,252         6,940         276         5,657         603         1,506         9,000         573         33,810           MMX         9,252         6,941         179         3,803         484         1,088         5,743         573         28,820           MMI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           CL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,309           ML         12,997         9,748         410         9,727         805         2,372         7,145         440         43,462           MM         12,997         9,748         316         6		ML	9.252	6.940	302	6.271	656	1.675	9.897	573	35.566
E         CM         9,252         6,940         264         5,573         584         1,639         8,566         573         33,390           MM         9,252         6,940         256         5,166         563         1,507         8,284         573         32,541           MLX         9,252         6,940         206         4,609         555         1,200         6,664         573         29,998           MMX         9,252         6,940         179         3,803         484         1,088         5,743         573         28,062           MMI         9,252         6,941         278         5,657         603         1,506         9,000         573         33,810           MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,862           CL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,62           CL         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         41		EM	9.252	6.940	262	5.465	579	1.603	8.495	573	33,169
MM         9,252         6,940         256         5,166         563         1,507         8,284         573         32,541           MLX         9,252         6,940         206         4,609         555         1,200         6,664         573         29,998           MMX         9,252         6,940         179         3,803         484         1,088         5,743         573         28,062           MMI         9,252         6,941         190         4,161         515         1,008         6,103         573         28,800           MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           MMXI         12,997         9,748         478         11,776         944         2,647         8,433         440         47,622           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         43,723           CM         12,997         9,748         410         9,770         805         2,372         7,145         440         43,642           MMX         12,997         9,748         354	E	СМ	9,252	6,940	264	5,573	584	1,639	8,566	573	33,390
MLX         9,252         6,940         206         4,609         555         1,200         6,664         573         29,998           MMX         9,252         6,940         179         3,803         484         1,088         5,743         573         28,062           MMI         9,252         6,941         278         5,657         603         1,506         9,000         573         33,810           MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           CL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,462           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           MLX         12,997         9,748         411         9,770         808         2,344         7,166         440         43,723           CM         12,997         9,748         314         6,258         698         1,665         5,449         440         37,574           MLX         12,997         9,751         329	Sale	MM	9,252	6,940	256	5,166	563	1,507	8,284	573	32,541
MMX         9,252         6,940         179         3,803         484         1,088         5,743         573         28,062           MMI         9,252         6,941         278         5,657         603         1,506         9,000         573         33,810           MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           EL         12,997         9,748         478         11,766         944         2,647         8,433         440         47,462           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,464           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMX         12,997         9,751         329	0)	MLX	9,252	6,940	206	4,609	555	1,200	6,664	573	29,998
MMI         9,252         6,941         278         5,657         603         1,506         9,000         573         33,810           MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           EL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,462           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,624           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMX         12,997         9,751         329		MMX	9,252	6,940	179	3,803	484	1,088	5,743	573	28,062
MMXI         9,252         6,941         190         4,161         515         1,085         6,103         573         28,820           EL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,462           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,664           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         329		MMI	9,252	6,941	278	5,657	603	1,506	9,000	573	33,810
EL         12,997         9,748         478         11,776         944         2,647         8,433         440         47,622           CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,642           MM         12,997         9,748         421         9,403         803         2,304         7,346         440         43,642           MLX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMX         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMX         12,997         9,744         545		MMXI	9,252	6,941	190	4,161	515	1,085	6,103	573	28,820
CL         12,997         9,748         475         11,697         936         2,631         8,385         440         47,309           ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,644           MM         12,997         9,748         421         9,403         803         2,304         7,346         440         43,642           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           CL         12,591         9,444         545		EL	12,997	9,748	478	11,776	944	2,647	8,433	440	47,462
ML         12,997         9,748         481         11,305         928         2,548         8,491         440         46,938           EM         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,644           MM         12,997         9,748         421         9,403         803         2,304         7,346         440         43,642           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           CL         12,591         9,444         545		CL	12,997	9,748	475	11,697	936	2,631	8,385	440	47,309
EM         12,997         9,748         411         9,770         808         2,384         7,166         440         43,723           CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,644           MM         12,997         9,748         421         9,403         803         2,304         7,346         440         43,642           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           CL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         503		ML	12,997	9,748	481	11,305	928	2,548	8,491	440	46,938
CM         12,997         9,748         410         9,727         805         2,372         7,145         440         43,644           MM         12,997         9,748         421         9,403         803         2,304         7,346         440         43,642           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           CL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503	Ŀ	EM	12,997	9,748	411	9,770	808	2,384	7,166	440	43,723
m         12,997         9,748         421         9,403         803         2,304         7,346         440         43,462           MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           CL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503	υve	CM	12,997	9,748	410	9,727	805	2,372	7,145	440	43,644
MLX         12,997         9,748         354         7,472         794         1,824         6,120         440         39,749           MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           EL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,176         624         51,737           ML         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503	Dei	MM	12,997	9,748	421	9,403	803	2,304	7,346	440	43,462
MMX         12,997         9,748         318         6,258         698         1,665         5,449         440         37,574           MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           EL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,176         624         51,737           ML         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503	_	MLX	12,997	9,748	354	7,472	794	1,824	6,120	440	39,749
MMI         12,997         9,751         441         10,032         842         2,303         7,671         440         44,475           MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           EL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,176         624         51,737           ML         12,591         9,444         560         10,877         857         2,258         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         522         8,941         731         2,076         13,552         624         48,480           MLX         12,591         9,444         433 <td></td> <td>MMX</td> <td>12,997</td> <td>9,748</td> <td>318</td> <td>6,258</td> <td>698</td> <td>1,665</td> <td>5,449</td> <td>440</td> <td>37,574</td>		MMX	12,997	9,748	318	6,258	698	1,665	5,449	440	37,574
MMXI         12,997         9,751         329         6,644         728         1,661         5,632         440         38,182           EL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,176         624         51,737           ML         12,591         9,444         560         10,877         857         2,258         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MMX         12,591         9,444         522         8,941         731         2,076         13,552         624         44,480           MLX         12,591         9,444         433 <td></td> <td>MMI</td> <td>12,997</td> <td>9,751</td> <td>441</td> <td>10,032</td> <td>842</td> <td>2,303</td> <td>7,671</td> <td>440</td> <td>44,475</td>		MMI	12,997	9,751	441	10,032	842	2,303	7,671	440	44,475
EL         12,591         9,444         545         11,226         861         2,324         14,212         624         51,828           CL         12,591         9,444         544         11,186         857         2,315         14,176         624         51,828           ML         12,591         9,444         560         10,877         857         2,258         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MMX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,446         539 <td></td> <td>MMXI</td> <td>12,997</td> <td>9,751</td> <td>329</td> <td>6,644</td> <td>728</td> <td>1,661</td> <td>5,632</td> <td>440</td> <td>38,182</td>		MMXI	12,997	9,751	329	6,644	728	1,661	5,632	440	38,182
CL         12,991         9,444         544         11,186         857         2,315         14,176         624         51,737           ML         12,591         9,444         560         10,877         857         2,258         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,259           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MMX         12,591         9,444         522         8,941         731         2,076         13,552         624         48,480           MLX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539 <td> </td> <td>EL O'</td> <td>12,591</td> <td>9,444</td> <td>545</td> <td>11,226</td> <td>861</td> <td>2,324</td> <td>14,212</td> <td>624</td> <td>51,828</td>		EL O'	12,591	9,444	545	11,226	861	2,324	14,212	624	51,828
Image: Nic         12,591         9,444         500         10,877         857         2,258         14,612         624         51,823           EM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,259           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         522         8,941         731         2,076         13,552         624         44,480           MLX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446 <t< td=""><td> </td><td></td><td>12,591</td><td>9,444</td><td>544</td><td>11,186</td><td>857</td><td>2,315</td><td>14,176</td><td>624</td><td>51,737</td></t<>			12,591	9,444	544	11,186	857	2,315	14,176	624	51,737
CM         12,591         9,444         504         9,208         729         2,128         13,031         624         48,259           CM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,259           MM         12,591         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         522         8,941         731         2,076         13,552         624         48,480           MLX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446         426         7,150         689         1,527         10,744         624         43,197			12,591	9,444	560	10,877	857	2,258	14,612	624	51,823
B         CM         12,991         9,444         503         9,185         727         2,122         13,011         624         48,207           MM         12,591         9,444         522         8,941         731         2,076         13,552         624         48,480           MLX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446         426         7,150         689         1,527         10,744         624         43,197	go		12,591	9,444	504	9,208	729	2,128	13,031	624	48,259
E         Imin         12,331         9,444         322         0,941         731         2,070         13,332         624         48,480           MLX         12,591         9,444         433         7,869         743         1,654         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446         426         7,150         689         1,527         10,744         624         43,197	ica		12,091	9,444	503	9,100	121	2,122	13,011	624	40,207
MIX         12,591         9,444         433         7,509         743         1,534         11,092         624         44,450           MMX         12,591         9,444         417         6,637         664         1,530         10,544         624         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446         426         7,150         689         1,527         10,744         624         43,197	Ь		12,091	9,444	52Z	0,941	7/37	2,076	11,002	624	40,400
MMX         12,551         9,444         417         0,057         004         1,550         10,344         024         42,452           MMI         12,591         9,446         539         9,759         766         2,073         13,947         624         49,745           MMXI         12,591         9,446         426         7,150         689         1,527         10,744         624         43,197			12,091	9,444	403	1,009	143	1,004	10.544	624	44,400
MMXI 12,591 9,446 426 7,150 689 1,527 10,744 624 43,145		MMI	12,091	9,444 0 <i>11</i> 6	530	0,037 0 750	766	2 073	12 0/7	624	42,432
		MMXI	12,501	9 446	426	7 150	007 689	1 527	10 744	624	43 197

#### Table B2. VisualDOE Annual Electrical and Fuel Cost

		Cost savings						
City	Scenario	Compared to similar building, %	Compared to EL, %					
	EL	0.0	0.0					
	CL	0.0	-0.5					
	ML	0.0	-3.6					
	EM	2.7	2.7					
mi	CM	2.9	2.4					
Mia	MM	2.4	-1.1					
	MLX	5.8	2.4					
	MMX	7.8	4.5					
	MMI	2.1	-1.5					
	MMXI	7.6	4.3					
	EL	0.0	0.0					
	CL	0.0	-0.8					
	ML	0.0	-6.6					
.×	EM	3.8	3.8					
en	CM	3.8	3.0					
hc	MM	4.0	-2.3					
ш	MLX	11.4	5.5					
	MMX	14.8	9.2					
	MMI	2.7	-3.7					
L	MMXI	14.0	8.3					
	EL	0.0	0.0					
	CL	0.0	-0.8					
	ML	0.0	1.0					
is	EM	5.5	5.5					
h	CM	6.6	5.9					
len	MM	5.9	6.8					
2	MLX	10.9	11.8					
	MMX	14.8	15.7					
	MMI	3.8	4.7					
	MMXI	13.4	14.2					
	EL	0.0	0.0					
	CL	0.0	-0.9					
	ML	0.0	2.3					
۶	EM	8.9	8.9					
aler	CM	9.1	8.3					
ŝ	MM	8.5	10.6					
	MLX	15.7	17.6					
	IVIIVIX	21.1	22.9					
	MIMI	4.9	7.2					
		19.0	20.9					
		0.0	0.0					
		0.0	0.3					
		0.0	1.1					
er		1.9 77	1.9					
NU€		1.1 7 A	0.U 8 /					
ď		1.4	0.4					
		20.0	20.0					
		20.0 5.2	20.0 6 3					
	MMYI	18 7	10.5					
	FI	0.0	0.0					
		0.0	0.0					
	MI	0.0	0.2					
_	FM	6.0	6.0					
oɓu	CM	6.8	7.0					
lice	MM	6.5	65					
ъ С	MIX	14.2	14.2					
	MMX	18.1	18.1					
	MMI	4 0	4 0					
	MMXI	16.6	16.7					
L		10.0	10.7					

### Table B3. VisualDOE Percent Cost Savings

**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.











Legend:



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.

![](_page_41_Figure_0.jpeg)

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.

![](_page_42_Figure_0.jpeg)

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

![](_page_43_Figure_0.jpeg)

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

![](_page_44_Figure_0.jpeg)

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.

![](_page_45_Figure_0.jpeg)

Figure C7. Energy cost savings (from Energy-10) as a percent of structural frame 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.

![](_page_46_Figure_0.jpeg)

Figure C8. 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.

Z

# **APPENDIX D – ENERGY-10 DATA TABLES**

City         Scenario         Lights         Equipment         Heating         Cooling         Pumps/ Nullary         Fans         Space heating         Hot water Mut         Null Space           EL         156.023         30.217         31.010         6.44         28.019         77.766           CL         156.023         30.217         310.602         31.786         5.748         28.019         578.400           EM         156.023         30.217         315.809         29.724         1.849         28.019         568.301           MM         156.023         30.217         228.966         -30.058         1.874         28.019         572.789           MMX         156.023         30.217         284.720         24.635         254.4         28.019         572.789           MMX         156.023         30.217         297.563         44.982         104.416         28.019         652.20           CL         156.023         30.217         298.587         44.982         104.416         28.019         651.221           MMX         156.023         30.217         298.393         44.766         92.857         28.019         651.221           MMX         156.023         30.217			Electrical, kWh							Fuel, kWh	
EL 156.023 36.217 321.603 31.786 5.748 28.019 574.766 CL 156.023 36.217 321.603 31.786 5.748 28.019 574.766 EM 156.023 36.217 315.869 29.724 1.849 28.019 574.766 EM 156.023 36.217 315.869 29.724 1.849 28.019 568.03 MLX 156.023 36.217 228.965 30.058 1.862 28.019 578.567 MMX 155.023 36.217 284.720 24.635 254 28.019 578.567 MMX 155.023 36.217 297.553 44.882 10.4416 28.019 685.220 MM 156.023 36.217 297.563 44.682 10.676 15.902 28.019 673.368 ML 156.023 36.217 297.563 44.982 10.4416 28.019 685.220 MM 156.023 36.217 297.563 44.982 10.0778 28.019 685.220 MM 156.023 36.217 297.563 44.982 10.0778 28.019 685.220 MM 156.023 36.217 297.563 44.982 10.0778 28.019 685.220 MM 156.023 36.217 297.563 44.982 61.910.678 28.019 685.220 MM 156.023 36.217 297.568 44.9395 11.0578 28.019 685.220 MM 156.023 36.217 248.147 305.869 7.460.56 05.902 26.019 673.368 MMX 156.023 36.217 248.147 356.869 57.860 57.860 57.860 67.050 16 MMX 156.023 36.217 248.147 356.869 57.860 57.860 67.050 16 MMX 156.023 36.217 149.587 29.172 245.144 28.91905 26.019 673.368 MMX 156.023 36.217 149.587 29.172 245.014 44.766 92.657.126 16.91 97.036 MMX 156.023 36.217 162.223 33.244 289.905 26.019 673.368 MMX 156.023 36.217 149.587 29.172 246.014 69.765 16 EL 156.023 36.217 149.587 29.172 246.014 69.765 16 CL 156.023 36.217 149.587 29.172 246.014 69.765 19 MMX 156.023 36.217 149.582 20.919 77.246 144.519 92.60.19 773.246 MMX 156.023 36.217 149.582 20.919 783.54 MMX 156.023 36.217 145.582 20.919 48	City	Scenario	Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	l otal, kWh
CL         156,023         36,217         .321,603         .31,900         6.644         26,019         578,408           EM         156,023         36,217         .316,809         .29,724         1.849         280,018         568,334           MM         156,023         36,217         .228,965         .30,553         1.931         26,019         572,258           MMX         156,023         36,217         .228,965         .30,553         1.934         26,019         532,235           MMX         156,023         36,217         .284,965         .44,982         104,416         26,019         666,220           CL         156,023         36,217         .297,563         .44,982         104,416         26,018         666,220           CL         156,023         .36,217         .291,583         .44,395         91,405         26,018         667,308           MMX         156,023         .36,217         .249,147         .35,586         57,550         26,018         667,368           MMX         156,023         .62,17         .249,147         .35,586         57,550         26,019         671,368           MMXI         156,023         .62,17         .249,147         .35,586		EL	156,023	36,217	-	319,127	-	31,001	6,379	26,019	574,766
ML         156,023         36,217         -330,602         -31,785         5,748         26,019         566,701           CM         156,023         36,217         315,869         -22,724         18,484         26,019         566,701           MLX         156,023         36,217         228,965         -30,0581         18,814         26,019         572,955           MMX         156,023         36,217         284,720         24,635         254         26,019         652,7289           MMX         156,023         36,217         297,563         44,982         104,416         26,019         662,2019         671,368           MM         156,023         36,217         291,588         43,995         91,405         261,918         662,801         645,847           CM         156,023         36,217         245,589         44,760         102,728         26,019         667,328           ML         156,023         36,217         245,739         44,760         102,728         26,019         671,368           MLX         156,023         36,217         245,742         33,244         289,950         26,019         70,3631           CL         156,023         36,217         14		CL	156,023	36,217	-	321,603	-	31,900	6,644	26,019	578,406
EM         156,023         36,217         317,869         -         29,724         1,849         26,019         566,63           MM         156,023         36,217         312,860         30,553         1,931         26,019         566,63           MLX         156,023         36,217         286,233         25,868         1,862         26,019         522,235           MMX         156,023         36,217         294,720         24,635         254         26,019         522,325           MMX         156,023         36,217         297,553         44,982         104,416         26,019         665,220           ML         156,023         36,217         201,141         46,005         105,002         26,018         643,296           ML         156,023         36,217         208,389         44,766         92,657         26,018         612,218           ML         156,023         36,217         249,339         44,766         92,657         26,019         632,209           MLX         156,023         36,217         245,722         43,4389         94,405         20,118         643,329           MMX         156,023         36,217         149,587         26,019		ML	156,023	36,217	-	330,602	-	31,785	5,748	26,019	586,394
E         CM         156,023         36,217         312,860         -         30,653         1,931         26,019         579,555           MLX         156,023         36,217         288,623         25,868         1,874         268,019         579,555           MMX         156,023         36,217         284,720         24,635         25,640         677,955           MMX         156,023         36,217         297,563         44,982         104,416         26,019         677,306           ML         156,023         36,217         306,876         45,475         110,677         26,019         661,221           CL         156,023         36,217         291,886         43,985         91,405         26,019         661,221           CL         156,023         36,217         249,886         43,985         91,405         26,019         671,306           MLX         156,023         36,217         248,782         33,286         28,586         26,019         671,306           MMX         156,023         36,217         146,357         291,72         246,019         671,306           MMX         156,023         36,217         146,358         23,244         289,095		EM	156,023	36,217	-	315,869	-	29,724	1,849	26,019	565,701
B         MM         156,023         36,217         -328,965         -30,508         1,862         26,019         573,585           MLX         156,023         36,217         -284,720         -24,635         254         26,019         522,235           MMX         156,023         36,217         294,720         -24,635         254         26,019         522,235           MMXI         156,023         36,217         201,141         46,005         105,902         26,019         6645,227           CL         156,023         36,217         201,048         43,995         91,405         26,019         6645,247           ML         156,023         36,217         209,339         44,766         92,657         26,019         667,368           MLX         156,023         36,217         245,732         33,344         44,900         102,722         26,019         671,368           MLX         156,023         36,217         146,357         23,244         289,905         26,019         703,81           CL         156,023         36,217         164,223         32,247         26,019         613,82           MMXI         156,023         36,217         164,223         32,240	am	CM	156,023	36,217	-	317,860	-	30,553	1,931	26,019	568,603
MLX         156.023         36.217         - 286.233         - 28,686         1.874         226,015         522.35           MMX         1         -<	Mi	MM	156,023	36,217	-	328,965	-	30,508	1,862	26,019	579,595
MMX         156.023         38.217         224.720         24.635         224         26.015         527.869           MMXI         -		MLX	156,023	36,217	-	286,233	-	25,868	1,874	26,019	532,235
MMI         .		MMX	156,023	36,217	-	284,720	-	24,635	254	26,019	527,869
MMX1         -		MMI	-	-	-	-	-	-	-	-	-
EL         156,023         36,217         - 297,563         - 44,982         104,418         26,019         665,220           ML         156,023         36,217         - 300,878         - 45,475         110,678         26,019         663,220           EM         156,023         36,217         - 295,339         - 44,476         92,857         26,019         661,221           MM         156,023         36,217         - 249,147         - 35,666         57,850         26,019         671,388           MLX         156,023         36,217         - 249,147         - 35,666         57,850         26,019         671,388           MMX         156,023         36,217         - 149,147         - 35,666         57,850         26,019         671,388           MMXI  -           -		MMXI	-	-	-	-	-	-	-	-	-
CL         166,023         36,217         - 301,141         - 46,005         100,678         26,019         671,308           ML         156,023         36,217         - 291,888         - 43,995         91,405         26,019         645,547           CM         156,023         36,217         - 295,339         - 44,766         92,857         26,019         651,221           MM         156,023         36,217         - 249,147         - 35,586         57,850         26,019         651,221           MMX         156,023         36,217         - 245,732         - 34,388         49,130         26,019         577,860         26,019         577,860         26,019         577,860         26,019         577,960         26,019         577,960         26,019         577,960         26,019         703,631         33,808         295,472         26,019         703,631         33,3244         289,005         26,019         643,032         26,019         643,032         26,019         643,032         26,019         643,032         201,972         246,014         26,019         643,032         26,019         643,032         201,972         246,014         26,019         643,032         201,972         246,014         26,019         643,032 <td></td> <td>EL</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>297,563</td> <td>-</td> <td>44,982</td> <td>104,416</td> <td>26,019</td> <td>665,220</td>		EL	156,023	36,217	-	297,563	-	44,982	104,416	26,019	665,220
ML         166,023         36,217         208,878         -         46,475         110,678         20,198         683,290           CM         156,023         36,217         295,339         44,766         92,657         26,019         661,221           MLX         156,023         36,217         205,339         44,4766         92,657         26,019         671,368           MLX         156,023         36,217         249,147         35,586         57,850         26,019         560,842           MMX         156,023         36,217         245,732         -33,244         289,905         26,019         747,490           MMXI         -		CL	156,023	36,217	-	301,141	-	46,005	105,902	26,019	671,308
EM         166,023         36,217         - 291,888         - 44,766         92,657         26,019         645,547           EM         156,023         36,217         - 205,339         - 44,766         92,857         26,019         651,237           MM         156,023         36,217         - 245,732         - 34,368         49,130         26,019         651,237           MMX         156,023         36,217         - 245,732         - 34,368         49,130         26,019         547,490           MMXI                   MMXI         156,023         36,217         164,035         - 33,3244         289,062         26,019         703,631           CL         156,023         36,217         147,035         - 29,172         246,014         26,019         683,526           MI         156,023         36,217         145,360         - 27,956         238,407         26,019         683,563           MMX         156,023         36,217         143,160         24,812         200,888         26,019         783,464           MMXI         156,023         36,217         43,150         31,464 </td <td></td> <td>ML</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>308,878</td> <td>-</td> <td>45,475</td> <td>110,678</td> <td>26,019</td> <td>683,290</td>		ML	156,023	36,217	-	308,878	-	45,475	110,678	26,019	683,290
B         CM         156,023         36,217         -         245,339         -         444,766         92,287         26,019         671,388           MLX         156,023         36,217         -         249,147         -         35,586         57,850         26,019         571,388           MLX         156,023         36,217         -         249,147         -         35,586         57,850         26,019         547,490           MMX         156,023         36,217         -         162,223         - </td <td>ix</td> <td>EM</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>291,888</td> <td>-</td> <td>43,995</td> <td>91,405</td> <td>26,019</td> <td>645,547</td>	ix	EM	156,023	36,217	-	291,888	-	43,995	91,405	26,019	645,547
E         MM         156,023         36,217         - 245,831         - 44,490         102,782         26,019         560,842           MMX         156,023         36,217         - 245,732         - 34,386         49,130         26,019         560,842           MMX         156,023         36,217         - 245,732         - 34,386         49,130         26,019         57,490           MMXI         -	Der	CM	156,023	36,217	-	295,339	-	44,766	92,857	26,019	651,221
MILA         156,023         36,217         - 249,147         - 35,366         57,800         26,019         547,490           MMM         156,023         36,217         - 245,732         - 34,368         49,130         26,019         547,490           MMN         -	ΡΫ́	MM	156,023	36,217	-	305,891	-	44,490	102,728	26,019	671,368
MMX         156,023         36,217         -         245,722         -         34,368         49,130         26,019         547,430           MMX         - <td></td> <td>MLX</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>249,147</td> <td>-</td> <td>35,586</td> <td>57,850</td> <td>26,019</td> <td>560,842</td>		MLX	156,023	36,217	-	249,147	-	35,586	57,850	26,019	560,842
MMMI         -		IVIIVIX	156,023	36,217	-	245,732	-	34,368	49,130	26,019	547,490
NMMA         -			-	-	-	-	-	-	-	-	-
EL         130,023         36,217         102,223         33,244         298,303         20,019         703,019           GL         156,023         36,217         144,587         29,172         246,014         26,019         643,032           GL         156,023         36,217         157,034         32,028         280,834         26,019         643,032           MI         156,023         36,217         147,536         27,956         288,609         26,019         629,756           MM         156,023         36,217         145,350         27,956         288,407         26,019         629,726           MMX         156,023         36,217         128,043         23,744         202,003         26,019         572,049           MMX         1         -	-		156 000	-	-	160 000	-	- 22.044	200.005	- 26.010	-
CL         130,023         36,217         104,033         133,004         293,412         20,015         711,174           SE         ML         156,023         36,217         149,587         29,172         246,014         26,019         643,032           EM         156,023         36,217         157,034         32,028         280,834         26,019         6695,756           MM         156,023         36,217         145,350         27,956         238,407         26,019         629,975           MLX         156,023         36,217         131,609         24,812         208,889         26,019         639,576           MMX         156,023         36,217         128,043         23,744         202,003         26,019         77,949           MMI         -			150,023	30,217	-	164.025	-	33,244	209,900	26,019	703,031
Image         Instant         Instant <thinstant< th=""> <thinstant< th=""> <thins< td=""><td></td><td></td><td>156,023</td><td>30,217</td><td>-</td><td>140.597</td><td>-</td><td>20 172</td><td>295,472</td><td>26,019</td><td>642 022</td></thins<></thinstant<></thinstant<>			156,023	30,217	-	140.597	-	20 172	295,472	26,019	642 022
En         150,023         30,217         150,023         30,217         156,023         30,217         156,023         36,217         145,320         22,568         286,509         26,019         695,756           MM         156,023         36,217         145,320         23,548         20,003         26,019         629,972           MLX         156,023         36,217         131,609         24,812         208,889         26,019         583,569           MMX         156,023         36,217         131,609         24,812         208,889         26,019         572,049           MMX         156,023         36,217         43,150         31,460         488,591         26,019         781,460           CL         156,023         36,217         43,829         31,464         498,909         26,019         70,812           ML         156,023         36,217         37,70         29,728         485,453         26,019         710,812           CM         156,023         36,217         24,648         26,179         412,979         26,019         615,771           MLX         156,023         36,217         22,636         20,032         352,862         26,019         615,771			156,023	36,217	-	149,507	-	29,172	240,014	20,019	699 156
Bit         Chin         150,023         30,217         145,350         27,956         238,407         26,019         629,972           MLX         156,023         36,217         131,609         24,812         208,889         26,019         629,972           MLX         156,023         36,217         128,043         23,744         202,003         26,019         572,049           MMI         -	his	CM	156,023	36,217	-	158 420		32,020	286 500	26,019	695 756
B         Milk         156,023         36,217         131,609         24,812         208,889         26,019         583,569           MMX         156,023         36,217         128,043         23,744         202,003         26,019         583,569           MMX         156,023         36,217         128,043         23,744         202,003         26,019         572,049           MMX         1         -         <	d L	MM	156 023	36,217		145 350		27 956	238 407	26,019	629 972
Mixt         150,022         30,217         131,003         23,742         202,003         26,019         572,049           MMX         156,023         36,217         128,043         - <td>Me</td> <td>MIX</td> <td>156 023</td> <td>36 217</td> <td></td> <td>131 609</td> <td></td> <td>24,812</td> <td>208,407</td> <td>26,019</td> <td>583 569</td>	Me	MIX	156 023	36 217		131 609		24,812	208,407	26,019	583 569
MMX         100,022         001,211         100,023         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         20,171         21,160         448,591         26,019         781,460           CL         156,023         36,217         -43,829         -31,864         498,909         26,019         792,861           ML         156,023         36,217         -37,370         -29,729         485,635         26,019         70,813           EM         156,023         36,217         -37,732         -30,110         495,635         26,019         70,813           MM         156,023         36,217         -25,619         -21,057         350,836         26,019         613,789           MMX         156,023         36,217         -25,619         -21,057         350,836         26,019         772,844           MMX         156,023         36,217         -05,945         -36,641         451,999         26,019         772,844           CL         156,023         36,217         -65,828         -36,582		MMX	156 023	36 217		128 043		24,012	200,003	26,019	572 049
Immxi         - <td></td> <td>MMI</td> <td>- 100,020</td> <td></td> <td>-</td> <td></td> <td>-</td> <td>- 20,744</td> <td>- 202,000</td> <td>- 20,010</td> <td></td>		MMI	- 100,020		-		-	- 20,744	- 202,000	- 20,010	
Bit         Is6,023         36,217         -         43,150         -         31,460         488,591         26,019         781,460           CL         156,023         36,217         -         43,829         -         31,864         498,909         26,019         792,861           ML         156,023         36,217         -         38,626         -         27,628         411,675         26,019         696,188           ML         156,023         36,217         -         37,732         -         30,110         495,635         26,019         770,817,36           CM         156,023         36,217         -         34,648         -         26,179         412,979         26,019         615,771           MMX         156,023         36,217         -         22,636         -         20,032         352,862         26,019         613,779           MMX         156,023         36,217         -         65,945         -         36,641         451,999         26,019         771,226           MMXI         1-         -         -         -         -         -         -         -         -         -         -         -         -         -		MMXI	-	-	-	-	-	-	-	_	-
CL         156,023         36,217         -         43,829         -         31,864         488,909         26,019         792,861           ML         156,023         36,217         -         38,626         -         27,628         411,675         26,019         696,188           EM         156,023         36,217         -         37,370         -         29,729         485,453         26,019         770,812           CM         156,023         36,217         -         37,732         -         30,110         495,635         26,019         696,188           MM         156,023         36,217         -         34,648         -         26,179         412,979         26,019         615,771           MMX         156,023         36,217         -         22,636         -         20,032         352,862         26,019         613,789           MMMI         - <td< td=""><td></td><td>EL</td><td>156.023</td><td>36.217</td><td>-</td><td>43.150</td><td>-</td><td>31,460</td><td>488.591</td><td>26.019</td><td>781.460</td></td<>		EL	156.023	36.217	-	43.150	-	31,460	488.591	26.019	781.460
ML         156,023         36,217         -         38,626         -         27,628         411,675         26,019         699,188           EM         156,023         36,217         -         37,370         -         29,729         485,453         26,019         770,812           CM         156,023         36,217         -         37,732         -         30,110         495,635         26,019         781,736           MM         156,023         36,217         -         24,648         -         26,179         412,979         26,019         615,771           MLX         156,023         36,217         -         22,636         -         20,032         352,862         26,019         613,789           MMI         -		CL	156.023	36.217	-	43.829	-	31.864	498,909	26.019	792.861
Em         156,023         36,217         -         37,370         -         29,729         485,453         26,019         770,812           CM         156,023         36,217         -         37,732         -         30,110         495,635         26,019         781,736           MM         156,023         36,217         -         34,648         -         26,179         412,979         26,019         682,065           MLX         156,023         36,217         -         25,619         -         20,032         352,862         26,019         613,779           MMX         156,023         36,217         -         22,636         -         20,032         352,862         26,019         772,844           CL         156,023         36,217         -         65,828         36,682         450,557         26,019         752,546           ML         156,023         36,217         -         60,619         -         34,870         444,758         26,019         756,596           CM         156,023         36,217         -         60,619         -         34,870         444,758         26,019         756,596           CM         156,023         36,217		ML	156.023	36.217	-	38.626	-	27.628	411.675	26.019	696,188
E         CM         156,023         36,217         -         37,732         -         30,110         495,635         26,019         781,736           MM         156,023         36,217         -         34,648         -         26,179         412,979         26,019         692,065           MLX         156,023         36,217         -         25,619         -         21,057         350,836         26,019         613,789           MMX         156,023         36,217         -         2,636         -		EM	156,023	36,217	-	37,370	-	29,729	485,453	26,019	770,812
Ø         MM         156,023         36,217         -         34,648         -         26,179         412,979         26,019         692,065           MLX         156,023         36,217         -         25,619         -         21,057         350,836         26,019         615,771           MMX         156,023         36,217         -         22,636         -         20,032         352,862         26,019         613,789           MMI         -<	еШ	CM	156,023	36,217	-	37,732	-	30,110	495,635	26,019	781,736
MLX         156,023         36,217         25,619         21,057         350,836         26,019         615,771           MMX         156,023         36,217         22,636         20,032         352,862         26,019         613,789           MMI         - </td <td>Sal</td> <td>MM</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>34,648</td> <td>-</td> <td>26,179</td> <td>412,979</td> <td>26,019</td> <td>692,065</td>	Sal	MM	156,023	36,217	-	34,648	-	26,179	412,979	26,019	692,065
MMX         156,023         36,217         22,636         20,032         352,862         26,019         613,789           MMI         - <td></td> <td>MLX</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>25,619</td> <td>-</td> <td>21,057</td> <td>350,836</td> <td>26,019</td> <td>615,771</td>		MLX	156,023	36,217	-	25,619	-	21,057	350,836	26,019	615,771
MMI         -		MMX	156,023	36,217	-	22,636	-	20,032	352,862	26,019	613,789
MMXI         -		MMI	-	-	-	-	-	-	-	-	-
EL         156,023         36,217         -         65,945         -         36,641         451,999         26,019         772,844           CL         156,023         36,217         -         65,828         -         36,582         450,557         26,019         771,226           ML         156,023         36,217         -         63,433         -         34,773         436,081         26,019         752,546           EM         156,023         36,217         -         60,619         -         34,870         444,758         26,019         758,506           CM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         758,506           MM         156,023         36,217         -         58,662         -         32,943         431,397         26,019         678,334           MMX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         670,990           MMI         -         -         -         -         -         -         -         -         -         -         -         -         -         - <td< td=""><td></td><td>MMXI</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></td<>		MMXI	-	-	-	-	-	-	-	-	-
CL         156,023         36,217         -         65,828         -         36,582         450,557         26,019         771,226           ML         156,023         36,217         -         63,433         -         34,773         436,081         26,019         752,546           EM         156,023         36,217         -         60,619         -         34,870         444,758         26,019         758,506           CM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         758,506           MM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         771,226           MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         -         -         -         -         -         -         -         -         -         -         -         -         -         - <t< td=""><td></td><td>EL</td><td>156,023</td><td>36,217</td><td>-</td><td>65,945</td><td>-</td><td>36,641</td><td>451,999</td><td>26,019</td><td>772,844</td></t<>		EL	156,023	36,217	-	65,945	-	36,641	451,999	26,019	772,844
ML         156,023         36,217         -         63,433         -         34,773         436,081         26,019         752,546           EM         156,023         36,217         -         60,619         -         34,870         444,758         26,019         758,506           CM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         758,506           MM         156,023         36,217         -         58,662         -         32,943         431,397         26,019         741,261           MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         - <td< td=""><td></td><td>CL</td><td>156,023</td><td>36,217</td><td>-</td><td>65,828</td><td>-</td><td>36,582</td><td>450,557</td><td>26,019</td><td>771,226</td></td<>		CL	156,023	36,217	-	65,828	-	36,582	450,557	26,019	771,226
EM         156,023         36,217         -         60,619         -         34,870         444,758         26,019         758,506           CM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         758,506           MM         156,023         36,217         -         58,662         -         32,943         431,397         26,019         741,261           MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         -		ML	156,023	36,217	-	63,433	-	34,773	436,081	26,019	752,546
Server         CM         156,023         36,217         -         60,564         -         34,818         443,249         26,019         756,891           MM         156,023         36,217         -         58,662         -         32,943         431,397         26,019         741,261           MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         -	Ŀ	EM	156,023	36,217	-	60,619	-	34,870	444,758	26,019	758,506
MM         156,023         36,217         -         58,662         -         32,943         431,397         26,019         741,261           MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         -<	nve	CM	156,023	36,217	-	60,564	-	34,818	443,249	26,019	756,891
MLX         156,023         36,217         -         46,151         -         26,911         387,013         26,019         678,334           MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         - </td <td>De</td> <td>MM</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>58,662</td> <td>-</td> <td>32,943</td> <td>431,397</td> <td>26,019</td> <td>741,261</td>	De	MM	156,023	36,217	-	58,662	-	32,943	431,397	26,019	741,261
MMX         156,023         36,217         -         42,582         -         25,609         384,540         26,019         670,990           MMI         - <td></td> <td>MLX</td> <td>156,023</td> <td>36,217</td> <td>-</td> <td>46,151</td> <td>-</td> <td>26,911</td> <td>387,013</td> <td>26,019</td> <td>678,334</td>		MLX	156,023	36,217	-	46,151	-	26,911	387,013	26,019	678,334
MIMI         -		MMX	156,023	36,217	-	42,582	-	25,609	384,540	26,019	670,990
MMXI         -			-	-	-	-	-	-	-	-	-
EL         156,023         36,217         -         74,834         -         31,339         639,867         26,019         964,299           CL         156,023         36,217         -         74,759         -         31,293         638,193         26,019         964,299           ML         156,023         36,217         -         74,759         -         29,970         623,765         26,019         945,039           EM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           CM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           CM         156,023         36,217         -         71,182         -         29,829         641,930         26,019         961,158           MM         156,023         36,217         -         69,938         -         28,342         628,735         26,019         945,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023			450.000	-	-	-	-	-	-	-	-
OL         130,023         30,217         -         74,739         -         31,293         638,193         26,019         962,504           ML         156,023         36,217         -         73,045         -         29,970         623,765         26,019         945,039           EM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           CM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           CM         156,023         36,217         -         71,182         -         29,829         641,930         26,019         963,002           MM         156,023         36,217         -         69,938         -         28,342         628,735         26,019         945,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMX         156,023			150,023	30,217	-	74,834	-	31,339	629,00/	20,019	904,299
Imil         130,023         30,217         -         73,045         -         29,970         623,765         26,019         945,039           EM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           CM         156,023         36,217         -         71,182         -         29,874         643,687         26,019         963,002           MM         156,023         36,217         -         71,140         -         29,829         641,930         26,019         961,158           MM         156,023         36,217         -         69,938         -         28,342         628,735         26,019         945,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMX         156,023         36,217         -         -         -         -         -         -         -         -         -         -         -         - <td></td> <td></td> <td>156,023</td> <td>30,217</td> <td>-</td> <td>72 045</td> <td>-</td> <td>20.070</td> <td>622 765</td> <td>20,019</td> <td>902,504</td>			156,023	30,217	-	72 045	-	20.070	622 765	20,019	902,504
Open         Livi         130,023         30,217         -         71,102         -         29,674         043,067         26,019         963,002           CM         156,023         36,217         -         71,140         -         29,829         641,930         26,019         961,158           MM         156,023         36,217         -         69,938         -         28,342         628,735         26,019         945,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMI         -         -         -         -         -         -         -         -         -           MMXI         -			156,023	30,217	-	71 100	-	29,970	642 607	20,019	940,039
B         Com         130,023         30,217         -         71,140         -         23,023         041,350         26,019         961,156           MM         156,023         36,217         -         69,938         -         28,342         628,735         26,019         945,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMI         -         -         -         -         -         -         -         -         -         -         -           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMX         -	go		156,023	30,217	-	71 1/02	-	29,014	6/1 020	20,019	903,002
D         Milling         130,223         30,217         03,330         20,042         020,735         20,019         940,274           MLX         156,023         36,217         -         56,195         -         23,392         549,385         26,019         847,231           MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMI         -         -         -         -         -         -         -         -         -           MMXI         -	ica	MM	156 022	30,217	-	60 039	-	23,023	628 725	20,019	945 274
MMX         156,023         36,217         -         53,741         -         22,192         553,378         26,019         847,570           MMI         - <td>5</td> <td>MIX</td> <td>156 023</td> <td>36 217</td> <td>-</td> <td>56 105</td> <td>-</td> <td>20,342</td> <td>549 385</td> <td>26,019</td> <td>847 221</td>	5	MIX	156 023	36 217	-	56 105	-	20,342	549 385	26,019	847 221
Militia         - </td <td> </td> <td>MMX</td> <td>156 023</td> <td>36 217</td> <td></td> <td>53 7/1</td> <td>-</td> <td>20,002</td> <td>553 378</td> <td>26,019</td> <td>847 570</td>		MMX	156 023	36 217		53 7/1	-	20,002	553 378	26,019	847 570
		MMI			-		-	-		- 20,013	
		MMXI	-	-	-	-	-	-	-	-	-

### Table D1. Energy-10 Annual Electrical and Fuel End-Uses

Electrical. \$					Fue					
City	Scenario	Lights	Equipment	Heating	Cooling	Pumps/ auxiliary	Fans	Space heating	Hot water heating	Total, \$
	EL	11,920	2,767	-	24,381	-	2,368	237	969	42,643
	CL	11,920	2,767	-	24,570	-	2,437	247	969	42,911
	ML	11,920	2,767	-	25,258	-	2,428	214	969	43,556
	EM	11,920	2,767	-	24,132	-	2,271	69	969	42,128
am	CM	11,920	2,767	-	24,285	-	2,334	72	969	42,346
Mi	MM	11,920	2,767	-	25,133	-	2,331	69	969	43,189
	MLX	11,920	2,767	-	21,868	-	1,976	70	969	39,570
	MMX	11,920	2,767	-	21,753	-	1,882	9	969	39,300
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
	EL	14,900	3,459	-	28,417	-	4,296	2,761	688	54,521
	CL	14,900	3,459	-	28,759	-	4,393	2,800	688	55,000
	ML	14,900	3,459	-	29,498	-	4,343	2,927	688	55,814
ic	EM	14,900	3,459	-	27,875	-	4,202	2,417	688	53,541
oer		14,900	3,459	-	28,205	-	4,275	2,456	688	53,983
Ρ̈́		14,900	3,459	-	29,213	-	4,249	2,717	688	55,225
		14,900	3,459	-	23,794	-	3,398	1,530	688	47,769
		14,900	3,459	-	23,467	-	3,282	1,299	688	47,096
		-	-	-	-	-	-	-	-	-
		-	2,676	-	-	-	-	0 5 2 7	-	27.054
		11,530	2,070	-	12 122	-	2,437	0,007 9,701	700	29 204
		11,530	2,070	-	12,122	-	2,490	0,701 7.244	700	36,294
	EM	11,530	2,070	-	11,034		2,150	8 270	766	37 21/
sihis	CM	11,530	2,070		11,003		2,307	8 437	766	37 524
Ĕ	MM	11,530	2,070		10 741		2,407	7 020	766	34 800
Me	MIX	11,530	2,070		9 726		1 834	6 151	766	32 683
	MMX	11,530	2,070	_	9 462	-	1,004	5 948	766	32,000
	MMI		- 2,070	_	- 0,402	-		- 0,040		
	MMXI	-	-	-	-	-	-	-	-	-
	FI	9,252	2,148	-	2,559	-	1.866	13,170	701	29,696
	CL	9.252	2.148	-	2.599	-	1.890	13.449	701	30.038
	ML	9.252	2,148	-	2.291	-	1.638	11.097	701	27.127
	EM	9,252	2,148	-	2,216	-	1,763	13,086	701	29,166
E	CM	9,252	2,148	-	2,238	-	1,786	13,360	701	29,485
Salo	MM	9,252	2,148	-	2,055	-	1,552	11,132	701	26,840
0,	MLX	9,252	2,148	-	1,519	-	1,249	9,457	701	24,326
	MMX	9,252	2,148	-	1,342	-	1,188	9,512	701	24,143
	MMI	-	-	-	-	-	-	ľ	-	-
	MMXI	-	-	-	-	-	-	-	-	-
	EL	12,997	3,017	-	5,493	-	3,052	8,992	518	34,068
	CL	12,997	3,017	-	5,483	-	3,047	8,963	518	34,025
	ML	12,997	3,017	-	5,284	-	2,897	8,675	518	33,387
Ľ	EM	12,997	3,017	-	5,050	-	2,905	8,847	518	33,333
υve	CM	12,997	3,017	-	5,045	-	2,900	8,817	518	33,294
De	MM	12,997	3,017	-	4,887	-	2,744	8,582	518	32,744
	MLX	12,997	3,017	-	3,844	-	2,242	7,699	518	30,316
	MMX	12,997	3,017	-	3,547	-	2,133	7,650	518	29,861
	MMI	-	-	-	-	-	-	-	-	-
	MMXI	-	-	-	-	-	-	-	-	-
	EL	12,591	2,923	-	6,039	-	2,529	17,969	731	42,781
		12,591	2,923	-	6,033	-	2,525	17,922	/31	42,725
		12,591	2,923	-	5,895	-	2,419	17,517	/31	42,074
go		12,591	2,923	-	5,744	-	2,411	18,076	/31	42,476
ica		12,591	2,923	-	5,741	-	2,407	10,027	731	42,419
Ч		12,591	2,923	-	2,044	-	2,287	17,000	731	41,832 20.005
		12,591	2,923	-	4,000	-	1,008	15,428	731	30,095
		12,591	2,923	-	4,337	-	1,791	10,040	131	37,912
		-		-	-	-	-	-		-
L	ΙΛΙΝΙΝ	-	-	-	-	-	-	-	-	-

### Table D2. Energy-10 Annual Electrical and Fuel Cost

		Cost s	avings
City	Scenario	Compared to similar building, %	Compared to EL, %
	EL	0.0	0.0
	CL	0.0	-0.6
	ML	0.0	-2.1
	EM	1.2	1.2
E	CM	1.3	0.7
Mia	MM	0.8	-1.3
	MLX	9.2	7.2
	MMX	9.8	7.8
	MMI	-	-
	MMXI	-	-
	EL	0.0	0.0
	CL	0.0	-0.9
	ML	0.0	-2.4
.×	EM	1.8	1.8
en	CM	1.8	1.0
pho	MM	1.1	-1.3
а.	MLX	14.4	12.4
	MMX	15.6	13.6
	MMI	-	-
	MMXI	-	-
	EL	0.0	0.0
	CL	0.0	-0.9
	ML	0.0	6.7
is:	EM	2.0	2.0
þ	CM	2.0	1.1
len	MM	1.8	8.3
≥	MLX	7.7	13.9
	MMX	9.3	15.3
	MMI	-	-
	MMXI	-	-
	EL	0.0	0.0
	CL	0.0	-1.2
	ML	0.0	8.7
c	EM	1.8	1.8
len	CM	1.8	0.7
Sa	MM	1.1	9.6
	MLX	10.3	18.1
	MMX	11.0	18.7
	MMI	-	-
	MMXI	-	-
	EL	0.0	0.0
1	CL	0.0	0.1
1	ML	0.0	2.0
ē	EM	2.2	2.2
Ň	CM	2.1	2.3
De	MM	1.9	3.9
	IVILX	9.2	11.0
	IVIIVIX	10.6	12.3
		-	-
		-	-
		0.0	0.0
1		0.0	0.1
		0.0	1./
go		0.7	0.0
ica		0.7	0.8
Ch.		0.6	2.2
<b>-</b>	IVILX	9.5	11.0
	IVIIVIX	9.9	11.4
		-	-
<u> </u>	IVINIXI	-	-

### Table D3. Energy-10 Percent Cost Savings

**APPENDIX E – SENSITIVITY ANALYSIS ON FLOOR THICKNESS** 

City	Interior floor	Scenario*	Total annual	Total annual	Percent savin to	gs compared EL	Incremental cost savings compared to same scenario		
	thickness, in.		cost, \$	energy, kw	Cost, \$	Energy, kW	%	Cost, \$	
	4	EL	\$60,528	750,662	-	-	-	-	
	7.5	CM	\$58,794	705,158	2.9%	6.1%	-	-	
	7.5	MM	\$62,010	760,393	-2.4%	-1.3%	-	-	
	7.5	MMX	\$55,042	641,883	9.1%	14.5%	-	-	
	4	EL	\$60,528	750,662	-	-	-	-	
	9	CM	\$58,735	703,846	3.0%	6.2%	0.10%	\$59	
enix	9	MM	\$61,963	759,237	-2.4%	-1.1%	0.08%	\$47	
	9	MMX	\$54,999	640,909	9.1%	14.6%	0.08%	\$43	
ho	4	EL	\$60,528	750,662	-	-	-	-	
ш	10.5	CM	\$58,708	703,186	3.0%	6.3%	0.05%	\$27	
	10.5	MM	\$61,938	758,601	-2.3%	-1.1%	0.04%	\$25	
	10.5	MMX	\$54,984	640,400	9.2%	14.7%	0.03%	\$15	
	4	EL	\$60,528	750,662	-	-	-	-	
	12	CM	\$58,694	702,789	3.0%	6.4%	0.02%	\$14	
	12	MM	\$61,923	758,191	-2.3%	-1.0%	0.02%	\$15	
	12	MMX	\$54,971	640,069	9.2%	14.7%	0.02%	\$13	
	4	EL	\$36,417	836,598	-	-	-	-	
	7.5	CM	\$33,524	751,703	7.9%	10.1%	-	-	
	7.5	MM	\$32,676	731,711	10.3%	12.5%	-	-	
	7.5	MMX	\$28,153	603,552	22.7%	27.9%	-	-	
	9	EL	\$36,417	836,598	-	-	-	-	
	9	CM	\$33,446	749,599	8.2%	10.4%	0.2%	\$78	
	9	MM	\$32,605	729,797	10.5%	12.8%	0.2%	\$71	
em	9	MMX	\$28,106	602,281	22.8%	28.0%	0.2%	\$47	
Sal	4	EL	\$36,417	836,598	-	-	-	-	
	10.5	СМ	\$33,410	748,597	8.3%	10.5%	0.1%	\$36	
	10.5	MM	\$32,565	728,650	10.6%	12.9%	0.1%	\$40	
	10.5	MMX	\$28,077	601,463	22.9%	28.1%	0.1%	\$29	
	4	EL	\$36,417	836,598	-	-	-	-	
	12	CM	\$33,390	747,985	8.3%	10.6%	0.1%	\$20	
	12	MM	\$32,540	727,954	10.6%	13.0%	0.1%	\$25	
	12	MMX	\$28,061	601,013	22.9%	28.2%	0.1%	\$16	
	4	EI	\$47,461	909,259	-	-	-	-	
	7.5	СМ	\$43,778	817,744	7.8%	10.1%	-	-	
	7.5	MM	\$43,617	823,684	8.1%	9.4%	-	-	
	7.5	MMX	\$37,675	679,195	20.6%	25.3%	-	-	
	4	EI	\$47,461	909,259	-	-	-	-	
	9	CM	\$43,708	815,886	7.9%	10.3%	0.2%	\$70	
	9	MM	\$43,539	821,707	8.3%	9.6%	0.2%	\$78	
ver	9	MMX	\$37,617	677,656	20.7%	25.5%	0.2%	\$58	
Den	4	EI	\$47,461	909,259			-	-	
	10.5	CM	\$43,666	814,762	8.0%	10.4%	0.1%	\$42	
	10.5	MM	\$43,487	820,441	8.4%	9.8%	0.1%	\$52	
	10.5	MMX	\$37,589	676,906	20.8%	25.6%	0.1%	\$28	
	4	EL	\$47,461	909,259	-	-	-	-	
	12	СМ	\$43,644	814,166	8.0%	10.5%	0.1%	\$22	
	12	MM	\$43,462	819,681	8.4%	9.9%	0.1%	\$25	
	12	MMX	\$37,573	676,399	20.8%	25.6%	0.04%	\$16	

#### Table E1. Results of Sensitivity Analysis on Floor Thickness

\*Scenario EL, with a floor thickness of 4 in., is included because it is the baseline building to which comparisons must be made to satisfy LEED requirements.