Operating Energy Analysis

This section describes the approach utilized to develop operating energy profiles for the six building typologies included in this study.

I. APPROACH & METHODOLOGY

While actual buildings were used for the renovation and reuse (RR) and new construction (NC) building scenarios to derive materials quantities, their actual energy consumption and end-use profiles were not used, because doing so would have defined energy performance for each building type too narrowly. This would have made potential building-specific performance anomalies difficult to detect, including those involving maintenance, management and occupant behavior. Thus, analysis was undertaken to determine energy use intensities (EUIs) and energy end-use distribution profiles for each building type; these are assumed to be standard representations of all buildings within a given typology group.[1]

The methodologies utilized in this study varied slightly by building type. However, expert peer review and professional judgment were used to ensure that the operating energy values used in this analysis provide a reasonable approximation of performance for each building across each of the four test cities: Portland, Phoenix, Chicago, and Atlanta.

Energy-Performance Test Conditions

Three operating energy-performance *test conditions* were developed for each case study building in order to explore the effect of increased energy efficiency on life cycle environmental impacts.

The following energy-performance test conditions were used in this study:

- **Base Case**: A base case is typically used in the building industry to represent an energy performance level to compare against. For this study, this condition represents a typical building that has been built or renovated to operate at an *average* level of energy performance for each building type in each city selected for the study.[2] The Base Case assumes that buildings in both the NC and RR scenarios have the same operating energy performance. This test condition assumes that a renovated building has been retrofitted to include energy efficiency measures (EEMs), such that it is operating on par with new construction. In some instances, EEMs are added to new construction to enable it to meet the Base Case level of performance.

  The methodology for determining average energy use for each building type in each city is described in the following sections.

- **Advanced Case:** This condition represents an energy performance improvement over the Base Case and applies to instances where buildings are operating at an advanced level of energy efficiency. For the Advanced Case level of performance, both buildings include EEMs that increase their operating energy performance by an estimated 30 percent.

- **Pre-Energy Efficiency Measure ('Pre-EEM') Case**: This condition evaluates the life cycle impacts of an existing building that has been renovated to bring it to contemporary, functional use (as is common for older buildings) but which has *not included EEMs* to bring it up to an average level of energy performance. This test condition is key; in many instances, older buildings have inherent efficiency strengths related to their original design and construction elements and perform on par with new construction.

  In this study, the Pre-EEM Case is analyzed for the *commercial office building only*. The operating energy of the Pre-EEM Case is assumed to be equivalent to the Base Case test condition.

II. DETERMINING ENERGY PROFILES

A multi-step approach was used to develop annual energy consumption and end-use profiles for each test condition.

<u>Step 1</u> – Base Case energy use was established. The energy use for the Base Cases of each typology was drawn from credible building energy-performance studies and national survey data.

The following six building types were evaluated: Single-Family Residential, Multifamily Residential, Commercial Office, Urban Village Mixed Use, Elementary School, and Warehouse. These types were analyzed across four representative cities: Portland, Phoenix, Chicago, and Atlanta.

<u>Step 2</u> – Base Case energy was apportioned by end use. For each building typology and city, annual energy use was broken down and apportioned based on kWh of electricity and therms of natural gas, for the following categories: Space heating and cooling, lighting, fan/pump energy, and hot water, among other categories.[3]

For each building type studied, energy end-use profiles were derived from previous building energy studies and national survey data.

<u>Step 3</u> – Appropriate EEMs were identified, by building type, and EEMs were selected to bring each case study building to the Base Case level of performance. The project team developed an extensive list of EEMs that could be applied to various building types. These were derived from energy code prescriptive requirements, energy performance guides, and professional experience. Professional judgment was then used to generate a specific set of EEMs appropriate to each case study building, to bring the buildings up to the Base Case energy usage.

<u>Step 4</u> – EEMs were selected to bring each building type up to an Advanced Case level of energy performance and energy savings were calculated over the Base Case. A 'package' of EEMs was identified to achieve an Advanced Case level of performance appropriate to each building type. EEMs to reduce electrical loads (i.e., cooling, lighting, plug loads, pumps, fans, and equipment) and natural gas loads (i.e., heating and domestic hot water) were assumed to be achievable through the integration of more efficient heating and cooling systems, high-efficiency lighting, equipment, and appliances.

The Advanced Case energy profiles were calculated, for each building type, by taking the Base Case EUI and reducing electrical and gas energy end uses by 30 percent, for an overall energy savings of 30 percent (compared to the Base Case).

<u>Step 5</u> – Results were documented. The energy use data was tabulated in a spreadsheet format; key assumptions were documented; and the energy use results for all building types in each city were analyzed. These results were used as inputs for the life cycle assessment (LCA) analysis. The material inputs for EEMs, e.g., additional insulation, were also quantified and included in the LCA modeling.

III. APPLYING THE METHODOLOGY

Commercial Office Buildings

The following section describes the methodology that was applied to the Commercial Office case study building. Similar approaches were used for the other commercial-building case studies, i.e. Elementary School, Urban Village Mixed Use, and Warehouse-to-Commercial Office Conversion.

<u>Step 1</u> – Base Case energy use was established.

A variety of data sources were used to determine reasonable EUIs for the various commercial buildings analyzed. Sources included analyses and surveys by the Energy Information Administration, the New Buildings Institute, Cadmus, and the Oregon Department of Energy's State Energy Efficiency Design (PGE User Guide, SEED) program.[4] Due to the limitations of the Commercial Buildings Energy Consumption Survey (CBECS) sample sizes for the building types and cities/climate regions analyzed in this study, the team opted to use multiple data sources rather than rely solely on national survey data.

The Cadmus study, which provides energy survey data for over 2,000 commercial buildings in the Pacific Northwest, was used to select a reasonable Base Case EUI for a commercial office building located in Portland, Oregon,[5] Base Case EUIs for the Elementary School and Urban Village Mixed Use buildings in Portland were derived from the Portland General Electric (PGE) User Guide of the Oregon Department of Energy.[6]

It was assumed that a Warehouse-to-Commercial Office Conversion operates the same as a new or retrofitted commercial office.[7]

Next, the NBI's sensitivity analysis research was utilized; it is based on energy modeling and examines buildings across multiple climate regions. The NBI research finds that the EUI for an office building in Portland is expected to be *lower than its counterparts in Phoenix, Chicago and Atlanta*, by 2 percent, 33 percent and 8 percent, respectively (see Table 1). These relative climatic adjustment factors were applied consistently across the other commercial building types used in this study, i.e., Elementary School, Urban Village Mixed Use, and Warehouse-to-Commercial Office Conversion. An extensive peer review process was used to vet the Commercial Building EUI data and assumptions.

Table 1. Office Building End-Use EUI Comparison Table by Climate Zone

End-Use	Climate Zone Relative EUI (kBtu/sf/yr)			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	2	20	7	13
Space Heating	19	0	38	16
DHW	1	1	1	1
Vent Fans	12	14	11	10
Pumps & Aux	0	0	0	0
Extr. Lighting	5	5	5	5
Misc. Equip.	16	16	16	16
Int. Lighting	15	15	15	15
Subtotal	70	71	93	76
Adjustment Factor %	1	1.02	1.33	1.08

Notes:

1) EUI of 70 kBtu/sf chosen for base case (Portland) based on Cadmus Study entitled 'Northwest Commercial Building Stock Assessment'.

2) Methodology devised from feedback from peer group and NBI on there research across different climate zones

3) EUI's adjusted by climate zone in alignment with Table 6 in NBI Sensitivity Analysis Study (page 47) dated July 2011.

4) Climate zone adjustment factors above will be used consistently across all other commercial buildings in this study.

5) Space heating and domestic hot water assumed to be gas, all other end-uses assumed to be electric in this study.

Source: Energy Information Administration, the New Buildings Institute, Cadmus, and the Oregon Department of Energy's State Energy Efficiency Design (PGE User Guide, SEED) program. See Endnote No. 4.

<u>Step 2</u> – Base Case energy was apportioned by end use.

Total building energy use was divided into the following end-use categories: space heating, space cooling, ventilation (i.e., typically fan energy), water heating, pump energy, lighting, and miscellaneous equipment (a catch-all for plug loads and other equipment loads).

For the Commercial Office Building and the Warehouse-to-Commercial Office Building scenarios, findings by NBI provided end-use proportions for the test cities used in this analysis.[8] End-use energy distributions for the Elementary School and the Urban Village Mixed Use typologies in Portland were derived from the Portland General Electric EUI data. This data is listed in the 2006 SEED Guidelines, which provides industry-accepted EUI baselines for these building types in the city of Portland.

While these reports provided a basis for the Commercial Building end-use profiles, the team performed a sensitivity analysis to confirm assumptions regarding the end-use profiles of the commercial building types. Using CBECS climate zone data, each building's internal loads were held constant, while space heating and cooling—which are influenced by climate—were adjusted to best reflect climate-related influences. The resulting space cooling and heating EUIs were compared to various climate-based data, including Heating Degree Days (HDD)/Cooling Degree Day (CDD), from ASHRAE 2009 Fundamental Journal[9], and the software tool Climate Consultant[10] which uses raw Energy Plus weather files.

Once the EUIs and end-uses were defined for each building type in Portland, they were used as bases and adjusted to the three other cities using the adjustment factors show above, in Table 1. This process of apportioning the space cooling and heating end uses was used for all the building typologies and cities.

Figures 1-4 (derived from Table 1 above) depict the annual energy end-use distributions, per square foot, for commercial office buildings in the four test cities derived from the sources listed above.

Figures 1-4. Apportionment of Energy End Use for Commercial Office Buildings

Figure 1 - Office End-Use Profile - Portland (Base)

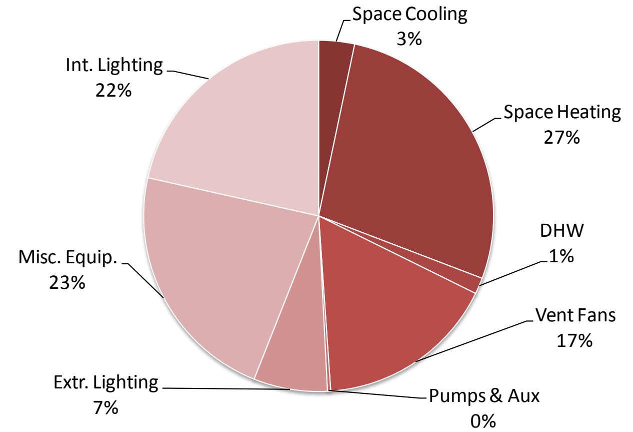


Figure 2 - Office End-Use Profile - Chicago

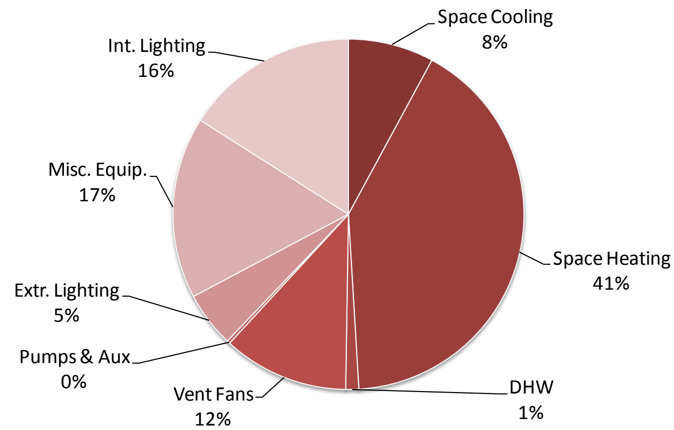


Figure 3 - Office End-Use Profile - Phoenix

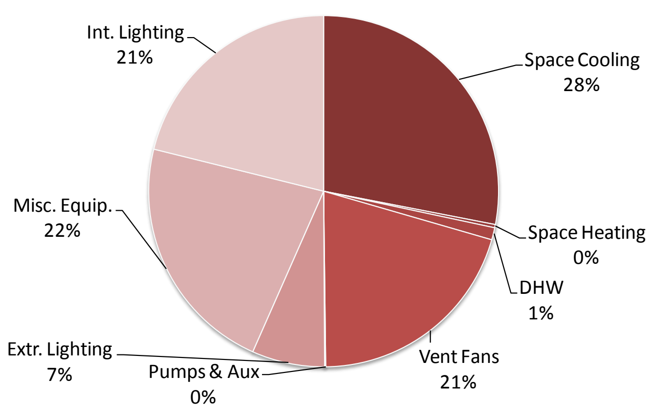
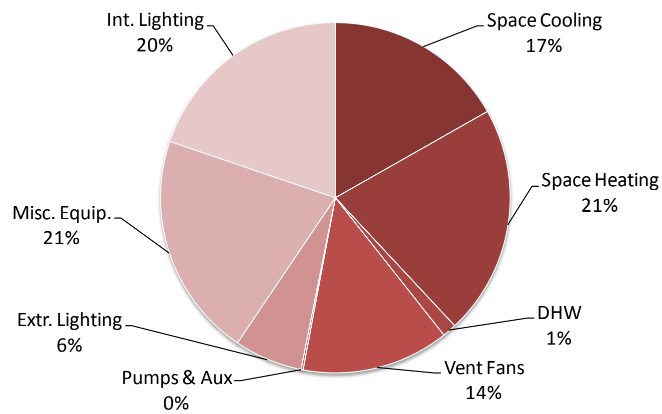


Figure 4 - Office End-Use Profile - Atlanta



Source: Figures 1-4 derived from Table 1 above

<u>Step 3</u> – A list of appropriate EEMs was identified by building type, and EEMs were selected to bring each case study building to the Base Case level of performance.

The next step entailed an analysis of measures to improve energy efficiency in the Commercial Office Building scenarios. In developing a recommended list of EEMs that would likely bring the case study buildings up to the Base Case level of energy performance, the project team relied upon published guidelines, such as ASHRAE Advanced Energy Design Guides, as well as the expertise and judgment of team members and professional peers.

Table 2 identifies the possible EEMs that could be applied to the commercial office buildings. EEMs were then chosen to achieve Base Case levels of energy performance.

Table 2. Potential EEMs for Office Buildings

EEM #	EEM Description	Portland	Chicago	Atlanta	Phoenix
1	R-20 c.i roof insul.	✓	✓	✓	✓
2	R-13 insulated walls	✓	✓	✓	✓
3	Infiltration Reduction - Chaulking	✓	✓	✓	✓
4	Glazing U-value 0.32	✓	✓	✓	✓
5	Low-e coated glazing/solar film	✗	✗	✓	✓
6	Interior LPD 0.8 w/sf	✓	✓	✓	✓
7	Night Sweep/Occ Snsrs Lght Control	✓	✓	✓	✓
8	Demand Control Ventilation (DCV)	✓	✓	✓	✓
9	VFD HVAC Motors	✓	✓	✓	✓
10	Chilled Beams	✓	✓	✓	✓
11	HVAC Cooling Efficiency - 0.3 EIR	✓	✓	✓	✓
12	Direct/Indirect Evap. Cooling	✗	✗	✗	✓
13	HVAC Heating - 83%min. efficiency	✓	✓	✓	✗
14	Ground Source Heat Pump System	✓	✓	✓	✓
15	Economizer Control	✓	✓	✗	✓
16	Heat Recovery of exhaust flow	✓	✓	✓	✓
17	Solar preheating of outside air	✓	✓	✓	✗
18	HW Pipe Insulation R-4	✓	✓	✓	✓
19	90%+AFUE DHW System	✓	✓	✓	✓
20	Energy Star rated equip/appliances	✓	✓	✓	✓

Source: EEMs derived from AHSRAE Advanced Design Guides and professional experience

<u>Step 4</u> – EEMs were selected to bring each building type up to an Advanced Case level of energy performance and energy savings were calculated over the Base Case.

The project team identified a package of EEMs that would bring both the RR and the NC buildings to an Advanced Case level of energy performance, which is a 30 percent improvement in energy efficiency compared to the Base Case. The summary of EEMs is based on analysis of the approximate energy savings from each energy efficiency measure shown in Table 3. The project team utilized professional judgment and expertise, as well as the the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Advanced Design Guides, which provide a prescriptive list of energy efficiency measures which are expected to provide an anticipated 30 percent energy use reduction compared to the ASHRAE 90.1 – 2004 baseline, to determine which EEMs would likely result in a 30% percent improvement in energy performance over the Base Case.[11]

Advanced Case energy use reductions were then calculated by reducing electrical loads by 30 percent and natural gas loads by 30 percent. Table 4 provides a summary of the resulting overall energy reduction by building type and city.

Table 3. Projected Savings Broken Down by EEM to Reach Advanced Case Energy Performance

Energy Measures		Savings %	
Base Case	Advanced	System	Building
Wall Insulation R-13	Same as Baseline	0%	0%
Roof Insulation R-20 ci	Same as Baseline	0%	0%
Wood/Vinyl Window U-0.54	Window U-0.38	30%	1-4%
No Low-e coated glazing	Low-e coated glazing/solar film	18%	1-3%
Building LPD 1.0 w/sf	Building LPD 0.85 w/sf	15%	2-4%
Office Lighting LPD 1.1 w/sf	Office Lighting LPD 0.8 w/sf	27%	1-2%
Occ Snsrs Lght Control	Night Sweep/Occ Snsrs Lght Control	10%	0-2%
No Daylight Dimming Controls	Daylighting Dimming Controls	35%	2-4%
No DCV Controls	DCV in Conf. Rooms & Assembly Spaces	20%	0-2%
No Chilled Beams	Chilled Beams in Offices	30%	1-3%
VFD HVAC Motors	VFD HVAC Motors	0%	0%
Infiltration 0.40 ACH	Infiltration 0.20 ACH	50%	1-3%
Boiler - 80% min. efficiency	Boiler - 90% + min. efficiency	12%	1-4%
HVAC Chiller Efficiency - 4.5 to 6.4 COP	Same as Baseline	0%	0%
No ERV required	ERV	45%	1-2%
No Solar Thermal Hot Water System	Solar Thermal Hot Water System	40%	1-2%
DHW - Gas heat w/ 80% eff.	DHW - Gas heat w/ 93% eff.	13%	0-1%
Standard water flow fixtures	Low-flow water fixtures	35%	1-2%
			30%[1]

Notes:

1) Overall building savings will depend on interactive relationships between EEMs

Source: ASHRAE Advanced Design Guides and professional experience

Table 4. Commercial Building Energy Use

Building Type and Region		Base Case EUI (kBtu/sf/yr)			Advanced Case EUI (kBtu/sf/yr)			Percentage
		Base Case EUI	Fuel EUIs[1] (kBtu/sf/yr)		Adv. Case EUI[2]	Fuel EUIs[1] (kBtu/sf/yr)		Overall Energy
Building Type	Region	(kBtu/sf/yr)	Electric	Gas	(kBtu/sf/yr)	Electric	Gas	Reduction
Office	Portland	70	49.7	20.3	49.0	34.8	14.2	30%
	Phoenix	71	69.9	1.1	49.7	48.9	0.8	30%
	Chicago	93	53.7	39.3	65.1	37.6	27.5	30%
	Atlanta	76	58.9	17.1	53.2	41.2	12.0	30%
Mixed Use	Portland	71	51.9	19.1	49.7	36.3	13.4	30%
	Phoenix	72	65.9	6.1	50.4	46.1	4.3	30%
	Chicago	94	50.0	44.0	65.8	35.0	30.8	30%
	Atlanta	76	57.7	18.3	53.2	40.4	12.8	30%
Elementary	Portland	60	27.0	33.0	42.0	18.9	23.1	30%
	Phoenix	61	49.8	11.2	42.7	34.9	7.8	30%
	Chicago	80	26.1	53.9	56.0	18.3	37.7	30%
	Atlanta	65	40.1	24.9	45.5	28.1	17.4	30%
Warehse to Office	Portland	70	49.7	20.3	49.0	34.8	14.2	30%
	Phoenix	71	69.9	1.1	49.7	48.9	0.8	30%
	Chicago	93	53.7	39.3	65.1	37.6	27.5	30%
	Atlanta	76	58.9	17.1	53.2	41.2	12.0	30%

Source: Base Case EUI and Fuel EUIs derived from Table 1 above

<u>Step 5</u> – The results were documented.

The results from the commercial building energy analysis, shown in Table 4, were used to model the life cycle environmental impacts associated with each case study building.

IV. SINGLE-FAMILY RESIDENTIAL BUILDINGS

This section describes the energy methodology for determining operating energy for the single-family residential case study. Similar methods were used to determine multifamily energy use, except where noted.

Step 1 – **Base Case energy use was established.**

The Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS) formed the basis of the operating energy analysis for single-family and multifamily residential buildings.[12] RECS was used to establish the Base Case energy performance of homes, accounting for the influences that climate conditions play in energy consumption.

Table 5 (which uses from RECS table US1 for Climate Zones 2, 3, 4 and 5) shows the relative end-use EUIs (kBtu/sf/yr) for a single-family residence in various climate zones. This zone-specific data corresponds to the cities in which various building scenarios were evaluated in this analysis.

Table 5. Single-Family Residential End-Use EUI Comparison Table by Climate Zone

	Climate Zone Relative EUI (kBtu/sf/yr)			
End-Use	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	3	12	2	6
Space Heating	23	5	25	13
DHW	10	10	10	10
Refrigerators	2	2	2	2
Lighting & Appliances	8	8	8	8
Total	46	37	47	39

Notes:

1) EUIs in table above are from RECS Table US1 for climate zones 2 through 5.

Source: Total EUI based upon the Energy Information Administration's 2005 Residential Energy Consumption Survey. Domestic hot water, refrigeration lighting and appliances held constant based upon Portland data and held constant across all other city climates. Space heating and cooling is derived from the relative climate influences from using Climate Consultant software and Heating and Cooling Degree Days.

For multifamily residential buildings, RECS data for Apartments with 5 or more units served as the basis of the analysis. Base Case EUIs for multifamily buildings were then adjusted to account for common areas (since RECS data currently does not include these areas) by assuming that 80 percent of floorspace for each building is dedicated to living areas, while the remaining 20 percent is common core areas. EUIs for multifamily buildings are listed in Section V.

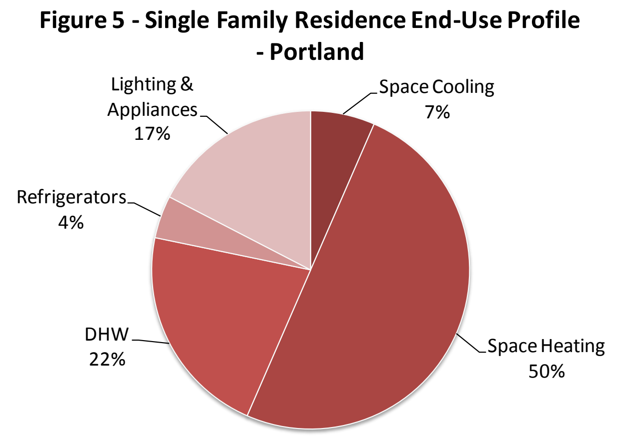
Step 2 – **Energy use was apportioned.**

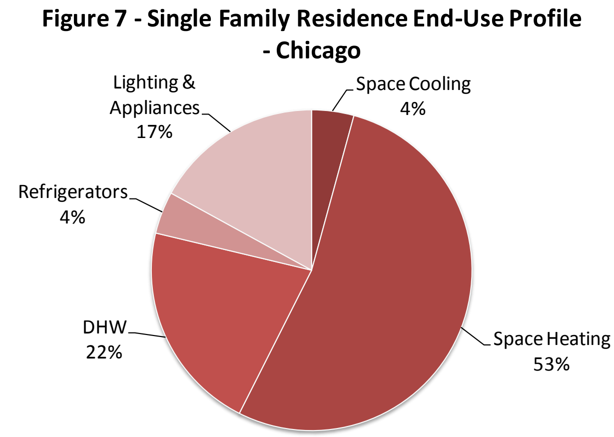
As with commercial buildings, energy was apportioned by end use to enable decision making on how various EEMs would improve energy performance. For single-family residential buildings, RECS provides data on end-use consumption, breaking data into five end uses: space heating, space cooling, lighting/appliances, refrigeration, and domestic hot water.

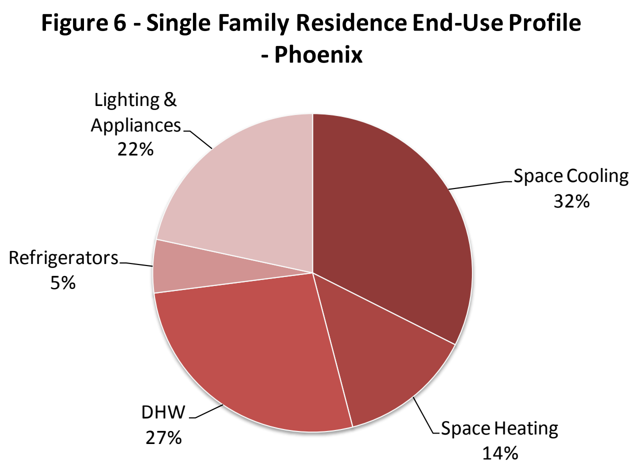
While RECS provides EUIs and energy end-use breakdowns for residential buildings, it does not provide breakdowns across different climate zones. Therefore, it was necessary to develop a sensitivity analysis in order to apportion end-use energy for the multifamily buildings in each of the four cities analyzed. Interior energy end uses (DHW, Refrigeration, and Lighting/Appliances) were held constant, while heating and cooling were reconciled across the different climate regions. Similar to the approach used for commercial buildings, the analysis involved examining historic weather data and heating and cooling degree days, as listed in ASHRAE 2009 Fundamentals, and comparing the data back to the EUI and end-use data provided by RECS.[13]

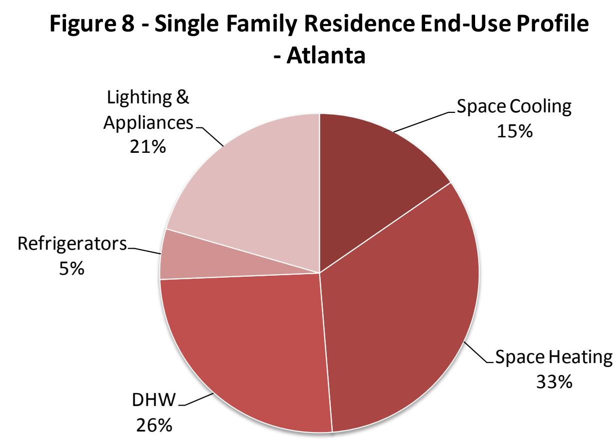
Figures 5-8 depict the annual energy end-use distributions for single-family residential buildings for the four climate zones in this study.

Figures 5-8. Apportionment of Energy End Use for Single-Family Residential Buildings









Source: Figures 5-8 derived from Table 5 above

<u>Step 3</u> – A list of appropriate EEMs was identified, by building type, and EEMs were selected to bring case study buildings to the Base Case level of performance.

The project team developed a list of EEMs for the residential building scenarios. Table 6 outlines the list of possible EEMs that could be applied to a residential building to make the design of its energy components more efficient. The list is derived from the project team's experience analyzing and modeling typical HVAC, lighting, and envelope designs, resulting in practical knowledge about those EEMs most likely to reduce energy end use.

As with the commercial building scenarios, certain EEMs were applied to both the NC home and RR home scenarios to achieve Base Case levels of energy performance.

Table 6 – Potential EEMs for Single-Family Residences

EEM #	EEM Description	Portland	Chicago	Atlanta	Phoenix
1	R-30 roof/attic insul.	✔	✔	✔	✔
2	R-13/R-19 insulated walls	✔	✔	✔	✔
3	Infiltration Reduction - Sealing	✔	✔	✔	✔
4	Glazing U-value 0.32 or Below	✔	✔	✔	✔
5	Insulated doors & window frames	✔	✔	✔	✔
6	Low-e coated glazing/solar film	✖	✖	✔	✔
7	Interior LPD <1.0 w/sf	✔	✔	✔	✔
8	Occ Sensors Light Control	✔	✔	✔	✔
9	Efficient Exterior Lighting (CFL/LED)	✔	✔	✔	✔
10	Skylights/Tubular Daylight Devices	✔	✔	✔	✔
11	Seal & Insulate Ductwork	✔	✔	✔	✔
12	HVAC Cooling Efficiency - SEER 14 +	✔	✔	✔	✔
13	Direct/Indirect Evap. Cooling	✔	✖	✖	✔
14	Gas Heating - 92%min. efficiency	✔	✔	✔	✔
15	Ground Source Heat Pump System	✔	✔	✔	✔
16	Hydronic Radiant Heating	✔	✔	✔	✔
17	Programmable Thermostats	✔	✔	✔	✔
18	HW Pipe Insulation R-4	✔	✔	✔	✔
19	90%+AFUE DHW System	✔	✔	✔	✔
20	Instaneous HW Heating System	✔	✔	✔	✔
21	Instant HW recirculation system	✔	✔	✔	✔
22	Solar Thermal HW System	✔	✔	✔	✔
23	Low-flow water fixtures	✔	✔	✔	✔
24	Energy Recovery Ventilators	✔	✔	✔	✔
25	Energy Star rated equip/appliances	✔	✔	✔	✔

Source: EEMs based upon professional experience

<u>Step 4</u> – EEMs were selected to bring each building type up to an Advanced Case level of energy performance, and energy savings were calculated over Base Case.

For Single-Family and Multifamily Residence scenarios, EEMs were selected by the project team to achieve an advanced level of energy performance over the Base Case for both the NC and RR buildings. Table 7 indicates the break down in potential savings from bundled EEMs. These EEMs are transferable across all climate regions and should suffice as the basis for moving existing or new single-family residences to an advanced level of energy performance. However, it should be noted that some of the EEMs listed would be more effective and appropriate for certain climates more than others.

Advanced Case energy-use reductions were then calculated by reducing electrical loads and natural gas loads by 30 percent. Table 8 provides a summary of the resulting overall energy reduction by building type and city.

Table 7. Bundled List of EEMs to Achieve Advanced Case Level of Performance for Single-Family and Multifamily Buildings

Energy Measures		Savings %	
Baseline/Code	Advanced	System	Building
Insulation R-13	Insulation R-19 [1]	25%	2-5%
Wood/Vinyl Window U-0.54	Energy Star Window U-0.32	40%	1-3%
Infiltration 0.7 ACH	Infiltration 0.35 ACH	100%	2-5%
Gas Boiler/Furnace 80% AFUE	Gas Boiler/Furnace 95% AFUE	18%	1-3%
Water Source HP 4.2 COP	Water Source HP 4.5 COP	7%	1-4%
No ERV required	ERV	50%	0-2%
Lighting: 50% of fixtures CFL	Lighting: 80% of fixtures CFL	35%	2-8%
DHW - Gas heat w/ 80% eff.	DHW - Gas heat w/ 93% eff.	13%	1-3%
Standard water flow fixtures	Low-flow water fixtures	35%	2-7%

20 to 40%[2]

Notes:

1) Existing framed walls (2x4 studs) may need to be furred out to accommodate additional R-19 insulation

2) Overall building savings will depend on interactive relationships between EEMs

Source: EEMs based upon professional experience

Table 8: Warehouse to Residential Conversion Use EEM List

Energy Measures		Estimated Savings %	
Baseline/Code	Advanced	System	Building
Wall Insulation R-13	Same as Baseline	0%	0%
Roof Insulation R-20 ci	Same as Baseline	0%	0%
Wood/Vinyl Window U-0.54	Window U-0.38	30%	2-3%
No Low-e coated glazing	Low-e coated glazing/solar film	18%	2-3%
Corridors LPD 0.5 w/sf	Corridors LPD 0.4 w/sf	20%	0-1%
Residential Lighting: 50% CFL	Residential Lighting: 85% CFL	35%	3-5%
No Occ Snsrs Lght Control in Corridors	Occ Snsrs Lght Control in Corridors	70%	1-2%
VFD HVAC Motors	Same as Baseline	0%	0%
Infiltration 0.75 ACH	Infiltration 0.35 ACH	50%	1-3%
Boiler - 80% min. efficiency	Boiler - 90% + min. efficiency	12%	2-4%
Standard Heat Pump - EER 10.1	VRF Units 3.2 to 4.5 COP	14%	1-2%
No ERV	ERV of Ventilation Air	45%	1-2%
No Solar Thermal Hot Water System	Solar Thermal Hot Water System	40%	2-6%
DHW - Gas heat w/ 80% eff.	DHW - Gas heat w/ 93% eff.	13%	1-3%
Standard water flow fixtures	Low-flow water fixtures	35%	4-6%

20 to 40%[1]

Notes:

1) Overall building savings will depend on interactive relationships between EEMs

Source: EEMs based upon professional experience

Table 9. Residential Building Energy Use

Building Type and Region		Base Case EUI (kBtu/sf/yr)			Advanced Case EUI (kBtu/sf/yr)			Percentage
		Base Case EUI	Fuel EUIs[1] (kBtu/sf/yr)		Adv. Case EUI[2]	Fuel EUIs[1] (kBtu/sf/yr)		Overall Energy
Building Type	Region	(kBtu/sf/yr)	Electric	Gas	(kBtu/sf/yr)	Electric	Gas	Reduction
Warehse to Apts.	Portland	63	21.0	42.0	44.1	14.7	29.4	30%
	Phoenix	50	30.0	20.0	35.0	21.0	14.0	30%
	Chicago	64	19.0	45.0	44.8	13.3	31.5	30%
	Atlanta	53	24.0	29.0	37.1	16.8	20.3	30%
MultiFamily	Portland	63	21.0	42.0	44.1	14.7	29.4	30%
	Phoenix	50	30.0	20.0	35.0	21.0	14.0	30%
	Chicago	64	19.0	45.0	44.8	13.3	31.5	30%
	Atlanta	53	24.0	29.0	37.1	16.8	20.3	30%
Single Family	Portland	46	13.0	33.0	32.2	9.1	23.1	30%
	Phoenix	37	22.0	15.0	25.9	15.4	10.5	30%
	Chicago	47	12.0	35.0	32.9	8.4	24.5	30%
	Atlanta	39	16.0	23.0	27.3	11.2	16.1	30%

Source: EUI based upon the Energy Information Administration's 2005 Residential Energy Consumption Survey.

Step 5 – Results were documented.

The results from the residential building energy analysis, shown in Table 8, were used to model the life cycle environmental impacts for each case study building.

V. ADDITIONAL BUILDING TYPES

This section provides the operating energy profiles for Urban Village Mixed Use, Elementary School, and Multifamily Residential Buildings.

Urban Village Mixed Use

Since the Urban Village Mixed Use building category consisted of two distinctive, functional uses (i.e., office and retail), it was determined that establishing an appropriate EUI would involve balancing their different energy-consumption profiles. This would be accomplished by determining the average weighting of their respective EUIs, for each of the two space types represented. For simplicity, the EUIs were weighted evenly (50/50) across both space types.

Tables 10-12 demonstrate how the Base Case EUI was derived for the Urban Village Mixed Use scenario.

Table 10. Mixed Use Building End-Use EUI Comparison by Climate Zone

End-Use	Climate Zone Relative EUI (kBtu/sf/yr)			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	3	17	3	10
Space Heating	17	4	42	16
DHW	2	2	2	2
Vent Fans	10	11	9	10
Pumps & Aux	0	0	0	0
Extr. Lighting	3	3	3	3
Misc. Equip.	16	16	16	16
Int. Lighting	19	19	19	19
Subtotal	71	72	94	76
Adustment Factor %	1	1.02	1.33	1.08

Source: Portland total EUI includes a weighted average of 50% office and 50% retail space. Office EUI based upon the Cadmus Group, Inc., 2009 study: Northwest Commercial Building Stock Assessment. Retail EUI based upon the User Guide for PGE Energy Use Index Guidelines, Oregon Department of Energy SEED, 2006. EUI's adjusted by climate zone in alignment with Table 6 in NBI Sensitivity Analysis Study (page 47) dated July 2011.

Table 11. Mixed Use Weighted Average EUI by Space Type

End-Use	Function Type EUI (kBtu/sf/yr)			
	Retail	Office	Avg Wgt EUI	%
Space Cooling	5.3	2.31	3.81	5.35%
Space Heating	12.84	19.25	16.05	22.55%
DHW	3.6	1.05	2.33	3.27%
Vent Fans	6.3	11.62	8.96	12.59%
Pumps & Aux	0	0.21	0.11	0.15%
Extr. Lighting	0	4.76	2.38	3.35%
Misc. Equip.	17.57	15.75	16.66	23.42%
Int. Lighting	26.67	15.05	20.86	29.32%
		Subtotal	71.14	

Notes:

1) Assumed 50/50 split between retail and general office areas.

Source: Portland total EUI includes a weighted average of 50% office and 50% retail space. Office EUI based upon the Cadmus Group, Inc., 2009 study: Northwest Commercial Building Stock Assessment. Retail EUI based upon the User Guide for PGE Energy Use Index Guidelines, Oregon Department of Energy SEED, 2006. EUI's adjusted by climate zone in alignment with Table 6 in NBI Sensitivity Analysis Study (page 47) dated July 2011.

Table 12. Mixed Use Building End-Use Profile by Climate Zone

End-Use	End-Use Profile by Climate Zone			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	5%	24%	3%	13%
Space Heating	24%	6%	45%	21%
DHW	3%	3%	2%	3%
Vent Fans	14%	15%	10%	13%
Pumps & Aux	0%	0%	0%	0%
Extr. Lighting	4%	4%	3%	4%
Misc. Equip.	23%	22%	17%	21%
Int. Lighting	27%	26%	20%	25%
Subtotal	100%	100%	100%	100%

Notes:

1) Portland end-use profile used from NBI (Office) & Oregon SEED EUI data (PGE Energy Use Index Guidelines) for retail type spaces.

2) Assumed 50/50 split between retail and general office areas.

3) Methodology devised from feedback from peer group and end-use profiles derived from NBI Senstivity Analysis Study (Appendix B).

Source: Table 10 above

Figures 9-12. Apportionment of Energy End Use for Mixed Use Buildings

Figure 9 - Mixed Use End-Use Profile - Portland (Base)

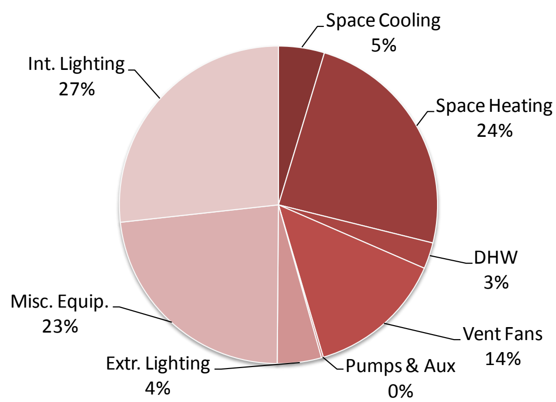


Figure 11 - Mixed Use End-Use Profile - Chicago

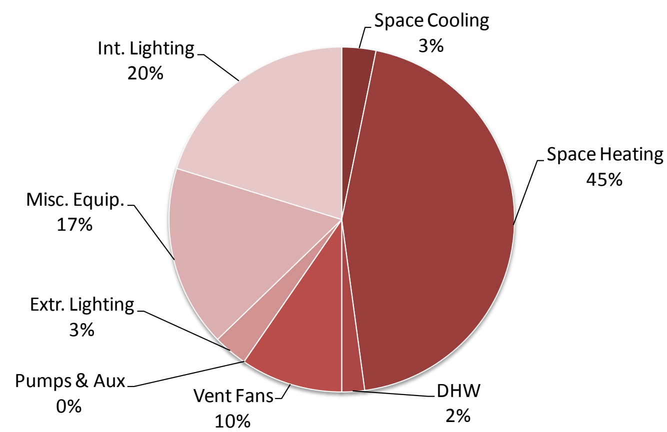


Figure 10 - Mixed Use End-Use Profile - Phoenix

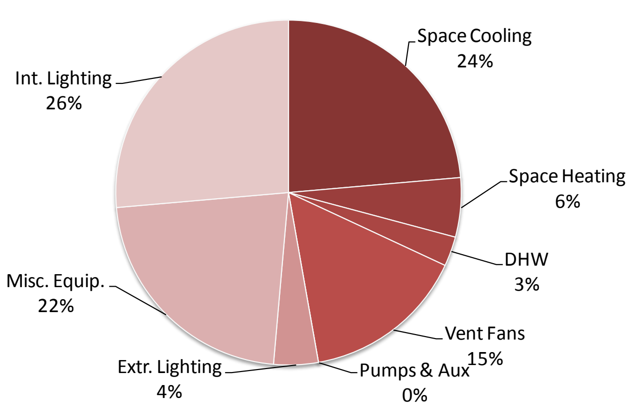
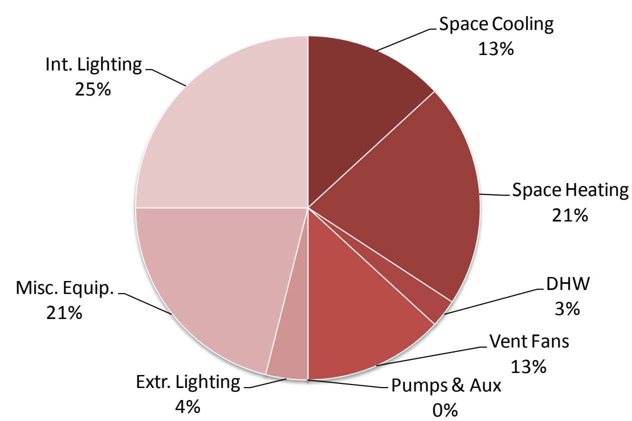


Figure 12 - Mixed Use End-Use Profile - Atlanta



Source: Figures 9-12 derived from Table 10 above

Elementary School

Table 13. Elementary School Building End-Use Profile by Climate Zone

End-Use	Climate Zone Adjustment Factors			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	5%	41%	4%	25%
Space Heating	45%	8%	60%	29%
DHW	10%	10%	8%	9%
Vent Fans	10%	11%	6%	9%
Pumps & Aux	0%	0%	0%	0%
Extr. Lighting	2%	2%	1%	2%
Misc. Equip.	12%	11%	9%	11%
Int. Lighting	17%	16%	13%	15%
Subtotal	100%	100%	100%	100%

Notes:

1) Portland end-use profile derived from Oregon SEED EUI data (PGE Energy Use Indices Guidelines). Portland used as control point to determine adjustment factors across the other 3 climate zones

2) Methodology devised from feedback from peer group and end-use profiles derived from NBI Sensitivity Analysis Study (Appendix B).

Source: Portland end-use profile used from Oregon SEED EUI data (PGE Energy Use Indices Guidelines). Portland used as a base to determine adjustment factors across the other 3 climate zones Methodology devised from feedback from peer group and end-use profiles derived from NBI Sensitivity Analysis Study (Appendix B)

Table 14. Elementary School Building End-Use EUI Comparison by Climate Zone

End-Use	Climate Zone Relative EUI (kBtu/sf/yr)			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	3	25	3	16
Space Heating	27	5	48	19
DHW	6	6	6	6
Vent Fans	6	7	5	6
Pumps & Aux	0	0	0	0
Extr. Lighting	1	1	1	1
Misc. Equip.	7	7	7	7
Int. Lighting	10	10	10	10
Subtotal	60	61	80	65
Adustment Factor %	1	1.02	1.33	1.08

Notes:

1) EUI of 60 kBtu/sf chosen for base case (Portland) based on table within Oregon DOE SEED EUIs for Elementary School.
2) Methodology devised from feedback from peer group and NBI on there research across different climate zones
3) EUI's adjusted by climate zone in alignment with Table 6 in NBI Sensitivity Analysis Study (page 47) dated July 2011.
4) Climate zone adjustment factors above will be used consistently across all other commercial buildings in this study.
5) Space Cooling & Heating figures derived from relative performance using CBECS data (http://buildingsdatabook.eren.doe.gov/CBECS.aspx). All other end-uses were kept consistent.

Source: see notes above

Figures 13-16. Apportionment of Energy End Use for Elementary Schools

Figure 13 - Elementary School End-Use Profile - Portland (Base)

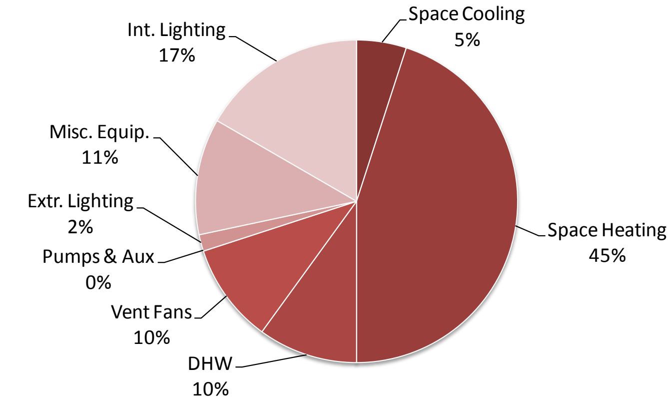


Figure 15 - Elementary End-Use Profile - Chicago

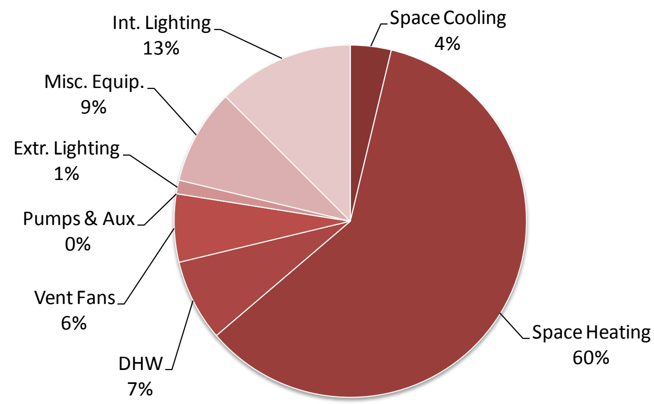


Figure 14 - Elementary School End-Use Profile - Phoenix

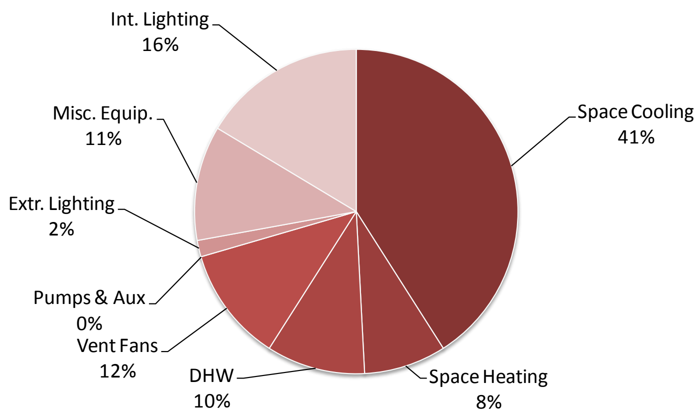
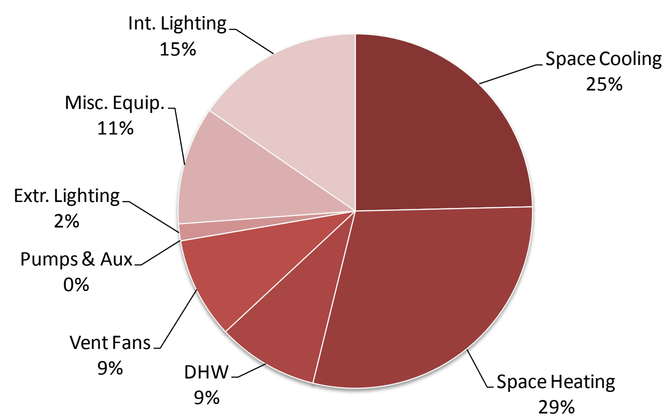


Figure 16 - Elementary End-Use Profile - Atlanta



Source: Figure 13-16 derived from Table 14 above

Multifamily Residential

Table 15. Multifamily Residential End-Use EUI Comparison by Climate Zone

End-Use	Climate Zone Relative EUI (kBtu/sf/yr)			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	4	13	2	7
Space Heating	28	6	31	15
DHW	14	14	14	14
Refrigerators	3	3	3	3
Lighting & Appliances	14	14	14	14
Subtotal	63	50	64	53

Notes:

1) Space Heating & Cooling EUIs in table above are from RECS Table US1 for climate zones 1 through 5.

2) Methodology devised from feedback from peer group and NBI research across different climate zones

3) EUI assumes 80% Apartment and 20% Core ratio.

Source: The Energy Information Administration's 2005 Residential Energy Consumption Survey

Table 16. Multifamily Residential End-Use EUI Profiles by Climate Zone

End-Use	Climate Zones			
	Portland (Base)	Phoenix	Chicago	Atlanta
Space Cooling	6%	26%	3%	13%
Space Heating	44%	12%	48%	28%
DHW	22%	28%	22%	26%
Refrigerators	5%	6%	5%	6%
Lighting & Appliances	22%	28%	22%	26%
Subtotal	100%	100%	100%	100%

Source: Table 15 above

Figures 17-20. Apportionment of Energy End Use for Multifamily Buildings

Figure 17 - Multifamily End-Use Profile - Portland (Base)

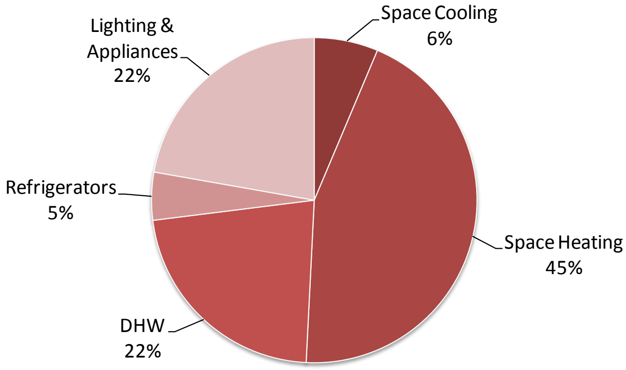


Figure 18 - Multifamily End-Use Profile - Phoenix

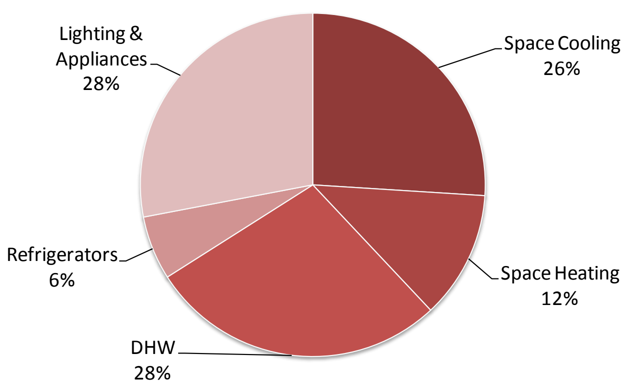


Figure 19 - Multifamily End-Use Profile - Chicago

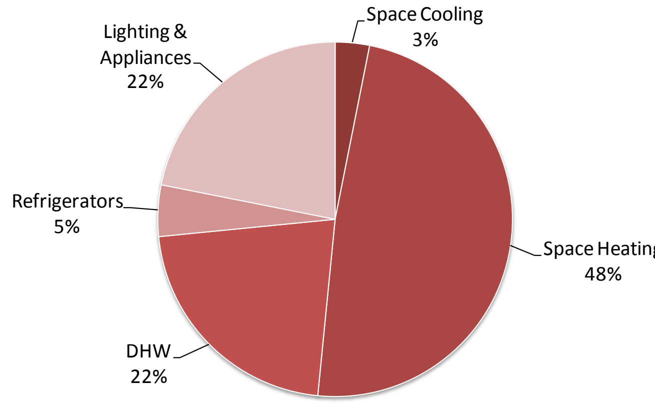
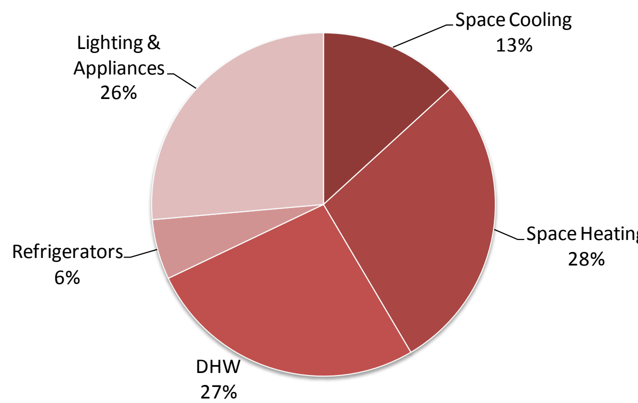


Figure 20 - Multifamily End-Use Profile - Atlanta



Source: Figures 17-20 derived from Table 15 above

ENDNOTES

[1] Actual building energy use may vary significantly due to factors such as occupancy or tenant behavior. However, these factors are beyond the scope of this study.

[2] Residential EUIs are sourced from the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS). Commercial EUIs are derived from a number of sources, including the EIA's 2003 Commercial Buildings Energy Consumption Survey (CBECS); the New Building Institute; The Cadmus Group, Inc.; and the Oregon Department of Energy. See *Sensitivity Analysis: Comparing the Impact of Design, Operation, and Tenant Behavior on Building Energy Performance*. New Buildings Institute, 2011, http://www.newbuildings.org/sites/default/files/110712_NBI_Sensitivity_Report_FINAL.pdf; *Northwest Commercial Building Stock Assessment*. The Cadmus Group, Inc., 2009, http://neea.org/research/reports/10-211CBSA.pdf; *User Guide for PGE Energy Use Index Guidelines.* Oregon Department of Energy SEED, 2006. http://www.oregon.gov/ENERGY/CONS/SEED/

[3] Space heating and water heating are assumed to be powered by natural gas, all other end uses are assumed to be power by electricity. This study acknowledges that while natural gas is the most common fuel source for space and water heating, other fuel sources such as heating oil, propane, and even electric heat pumps are found in various building types across the country.

[4] Commercial Buildings Energy Consumption Survey (CBECS). U.S. Energy Information Administration, 2003. http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html

Sensitivity Analysis: Comparing the Impact of Design, Operation, and Tenant Behavior on Building Energy Performance). New Buildings Institute, 2011.

http://newbuildings.org/sites/default/files/NBISensitivityReport.pdf Northwest Commercial Building Stock Assessment. The Cadmus Group, Inc., 2009.
http://neea.org/research/reports/10-211CBSA.pdf

User Guide for PGE Energy Use Index Guidelines. Oregon Department of Energy SEED, 2006.
http://www.oregon.gov/ENERGY/CONS/SEED/

[5] See end note #3.
[6] See end note #3.
[7] For the purposes of this study, warehouse buildings converted to commercial offices are assumed to operate the same as a new or retrofitted commercial office. This assumption is based on the fact that extensive renovation activities within the building in order to change its use would likely trigger code-compliant upgrades to the building's envelope and mechanical systems. In reality, warehouse conversions are difficult to generalize in terms of energy performance and further research beyond the scope of this study is needed to analyze warehouse conversion energy consumption.
[8] NBI's *Sensitivity Analysis: Comparing the Impact of Design, Operation, and Tenant Behavior on Building Energy Performance* (2011); Seattle was deemed a reasonably proxy to Portland.
[9] Owen MS. *2009 AHSRAE Handbook – Fundamentals.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.; 2009
[10] *Climate Consultant* [computer program]. Version 5. Los Angeles, CA: University of Californai, Los Angeles (UCLA) Energy Design Tools Group; October 2010.

Climate Consultant uses weather files from Energy Plus. Energy Plus is a simulation software that utilizes historic weather data formatted in the TMY3 file format. The weather files used are:

- Portland, OR: Portland Intl AP 726980 (TMY3) - EPW
- Phoenix, AZ: Phoenix-Sky Harbor Intl AP 722780 (TMY3) - EPW
- Atlanta, GA: Atlanta-Hartsfield-Jackson Intl AP 722190 (TMY3) – EPW
- Chicago, IL: Chicago-Midway AP 725340 (TMY3) - EPW

[11]The ASHRAE Advanced Energy Design Guides area a series of publications designed to provide recommendation for achieving energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1. The 30% reduction series includes energy savings guidelines for small office buildings, K-12 schools, small retail, and others. http://www.ashrae.org/technology/page/938

[12] Residential Energy Consumption Survey (RECS). U.S. Energy Information Administration, 2005. http://www.eia.doe.gov/emeu/recs/

[13] CITE: Chapter 14 appendix, ASHRAE 2009; Climate Consultant software