Commercial High Efficiency Packaged HVAC Equipment

Energy Savings Analysis

April 9, 2007

Objective

Develop technical information regarding estimated energy savings and incremental installed costs which will allow BPA to offer incentives for high-efficiency commercial packaged air-conditioning systems (RTU systems) in the 1-ton to 60-ton size range.

Approach

- Establish a method to estimate energy savings for different size RTU systems in the three Northwest climate zones. See Attachment 1.
- Establish incremental costs. See Attachment 2.
- Estimate high-efficiency RTU cost-effectiveness for different sized units and the three NW climate zones. See Attachment 3.
- Use the Consortium for Energy Efficiency (CEE) as the basis for unit availability and efficiency levels. See Attachment 4.

Assumptions

1. ASHRAE 90.1 establishes required minimum equipment efficiencies – State and Local Energy Codes meet or exceed ASHRAE 90.1.
2. More efficient equipment is more expensive than Energy Code-level equipment.
3. Higher rated efficiencies translate into higher operating efficiencies (lower annual energy use).

Results

Results from the analysis are shown below in Tables 1 through 4. Table 1 is the baseline energy use and Tables 2, 3, and 4 correspond with CEE Efficiency Tier Levels 1-3.

The estimated baseline energy use for cooling varies by location and size of unit from 0.85 to 1.69 kWh/sqft-yr. This compares favorably to an analysis done by NEEA on existing small commercial buildings using utility bills. This analysis showed wide variation in cooling electric energy use, but an average of around 1 kWh/sqft-yr.

Units less than 5 tons in size are not cost effective in any climate zone or at any CEE Tier level of efficiency. Units between 5 and 11 tons, 11 and 20 tons and 20 and 63 tons are cost-effective in most climate zones and CEE Tier levels of efficiency. High efficiency units above 63 tons are only cost-effective at the Tier 1 level in all climate zones.

For the sake of simplified program design and implementation, only Tier 2 and higher efficiency units will likely be eligible for rebates and only units in the size ranges of 5 to 63 tons. This grouping includes some size ranges that are marginally cost-effective in some climate zones. It excludes size ranges that are not cost-effective in any climate zone or CEE efficiency level.

Table 1: Baseline Energy Use

Size Range	Baseline EER	Zone 1 kWh/yr	Zone 2 kWh/yr	Zone 3 kWh/yr	Zone 1 kWh/sqft	Zone 2 kWh/sqft	Zone 3 kWh/sqft
< 5	11.4	1,276	1,764	2,043	0.85	1.18	1.36
5-11	10.2	3,565	4,928	5,708	0.95	1.31	1.52
11-20	9.5	7,655	10,582	12,258	1.02	1.41	1.63
20-63	9.4	20,632	28,519	33,035	1.03	1.43	1.65
> 63	9.2	39,526	54,635	63,287	1.05	1.46	1.69

Table 2: CEE Tier 1 Results

Size Range (tons)[1]	Tier 1 Min. Eff.[2]	Incr. Cost[3]	Zone 1 Energy Savings	Zone 2 Energy Savings	Zone 3 Energy Savings	Zone 1 B/C	Zone 2 B/C	Zone 3 B/C
< 5	11.4	$ 85	-	-	-	0.0	0.0	0.0
5-11	11.0	$ 217	259	358	415	1.2	1.7	2.0
11-20	10.8	$ 414	921	1,274	1,475	2.3	3.1	3.6
20-63	10.0	$ 1,131	1,238	1,711	1,982	1.1	1.5	1.8
> 63	9.7	$ 2,120	2,037	2,816	3,262	1.0	1.4	1.6

Table 3: CEE Tier 2 Results

Size Range (tons)[1]	Tier 2 Min. Eff.[2]	Incr. Cost[3]	Zone 1 Energy Savings	Zone 2 Energy Savings	Zone 3 Energy Savings	Zone 1 B/C	Zone 2 B/C	Zone 3 B/C
< 5	11.8	$ 186	43	60	69	0.2	0.3	0.4
5-11	11.5	$ 454	403	557	645	0.9	1.3	1.5
11-20	11.5	$ 954	1,331	1,840	2,132	1.4	2.0	2.3
20-63	10.5	$ 2,482	2,161	2,988	3,461	0.9	1.2	1.4
> 63	9.7	$ 4,654	2,037	2,816	3,262	0.4	0.6	0.7

Table 4: CEE Tier 3 Results

Size Range (tons)[1]	Tier 3 Min. Eff.[2]	Incr. Cost[3]	Zone 1 Energy Savings	Zone 2 Energy Savings	Zone 3 Energy Savings	Zone 1 B/C	Zone 2 B/C	Zone 3 B/C
< 5	12.3	$ 336	93	129	149	0.3	0.4	0.5
5-11	12.0	$ 845	535	739	856	0.6	0.9	1.0
11-20	12.0	$ 1,669	1,595	2,205	2,554	1.0	1.3	1.6
20-63	10.8	$ 4,479	2,674	3,697	4,282	0.6	0.8	1.0
> 63	10.2	$ 8,398	3,875	5,356	6,205	0.5	0.7	0.8

Notes to Tables 1-4:

1. Nominal equipment size ranges are as defined by ASHRAE 90.1.
2. CEE Tier Level efficiency is the minimum required EER for the energy savings shown.
3. Incremental cost developed from information published by DOE (see Attachment 2).
4. Energy Savings estimates are in kWh/yr and based on average unit size for the given range.
5. B/C ratio less than 1.0 indicates the efficiency upgrade is not cost-effective (red color); above 1.0 the upgrade is cost-effective (black color).

Attachment 1:

Energy Saving Estimates

Most of the published estimates for efficient HVAC equipment are based on some form of Equivalent Full-Load Hours (EFLH). EFLH is a single measure estimate of the cooling requirement for a climatic location. It allows easy comparisons of annual energy use or energy savings between equipment of different efficiencies.

The alternatives to EFLH might include multiple parametric energy simulations of multiple building prototypes. This approach has the potential disadvantage of depending on prototype building model input assumptions which would then likely translate into the measure criteria. For instance, this approach might result in allowing high-efficient rooftop units for small office buildings with a cooling demand greater than X and hours of use greater than Y. Programmatically it would be difficult to administer by both defining building categories and in defining the minimum criteria associated with each category.

Using EFLH the energy savings are estimated as:

$$\text{Equation 1:} \quad \text{Energy saved (kWh/yr)} = \left(1/\text{EER}_{\text{base}} - 1/\text{EER}_{\text{hi}}\right) \text{x Size x EFLH x K}$$

Where,
Size = Equipment size, Tons
EFLH = Equivalent Full-Load Hours
EER_{base} = Baseline equipment efficiency
EER_{hi} = High efficiency equipment efficiency
EER = Rated efficiency, (kBtuh output/kW input)
K = Conversion Factor = 12 kBtuh/ton

To estimate EFLH a simple eQUEST model was prepared. eQUEST uses equipment performance curves to estimate energy use. The relevant performance curves include Part Load Ratio (PLR) versus ambient temperature and wet-bulb temperature and EIR versus PLR. PLR is defined as hourly load divided by equipment capacity. EIR is a DOE-2 term that is defined as Electric Input Ratio and equals 1/COP or 3.413/EER.

The energy model used was a single zone with constant occupied hour's temperature set points, people, lighting, and equipment loads. It used 14 hour/day, 5 days/week and 4 hours/Saturday operation and a PSZ system type. The HVAC system was auto-sized to a 4-ton unit in the Seattle, WA TMY2 weather climate. The PSZ system included economizer controls. To model the economizer operation a high limit of 55 F was input.

Economizer controls are modeled as theory would predict by eQUEST; the model is incapable of estimating actual HVAC unit control functionality, temperature sensor accuracy, or damper operation functionality. The model used assumed a high limit of 55 F which eliminates economizer controls above that temperature, below that temperature

the economizer is 100% effective. This is an important assumption for estimating EFLH. If, as in most situations, the economizer controls are not functioning at any temperature then the EFLH will increase; if the economizer controls are functioning perfectly, then the EFLH will decrease.

The estimated energy use calculated from EFLH was compared to the eQUEST building model input. The results are essentially identical. Therefore, this simple, single measure approach will result in identical results to eQUEST modeling.

Using the data shown in Figures 1 and 2, it is possible to construct EFLH information for any site with bin temperature data. This was done for the five locations identified by the NW Power Planning Council to be used for NW climate zones 1, 2, and 3. Table 5 shows the results for Portland, OR and Table 6 summarizes the results for all sites and the aggregated climate zones 1, 2, and 3.

Table 5: EFLH for Portland, OR

Temperature Bin	Part Load Ratio	Bin Hours			Occ. Hours	EFLH
		01-08	09-16	17-24		
105 - 110	103.8%	0	0	0	0.0	0.0
100 - 105	95.3%	0	1	0	0.8	0.7
95 - 100	86.8%	0	3	2	2.9	2.3
90 - 95	78.3%	0	17	5	14.7	10.3
85 - 90	69.8%	0	38	16	34.1	20.7
80 - 85	61.3%	0	91	41	82.5	42.8
75 - 80	52.8%	0	134	76	125.6	54.6
70 - 75	44.3%	7	218	138	210.1	74.4
65 - 70	35.8%	36	305	230	310.9	86.3
60 - 65	27.3%	243	372	357	453.0	93.0
55 - 60	18.8%	519	368	412	538.5	73.7
TOTAL						**459**

Notes:
1. Part Load Ratio (from eQUEST simulation) = 0.017 x Avg. Bin Temp – 0.79
2. Bin Hours from AFM Manual 88-9.
3. Occ. Hours = [{01-08 hours} x 3/8 + {09-16 hours} + {17-24 hours} x 3/8] x 5 weekdays/7 days + {09 – 16 hours} x 4 x 1 Saturday/7 days
4. EFLH = Occ. Hours x [EIR(PLR)] / EIR_{FL}
5. EIR(PLR) = 0.86 x PLR^2 + 0.21 x PLR
6. EIR_{FL} = Full Load Energy Input Ratio = rated COP^{-1}

Table 6: EFLH by Location

Location	EFLH
Portland, OR	459
Seattle, WA	407
Boise, ID	647
Missoula, MT	387
Spokane, WA	625
Climate Zone 1	404
Climate Zone 2	558
Climate Zone 3	647

The CEE defines three levels of efficiency (Tiers) beyond and lists equipment by manufacturer and model number that meet each Tier (see Attachment 4). Efficiency levels are shown in Table 7 below.

Table 7: Efficiency Levels (EER)

Size Range	ASHRAE 90.1	CEE Tier 1	CEE Tier II	CEE Tier III
< 5	11.4	11.4	11.8	12.3
5-11	10.2	11.0	11.5	12.0
11-20	9.5	10.8	11.5	12.0
20-63	9.4	10.0	10.5	10.8
> 63	9.2	9.7	9.7	10.2

Energy savings are then calculated using Equation 1 with ASHRAE Standard 90.1 efficiency levels as the baseline. Energy savings are estimated for each of the three climate zones and each of the three CEE Tier levels of efficiency. The results are shown in Tables 1 through 4 above.

Several other utilities offer incentives for high efficiency commercial rooftop air-conditioning units. The energy savings estimates from these other programs are compared to those developed here. The results from the comparison are shown in Table 8. The BPA estimates of energy savings are lower than almost all other estimates, implying that they are conservative.

Table 8: Comparison of RTU Energy Savings Estimates (kWh/yr/ton)

Size (tons)	Fin Answer[1]	DEER[1]	Xcel Energy[1]	PG&E[1]	CEE[2]	ETO[3]	AVG		BPA[4]	
								Zone 1	Zone 2	Zone 3
< 5	142	201	92	321	108	166	172	44	43	45
5 – 10	122	210	134	109	101	45	120	50	48	49
10 – 20	118	121	194	118	170	76	133	53	55	56
> 20	78	72	129	130	N/A	38	89	54	56	57

Notes:
1. "2006 FinAnswer Express Characterization and Program Enhancements", Nexant.
2. Consortium for Energy Efficiency.
3. Energy Trust of Oregon HVAC Rebate Brochure.
4. Energy savings for equipment with efficiencies that meet the CEE Tier II.

Figure 1: Model predicted EIR vs PLR

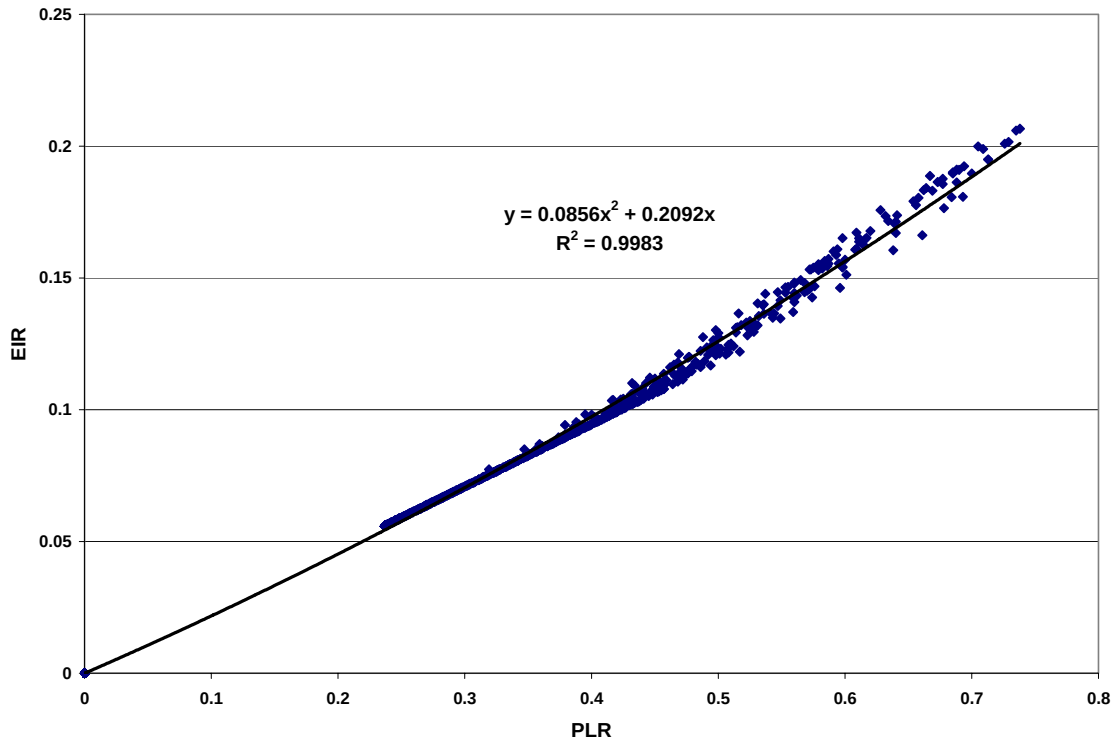
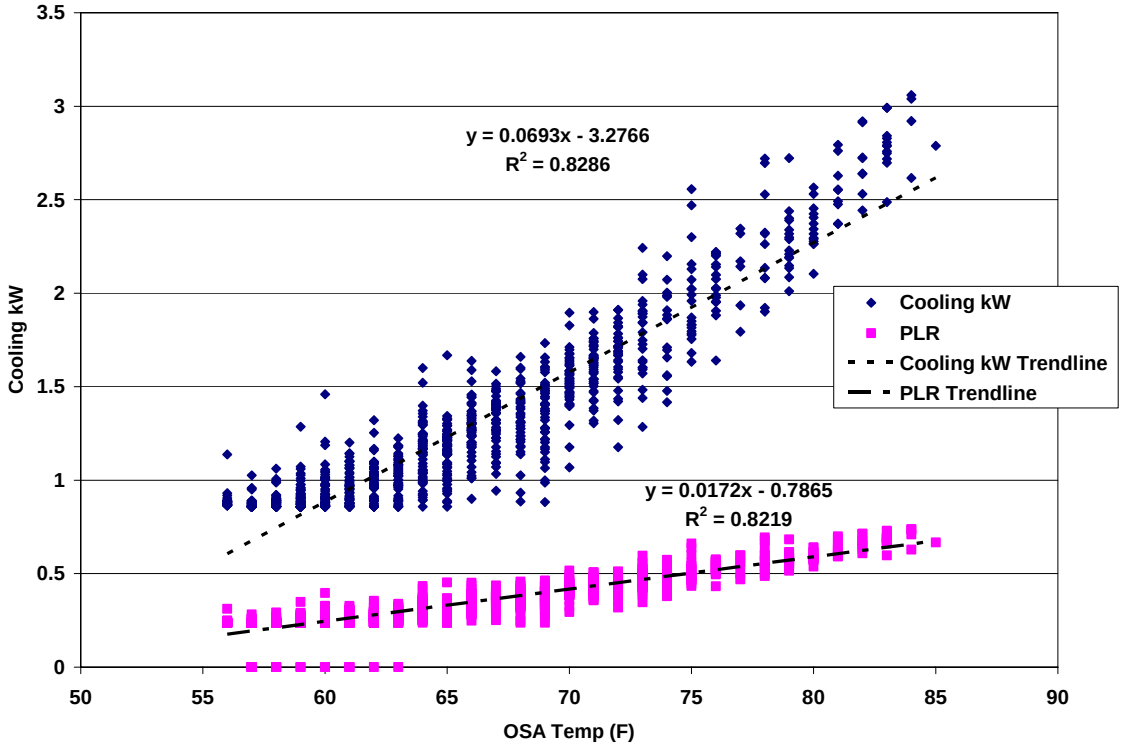


Figure 2: Model Predicted Performance vs OSA Temperature



Attachment 2:

Incremental Cost Estimates

Incremental cost estimates were derived from information published by the Department of Energy (DOE) at:

http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html

The DOE conducted a survey regarding costs for 7.5 ton and 15 ton RTU systems at varying efficiency levels. From this survey, incremental costs are extrapolated to the remaining RTU sizes and efficiencies.

The incremental costs from DOE are shown below in Table 9, reproduced from the DOE web-site. The median incremental cost increase at the desired EER level is multiplied by the overall mark-up factor (identified by DOE as 1.56) to arrive at the total incremental cost increase. For instance the incremental cost increase for a 7.5 ton unit with an EER of 12.0 is $542.78 x 1.56 = $846.74.

Table 9: Equipment Incremental Costs (reproduced from DOE website)

	Incremental Manufacture Cost									
	7.5 ton					15 ton				
Descrip.	Median	95% Low	95% High	Std. Dev.	Selected	Median	95% Low	95% High	Std. Dev.	Selected
	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)	(2001$)
EER=9.5	$0.00				$0.00	$0.00				$0.00
EER=10.0	$0.00				$0.00	$62.20	$26.50	$97.89	$17.85	$62.20
EER=10.1	$0.00				$0.00	$82.40	$35.57	$127.20	$23.42	$82.40
EER=10.5	$46.95	$33.15	$60.75	$6.90	$46.95	$164.74	$70.19	$259.29	$47.28	$164.74
EER=11.0	$139.33	$98.37	$180.30	$20.48	$139.33	$333.81	$142.23	$525.39	$95.79	$333.81
EER=11.5	$291.65	$205.90	$377.40	$42.88	$291.65	$612.55	$260.99	$964.11	$175.78	$612.55
EER=11.8	$427.25	$302.72	$559.41	$62.27	$427.25	$866.43	$369.93	$1360.61	$248.25	$866.43
EER=12.0	$542.78	$383.20	$702.35	$79.79	$542.78	$1072.12	$456.80	$1687.44	$307.66	$1072.12

Incremental costs are extrapolated for HVAC units of different tonnage than that surveyed based on the 7.5-ton and 15-ton data, as shown in Table 10. The average incremental cost/ton is applied to high-efficiency units based on efficiency level.

Table 10: Incremental Cost/Ton

Tons	Tier 3	Tier 2	Tier 1
7.5	$ 113	$ 61	$ 29
15	$ 111	$ 62	$ 28
Average	$ 112	$ 62	$ 28

Attachment 3:

Regional Cost Effective Estimates

Regional cost effectiveness is estimated using the Conservation Rate Credit and Conservation Acquisition Agreement Energy Savings Benefits and Reimbursement Calculator. The Calculator requires identification of the type of technology (New HVAC), costs, and energy savings. It estimates the overall Benefit to Cost ratio (B/C). The B/C ratio must be > 1.0 for the energy efficiency measure to be considered regionally cost effective.

The Calculator indicates a factor of $1.02/(site kWh) for Existing Small Office and Retail Building Central Air Conditioning Efficiency Improvements.

The calculated B/C ratios are shown in Tables 2, 3, and 4 presented in the first section of this report.

Attachment 4:

CEE – HVAC Equipment Availability

Equipment Type Size Category		Total Models	Tier 1		Tier 2		Tier 3	
			Mins	Models	Minimums	Models	Mins	Models
Air conditioner, Air Cooled								
< 65,000	Split System	71976	13 SEER 11.6 EER	14753	14 SEER 12.0 EER	8065	15 SEER 12.5 EER	47
	Single Package	5278	13 SEER 11.3 EER	421	14 SEER 11.6 EER	84	15 SEER 12.0 EER	19
>= 65,000 to < 135,000	Split System	882	11.0 EER 11.4 IPLV	77	11.5 EER 11.9 IPLV	24	12.0 EER 12.4 IPLV	4
	Single Package	1409		307		94		8
>= 135,000 to < 240,000	Split System	451	10.8 EER 11.2 IPLV	58	11.5 EER 11.9 IPLV	19	12.0 EER 12.4 IPLV	15
	Single Package	1161		367		110		12
>= 240,000 to <760,000**	Split & Single Package	230	10.0 EER 10.4 IPLV	212	10.5 EER 10.9 IPLV	116	10.8 EER 12.0 IPLV	8

Reproduced from CEE, "Table 1 - Impact of CEE levels on ARI Directory Model Data, February 2007"