ENERGY STAR® Performance Ratings
Technical Methodology for Warehouse

This document presents specific details on the EPA's analytical result and rating methodology for Warehouse. For background on the technical approach to development of the Energy Performance Ratings, refer to *Energy Performance Ratings – Technical Methodology* (http://www.energystar.gov/ia/business/evaluate_performance/General_Overview_tech_methodology.pdf). Please note the general technical methodology listed above reflects changes made to the methodology in 2007. The Warehouse model has not yet been revised in light of these changes; therefore some of the information in this description differs slightly.

Model Release Date

January 2004

Portfolio Manager Warehouse Definition

The Warehouse space type is intended to define facility space that is only used to store goods, manufactured products, merchandise or raw materials. Space types defined as Warehouse must not contain any onsite manufacturing. If the space is part of an industrial campus, the space defined as Warehouse must be a separate structure that is separately metered from any adjacent processing plants. Refrigerated Warehouse specifically denotes space designed to store perishable goods or merchandise under refrigeration at temperatures below 50 degrees Fahrenheit. Unrefrigerated Warehouse specifically denotes space designed to store non-perishable goods and merchandise. The total gross floor area should include all supporting functions such as offices, lobbies, stairways, rest rooms, equipment storage areas, elevator shafts, etc

Reference Data

The Warehouse regression model is based on data from the Department of Energy, Energy Information Administration's 1999 Commercial Building Energy Consumption Survey (CBECS). Detailed information on this survey, including complete data files, is publicly available at: http://www.eia.doe.gov/emeu/cbecs/contents.html.

Data Filters

Four types of filters are applied to define the peer group for comparison and to overcome any technical limitations in the data: Building Type Filters, EPA Program Filters, Data Limitation Filters, and Analytical Filters. A complete description of each of these categories is provided in Section V of the general technical description document: *Energy Performance Ratings – Technical Methodology*. **Table 1** presents a summary of each filter applied in the development of the Warehouse model and the rationale behind the filter. The 1999 CBECS dataset includes a total of 722 Warehouse records. After all filters are applied, the remaining dataset has 484 records.

Table 1 Summary of Warehouse Model Filters	
Condition for Including an Observation in the Analysis	**Rationale**
PBAPLUS7= 23 or 37	Building Filter – CBECS defines building types according to the variable "PBAPLUS7." Warehouses are coded as PBAPLUS7= 23 (non-refrigerated) or 37 (refrigerated)
Must operate for at least 35 hours per week	EPA Program Filter – Baseline condition for being a full time Warehouse.
Must operate for at least 10 months per year	EPA Program Filter – Baseline condition for being a full time Warehouse.
Total electricity used must be greater than 0	EPA Program Filter – Baseline condition for being a full time Warehouse.
Must have square foot less than 1,000,000	Data Limitation Filter – CBECS masks actual values above 1,000,000 using regional averages.
Must have square foot of at least 5,000	Analytical Limitation Filter – Analysis could not model behavior for buildings smaller than 5,000 ft^2.

Dependent Variable

The dependent variable in the Warehouse analysis is the natural log of annual source energy use (LN(Source Energy)). By setting LN(Source Energy) as the dependent variable, the regressions analyze the key drivers of the LN(Source Energy) – those factors that explain the variation in the natural log of source energy consumption in a Warehouse.

Independent Variables

The CBECS data contain numerous building operation questions that EPA identified as potentially important for Warehouses. These include characteristics such as the total square footage, the weekly hours of operation, whether the Warehouse is refrigerated or not, total number of walk-in refrigerators, number of workers on the main shift , the percentages lit by high intensity discharge and halogen lights, the percent of the building that is heated and cooled, and the number of heating and cooling degree days.

EPA performed extensive review on all of these operational characteristics. In addition to reviewing each characteristic individually, characteristics were reviewed in combination with each other (e.g., Heating Degree Days * Percent Heated). As part of the analysis, some variables were reformatted to reflect the physical relationships of building components. Based on analytical results and residual plots, variables were also examined using different transformations (such as the natural logarithm). The analysis consisted of multiple regression formulations. These analyses were structured to find the combination of statistically significant operating characteristics that explained the greatest amount of variance in the dependent variable: LN(Source Energy).

Based on the Warehouse regression analysis, the following eight characteristics were identified as key explanatory variables that can be used to estimate the expected LN(Source Energy) in a Warehouse:

- Natural log of gross square foot
- Natural log of number of workers on the main shift
- Natural log of weekly operating hours
- Whether or not the Warehouse is refrigerated
- Number of walk in refrigerators
- Sum of percentages of building lit by high intensity discharge and halogen lights
- Heating degree days times Percent of the building that is heated
- Cooling degree days times Percent of the building that is cooled

Regression Modeling Results

The final regression is an ordinary least squares regression across the filtered data set of 484 observations. The dependent variable is LN(Source Energy) and the mean value for LN(Source Energy) across the 484 observations is 14.897. Basic statistics of the final set of independent variables left in the model are provided in **Table 2**. The final model is presented in **Table 3**. All model variables are significant at the 90% confidence level or better, as shown by the significance levels (a p-level of less than 0.10 indicates 90% confidence). The model has an R^2 value of 0.80, indicating that this model explains 80% of the variance in LN(Source Energy) for Warehouse buildings. This is an excellent result for a statistically based energy model.

Detailed information on the ordinary least squares regression approach and the methodology for performing weather adjustments is available in the technical document: *Energy Performance Ratings – Technical Methodology*.

Table 2
Descriptive Statistics for Variables in Final Regression Model

Variable	Full Name	Mean	Minimum	Maximum
LnSqft	Natural Log of Square foot	9.276	8.517	13.764
LnNwker	Natural Log of Workers on Main Shift	4.04	0	8.294
LnWkhrs	Natural Log of Weekly Operating Hours	4.213	3.689	5.124
RegrifWh	Refrigerated (1) or Non-Refrigerated (0)	0.0744	0	1
HDDxheatp	Heating Degree Days x Percent Heated	230,262.78	0	822,300
CDDxcoolp	Cooling Degree Days x Percent Cooled	41,828.66	0	414,300
NumWiRef	Number of Walk-In Refrigerators	0.2438	0	11
SumHidHalo	Sum of Percentages Lit by high Intensity Discharge and Halogen Lights	31.004	0	105

Note: Statistics are computed over the filtered data set (n=484 observations)

Table 3 Final Regression Modeling Results				
Dependent Variable	LN(Source Energy)			
Number of Observations in Analysis	484			
Model R^2 value	0.8038			
Model F Statistic	243.329			
Model Significance (p-level)	0.000			
	Unstandardized Coefficients	**Standard Error**	**T value**	**Significance (p-level)**
(Constant)	4.293	0.464	9.259	<0.0001
LnSqft	0.714	0.036	19.876	<0.0001
LnNwker	0.286	0.0292	9.804	<0.0001
LnWkhrs	0.357	0.099	3.615	0.0003
RegrifWh	0.785	0.128	6.154	<0.0001
HDDxheatp	0.0001288	0.0000001661	7.757	<0.0001
CDDxcoolp	0.0001978	0.0000004009	4.933	<0.0001
NumWiRef	0.087	0.027	3.290	0.0011
SumHidHalo	0.002	0.001	1.848	0.0652
Note: Full variable names and definitions are presented in Table 2				

Warehouse Lookup Table

The final regression model (presented in **Table 3**) yields a prediction of LN(Source Energy) based on a building's operating constraints. Some buildings in the CBECS data sample use more energy than predicted by the regression equation, while others use less. The *actual* value of LN(Source Energy) for each CBECS observation is divided by its *predicted* value for LN(Source Energy) to calculate an energy efficiency ratio:

Energy Efficiency Ratio = Actual LN(Source Energy) / Predicted LN(Source Energy)

A lower efficiency ratio indicates that a building uses less energy than predicted, and consequently is more efficient. A higher efficiency ratio indicates the opposite. For each building, the ratio is expressed in terms of a normalized LN(Source Energy) to represent the value for LN(Source Energy) that the building would have if it were average. This *normalized energy use* is obtained by multiplying the efficiency ratio by the mean value of LN(Source Energy) [1]:

Normalized LN(Source Energy) = Energy Efficiency Ratio * 14.897

The normalized LN(Source Energy) values are sorted from smallest to largest and the cumulative percent of the population at each energy value is computed. A smooth curve is fitted to the data using a two parameter gamma distribution. The fit is performed in order to minimize the sum of squared differences between each building's actual percent rank in the population and each

[1] The mean value of LN(Source) is determined by the dataset and is presented Regression Modeling Results section. It is 14.897.

building's percent rank with the gamma solution. The fit is performed with the constraint that the gamma value of LN(Source Energy) at a rating of 75 must equal the actual value of LN(Source Energy) at 75.

The final gamma shape and scale parameters are used to calculate the normalized LN(Source Energy) value at each percentile (1 to 100) along the curve. For example, the normalized LN(Source Energy) value on the gamma curve at 1% corresponds to a rating of 99; only 1% of the population has a value this small or smaller. The normalized LN(Source Energy) value on the gamma curve at the value of 25% will correspond to the normalized LN(Source Energy) value for a rating of 75; only 25% of the population has normalized LN(Source Energy) values this small or smaller. The complete lookup table is presented at the end of the document. In order to read this lookup table, note that if the normalized LN(Source Energy) value is less than 13.492 the rating for that building should be 100. If the normalized LN(Source Energy) value is greater than or equal to 13.492 and less than 13.607, the rating for the building should be 99, etc.

Example Calculation

Below are the five steps to compute a rating for a hypothetical Warehouse building. Note that these steps are slightly different than those outlined in the document *Energy Performance Ratings – Technical Methodology*, which reflects changes made to the methodology in 2007. The Warehouse model has not yet been revised in light of these changes (departures from the current methodology are described in footnotes).

<u>Step 1 – User enters building data into Portfolio Manager</u>

For the purpose of this example, sample data is provided.

- Energy data
  - Total annual electricity = 200,000 kWh
  - Total annual natural gas = 3,300 therms
  - Note that this data is actually entered in monthly meter entries
- Operational data
  - Gross floor area (ft^2) = 200,000
  - Number of workers = 12
  - Weekly operating hours = 40
  - Refrigerated = 0 (No)
  - Percent of the building that is heated = 100
  - Percent of the building that is cooled = 50
  - Number of walk-in refrigerators = 0
  - Percent HID and halogen = 0
  - HDD (provided by Portfolio Manager, based on zip code) = 7084
  - CDD (provided by Portfolio Manager, based on zip code) = 385

<u>Step 2 – Portfolio Manager computes the actual value for the natural log of Source Energy Use</u>[2]

In order to compute actual Source Energy Use, Portfolio Manager must convert each fuel from the specified units (e.g. kWh) into Site kBtu, and must convert from Site kBtu to Source kBtu.

[2] Note that for models revised in 2007 or later, this step computes the actual source energy use intensity.

- Convert the meter data entries into site kBtu
  - Electricity: (200,000 kWh)*(3.412 kBtu/kWh) = 682,400 kBtu Site
  - Natural gas: (3,300 therms)*(100 kBtu/therm) = 330,000 kBtu Site
- Apply the site-to-source conversion factors to compute the source energy
  - Electricity:
    682,400 Site kBtu*(3.34 Source kBtu/ Site kBtu) = 2,279,216 kBtu Source
  - Natural gas:
    330,000 Site kBtu*(1.047 Source kBtu/Site kBtu) = 345,510 kBtu Source
- Combine source kBtu across all fuels
  - 2,279,216 kBtu + 345,510 kBtu = 2,624,726 kBtu
- Take the natural log of total source energy consumption
  - LN (2,624,726 kBtu) = 14.780

<u>Step 3 – Portfolio Manager computes the predicted natural log of Source Energy Use</u>[3]

Portfolio Manager uses the building data entered in Step 1 to compute the predicted energy consumption of the building with the given operational constraints.

- Compute each variable in the model
  - Use the operating characteristic values to compute each variable in the model.
    e.g. LN(Square Foot) = LN(200,000) = 12.20607
- Multiply each variable by the corresponding coefficient in the model
  - e.g. Coefficient * LN(Square Foot) = 0.714*12.20607 = 8.71513
- Sum each product (i.e. coefficient*variable) from the preceding step and add to the constant
  - This yields a predicted LN(Source Energy) of 15.04525
- This calculation is summarized in **Table 4**

<u>Step 4 – Portfolio Manager computes the normalized LN(Source Energy) value</u>[4]

The actual and predicted values for LN(Source Energy) are used to compute the energy efficiency ratio, which is converted into a normalized LN(Source Energy).

- Compute the energy efficiency ratio
  - Energy efficiency ratio =
    Actual LN(Source Energy) / Predicted LN(Source Energy)
  - 14.780 / 15.04525 = 0.9824
- Compute the normalized LN(Source Energy)
  - Normalized LN(Source Energy) =
    Energy Efficiency Ratio * Mean LN(Source Energy)
  - Mean LN(Source Energy), provided with Regression Modeling Results = 14.897
  - 0.9824 * 14.897 = 14.635

[3] Note that for models revised in 2007 or later, this step computes the predicted source energy use intensity.
[4] Note that for models revised in 2007 or later, this step computes the energy efficiency ratio.

Step 5 – Portfolio Manager looks up the normalized LN(Source Energy) in the Lookup Table

Starting at 100 and working down, Portfolio Manager searches the lookup table for the first ratio value that is larger than the computed ratio for the building.

- An adjusted value of 14.635 is less than 14.646 (requirement for 70) but greater than 14.632 (requirement for 71)
- ***The rating is a 70***

Table 4 Example Calculation – Computing predicted LN(Source Energy)			
Operating Characteristic	Variable Value	Coefficient	Coefficient * Variable
(Constant)	N/A	4.293	4.293
LnSqft	12.20607	0.714	8.71513
LnNwker	2.4849	0.286	0.71068
LnWkhrs	3.6889	0.357	1.31694
RegrifWh	0	0.785	0.00000
HDDxheatp	7084	0.000001288	0.00912
CDDxcoolp	192.5	0.000001978	0.00038
NumWiRef	0	0.087	0.00000
SumHidHalo	0	0.002	0.00000
Predicted LN(Source Energy) (LN(kBtu))			15.04525

Attachment

Table 5 lists the normalized LN(Source Energy) cut-off point for each rating, from 1 to 100.

Table 5 Lookup Table for Warehouse Rating						
Rating	**Cumulative Percent**	**Normalized LN(Source Energy)**		**Rating**	**Cumulative Percent**	**Normalized LN(Source Energy)**
100	0%	13.492		50	50%	14.976
99	1%	13.607		49	51%	14.993
98	2%	13.712		48	52%	15.009
97	3%	13.806		47	53%	15.025
96	4%	13.891		46	54%	15.041
95	5%	13.968		45	55%	15.056
94	6%	14.038		44	56%	15.070
93	7%	14.100		43	57%	15.084
92	8%	14.156		42	58%	15.098
91	9%	14.205		41	59%	15.111
90	10%	14.250		40	60%	15.123
89	11%	14.290		39	61%	15.135
88	12%	14.326		38	62%	15.146
87	13%	14.358		37	63%	15.158
86	14%	14.387		36	64%	15.168
85	15%	14.413		35	65%	15.179
84	16%	14.436		34	66%	15.189
83	17%	14.457		33	67%	15.199
82	18%	14.476		32	68%	15.210
81	19%	14.494		31	69%	15.221
80	20%	14.510		30	70%	15.232
79	21%	14.525		29	71%	15.244
78	22%	14.540		28	72%	15.256
77	23%	14.554		27	73%	15.270
76	24%	14.567		26	74%	15.285
75	25%	14.580		25	75%	15.302
74	26%	14.593		24	76%	15.320
73	27%	14.606		23	77%	15.341
72	28%	14.619		22	78%	15.365
71	29%	14.632		21	79%	15.392
70	30%	14.646		20	80%	15.422
69	31%	14.660		19	81%	15.457
68	32%	14.674		18	82%	15.495
67	33%	14.688		17	83%	15.539
66	34%	14.703		16	84%	15.588
65	35%	14.719		15	85%	15.643
64	36%	14.734		14	86%	15.705
63	37%	14.750		13	87%	15.775
62	38%	14.767		12	88%	15.852
61	39%	14.784		11	89%	15.939
60	40%	14.801		10	90%	16.035
59	41%	14.818		9	91%	16.141
58	42%	14.836		8	92%	16.258
57	43%	14.853		7	93%	16.388
56	44%	14.871		6	94%	16.531
55	45%	14.889		5	95%	16.688
54	46%	14.907		4	96%	16.859
53	47%	14.924		3	97%	17.047
52	48%	14.942		2	98%	17.253
51	49%	14.959		1	99%	17.476