



TETRA TECH



State of Wisconsin Public Service Commission of Wisconsin

Focus on Energy Evaluation

*Standard Calculation Recommendations for
Renewable Energy Systems*

Revised: January 18, 2011

Evaluation Contractor: Tetra Tech

Prepared by: Bobbi Tannenbaum, Doug Kneale, Brian Dunn, P.E., and
Brian Bak, KEMA



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1. INTRODUCTION

The purpose of this document is to provide a set of recommended standard calculations for estimating kWh, kW, and therms associated with renewable energy systems installed through the Focus on Energy program. The purpose of developing standard calculations and documentation for renewable energy systems is to ensure that the Focus Renewables Program estimation approach is transparent, consistent, and accurate. Biogas, biomass, and solar water heating calculations estimate annual therms displaced by renewable energy sources (savings). Biogas, photovoltaics (PV or solar electric), solar water heating, and wind calculations estimate annual kWh and average system peak kW generation displaced by the renewable energy source (savings).

kWh is estimated on an annual basis. kW is calculated based on the average kW savings over the period from 1 pm to 4 pm, Monday through Friday, during the months of June through August. Average kW is the kWh savings realized over the three-hour peak period (1 pm to 4 pm), divided by these same three hours per day.¹

This report is a revised version of the original standard calculation recommendations report.² KEMA initially established these standard calculations in conjunction with the Focus on Energy program in 2008. We published the first version of the standard calculation after a review of the program's calculations, secondary research, and meetings with the program leads for each of the renewable technologies. The Public Service Commission of Wisconsin (PSCW) and the program administrator reviewed and commented on the recommendations before publication. The revisions in this documentation are based on findings from applying these recommendations to the 18MCP and CY09 impact evaluations, additional program administrator comments and questions, and feedback from the public.

The standard calculation recommendations are provided in the following section. We discuss energy savings, demand savings (where applicable), and information required on the application or in program documents for each of the five measures installed through the program. The renewable energy technologies are presented in the following order:

- Biogas
- Biomass
- Photovoltaic (solar electric)
- Solar water heating
- Wind energy.

¹ See *BP OPS Manual*, "Revised Peak KW Reduction Description," p. 57, April 1, 2008.

² Bobbi Tannenbaum, Doug Kneale, and Brian Dunn, KEMA, Inc. *State of Wisconsin, Public Service Commission of Wisconsin, Focus on Energy Evaluation, Renewable Energy Program: Standard Calculation Recommendations*. September 10, 2008.



We provide recommendations for standard calculation approaches that are both reasonable (in terms of the amount of effort and data required to complete them) and accurate. Since we cannot anticipate all situations, we expect the program implementers may occasionally deviate from the recommended approach. In these situations the program files should include full documentation of the calculation approach used (input values and equations), as well as an explanation for the deviation from the recommended approach.

2. STANDARD CALCULATIONS

2.1 BIOGAS SYSTEMS

In this section, we discuss the calculation of therms, kWh, and kW displaced by biogas systems. Biogas systems can provide savings in two main ways. Biogas can be:

- Burned in a boiler or furnace to produce heat directly.
- Burned in a spark ignition engine generator set (genset) to produce electricity and displace kW and kWh. (The waste heat from the generator can also be captured.)

Because of the possible variations across projects, we provide standard calculations for biogas production for several situations and for electrical generation from biogas for various genset types. We emphasize the importance of providing thorough documentation regarding the calculation assumptions and data sources.

We recommend estimating biogas production from anaerobic digestion using the chemical oxidative destruction (COD) method. The COD method uses a standard rate of methane production per COD destroyed, which allows for a standard calculation of methane production regardless of digester inputs. This makes the COD method applicable to agricultural systems as well as industrial processes, such as food waste processing, landfill gas, and wastewater treatment. An alternative method uses volatile solids (VS) to estimate biogas production, but this method is less versatile than the COD approach (and is most easily applied to agricultural biogas applications).

Peak kW in the current contract period (and going forward) is based upon average kWh during system peak in the summer.

We provide the calculations for biogas systems in four sections. Section 2.1.1 defines the calculation to estimate methane gas production from the digestion process given certain operational parameters. Section 2.1.2 defines the calculation to estimate the kWh production of the engine-generator (genset) given operational values for the genset and the calculated estimate of methane gas production. Section 2.1.3 defines the calculation to estimate kW savings. Finally, section 2.1.4 defines the calculations to estimate therm savings.

2.1.1 Methane gas production

To estimate methane gas production from the digestion process, the bio-digester design consultant typically provides the values for the calculation variables based on farm type or industrial process as well as experience with a particular design and operation. For any particular site, the Program must thoroughly document the values used in the equations, their units, and their sources. This information should become part of the applicant's folder.

Calculate biogas (methane) production from the following variables and equations:

- A = Number of animals (agricultural) or gallons of influent/day (industrial)
- B = lb COD/animal/day (agricultural) or lb COD/gal (industrial)
- C = Manure collected in influent (percentage expressed as a decimal), 0.95–1.0 range (not used for industrial digester)

- D = Digester efficiency (percent expressed as a decimal), 0.1–0.9 range based on influent type and digester efficiency. According to NRCS, digester efficiencies range from 0.1 to 0.5 at dairy installations and from 0.3 to 0.7 at swine installations.³
- E = COD converted (ft³ methane/lb COD), 8.3ft³/lb at 95° F and 760 mm Hg,⁴ at other temperatures and pressures adjustment is made using the General Gas Law⁵
- F = Percent methane in biogas (percent expressed as a decimal), 0.55 to 0.80 range depending on digester type and influent source. Average biogas contains 65 percent methane.⁶

$$\text{Annual Biogas}(ft^3) = \frac{A \times B \times C \times D \times E \times 365 \text{ days}}{F} \text{ (farms)}$$

$$\text{Annual Biogas}(ft^3) = \frac{A \times B \times D \times E \times 365 \text{ days}}{F} \text{ (industrial)}$$

Where possible, the applicant or bio-digester design consultant should determine the COD content of the manure through laboratory analysis. Where this analysis is not available, the applicant or bio-digester design consultant may approximate the COD content based on the volatile solids (VS) content of the manure⁷ but must document the values used and approximations made.

Table 2-1 provides estimates for both VS and COD by animal type for agricultural digesters. These estimates do not include additional VS or COD content available from bedding or other substrates added to the waste stream.

³ USDA NRCS. *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities, Technical Note No. 1.* October 2007.

⁴ Dennis A. Burke, P.E. *Dairy Waste Anaerobic Digestion Handbook*, page 38. Environmental Energy Company, 6007 Hill Street, Olympia, WA 98516. June 2001.

⁵ The General Gas Law is expressed by the equation: $V_2 = V_1 \times (T_2/T_1) \times (P_1/P_2)$

Where: V_1 = gas volume (m³) at temperature T_1 (°K) and pressure P_1 (mm Hg)

V_2 = gas volume (m³) at temperature T_2 (°K) and pressure P_2 (mm Hg).

⁶ NRCS. October 2007. op. cit.

⁷ American Society of Agriculture and Biological Engineers, *ASAE D384.2: Manure production and characteristics*, The Society for Engineering in Agriculture, Food and Biological System, St. Joseph, MI, 2005.

Table 2-1. Volatile Solids and COD Excretion Rate by Type of Livestock⁸

Animal Type and Production Grouping	Pounds per Animal per Day (lb/a/d)	
	VS	COD
Beef - Cow (confinement)	13.000	14.000
Beef - Growing calf (confinement)	5.000	5.200
Dairy - Lactating cow	17.000	18.000
Dairy - Dry cow	9.200	9.700
Dairy - Heifer 970 lb	7.100	7.500
Horse - Sedentary 1,100 lb	6.600	
Horse - Intense Exercise 1,100 lb	6.800	
Layer (Hen)	0.036	0.039
Swine - Gestating sow 440 lb	0.990	1.000
Swine - Lactating sow 423 lb	2.300	2.400
Swine - Boar 440lb	0.750	0.600

2.1.2 kWh savings estimate

Based on the quantity of methane produced, the applicant or bio-digester design consultant can select a generator and calculate the potential annual electrical energy production. The applicant must document the operating parameters of the generator. This information should become part of the applicant's folder.

The actual quantity of electrical energy generated is a function of the quantity of methane delivered to the engine, heating value, capacity factor and the thermal conversion efficiency.⁹

$$Annual kWh = \frac{G \times H \times I \times J}{3,413}$$

- G = Annual biogas delivered to the genset engine. This quantity is the annual biogas produced minus biogas flared, sold, or used for heating.
- H = Thermal conversion efficiency (percentage expressed as a decimal), 22–25 percent for older, naturally aspirated gensets, 29–31 percent for lean-burn gensets, and ≤ 38 percent for larger (>1 MW) lean-burn gensets. Provide documentation supporting the thermal conversion efficiency used for the estimate.

⁸ Ibid.

⁹ John H. Martin, *A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures*, ASERTI, USDA – Rural Development and EPA AgStar, (www.epa.gov/agstar/pdf/protocol.pdf), January 2007.

- I = Lower heating value (LHV) of biogas (BTU/ft³) – (corrected for temperature and pressure of methane production); the value ranges from 500 to 800 BTU/ft³; average biogas is approximately 600 BTU/ft³. The lower heating value of biogas can be estimated as follows:

$$\text{LHV}_{\text{biogas}} = \text{LHV}_{\text{methane}} * F$$

where F is the fraction of biogas that is methane.¹⁰

Assume the lower heating value¹¹ (LHV) of methane (BTU/ft³) is 911 BTU/ft³ at standard conditions (60° F and 1 atmosphere).

- J = System utilization rate, 0.85 (the Program assumes this average for a mature, well-operated system)¹²

The anticipated methane production of the farm or industrial process is typically used to determine the genset size. The above equation assumes there is no over-production of biogas (relative to the size of the generator set) that is flared. When under-production of gas may take place (e.g., a genset is initially oversized in anticipation of later expansion), the system designer must document the potential impact on production. Some gensets (especially older models) decline in electric production efficiency at partial loading. The program should document any adjustments for these situations that affect estimation input values.

i. Parasitic Electrical Energy

Parasitic electrical load is the energy required to operate the renewable energy system (that would otherwise not be required). In this case, it includes the energy consumed by pumps, fans, and motors that are necessary to operate the digester energy system. The program-tracked savings (in the program database) should account for the parasitic loads. The Focus grant applications already contain a section for the applicant to list parasitic energy

¹⁰ TC Consulting Services. *Sample Measurement and Verification (M&V) Plan for Bob's Farm Anaerobic Digester Gas (ADG) System*. New York State Energy Research and Development Authority. July 10, 2009
<http://cdhnrqy1.user.openhosting.com/Documentation/ADG%20Sample%20M&V%20Plan.pdf>
 (accessed August 11, 2009).

¹¹ The lower heat value (LHV) of methane, which is the heat of combustion less the heat of vaporization of the water formed as a product of combustion, should be used because condensation of any water with an engine-generator set is unlikely. The LHV of methane is 960 BTU per ft³ at 0° C and 1.0 atmosphere or 911 BTU per ft³ at 60° F and 1.0 atmosphere. The LHV of methane varies for temperature and pressure in accordance with the general gas law, and the LHV of methane used to calculate thermal efficiency should be for the temperature and pressure at which biogas production is being measured.

¹² The system utilization rate accounts for factors such as generator downtime, maintenance, and other practical considerations affecting generation. Based on experience, existing installations have an average system utilization rate of 0.85.

information. To calculate parasitic electrical energy, add the annual kWh¹³ for all parasitic loads together.

When the renewable energy savings is for fossil fuels, count the parasitic load as negative kWh values in the tracking system. When the system is generating electricity, subtract the annual parasitic kWh from the annual generation and enter this value in the program tracking system. When the system is generating only biogas (therms), enter the parasitic electrical energy as a negative value for tracked electric energy. The documentation should clearly indicate the parasitic kWh estimates, including equipment type, size, and operating characteristics.

2.1.3 kW savings estimate

The definition of kW in the current contract period (and going forward) is associated with average kW savings at system peak.¹⁴ The kW savings is calculated based on the average hourly load displaced between 1 pm and 4 pm weekdays from June through August. For most farm and many other biogas systems, the peak kW is equal to the average kW. In other words, the system operates at a relatively constant level of output throughout the year and time of day. For these situations, use the following equation to estimate the peak kW savings for a Biogas system:

$$Peak\ kW = \frac{estimated\ kWh}{8760\ hours}$$

For cases in which the kWh production varies seasonally or daily (e.g., industrial waste processes), please provide the following:

- A description of how and why production varies. This description should include the expected times of year when production occurs and at what levels. When production occurs during the system peak period (as described above) the documentation should include a description of use during the peak period. Since past waste streams determine present biogas production, the description should include the assumptions of the delay between waste stream production and biogas production.
- Documentation of the peak demand savings estimation approach. Peak demand savings must be calculated based on production during the system peak as defined above. The documentation should include the calculations for estimating peak demand savings with clear indication of the source of the input values for the calculation.

i. Parasitic Electrical Demand

Parasitic electrical demand is the electrical power required to operate the renewable energy system (that would otherwise not be required) coincident with the utility peak. In this case, it

¹³ kWh (load) = kW (load) x hours of operation per year (note: 1.0 HP = 0.75 kW).

¹⁴ See *BP OPS Manual*, "Revised Peak KW Reduction Description," p. 57, April 1, 2008. Peak kW in this definition is being used as a measure of power load on the grid displaced by the biogas system.

includes the demand of pumps, fans, and motors that are necessary to operate the digester energy system. The program-tracked savings (in the program database) should account for the parasitic demands.

Calculate the parasitic kW using the equation for peak kW described above. The parasitic peak kW is computed for each load, and the sum of all loads is total parasitic peak kW.

When the renewable energy savings is for fossil fuels, count the parasitic load as negative kW values in the tracking system. When the system is generating electricity, subtract the peak parasitic kW from system peak savings and enter this value in the program tracking system. When the system is generating only biogas (therms), enter the parasitic load as a negative value for tracked peak electric demand savings.

The documentation should clearly indicate the parasitic kW estimates, including equipment type, size, and operating characteristics.

2.1.4 Therm savings estimate

There are three instances where therm savings for biogas systems are calculated as part of the Focus program.

1. On-site utilization of methane to fuel a boiler or furnace
2. Sale of biogas to a third party
3. Waste heat utilization from the engine-generator.

The calculation of thermal energy generated by the first two biogas applications can be made by the same calculation, whereas the third application requires a different equation.

A. *BIOGAS SALE AND UTILIZATION CALCULATION*

The thermal savings derived from the utilization of biogas for sale or as a fuel (Items 1 and 2 above) is a simple matter of calculating the thermal content of the methane combusted or stored with the equation:

$$AnnualTherm = \frac{AnnualMethane(ft^3)}{100ft^3 \text{ methane per therm}}$$

The equation for calculating annual methane production is discussed in Section 2.1.1. Care must be taken that the methane volume has been corrected to standard temperature and pressure using the General Gas Equation. The quantity of methane used in the above equation will not necessarily be the quantity of methane generated by the digester if full biogas production cannot be utilized. Please document all calculations and assumptions.

B. *WASTE HEAT UTILIZATION CALCULATION*

The therm saved through the utilization of the waste heat of the engine-generator (Item 3 above) can be calculated with the following equation:

$$AnnualTherm = \frac{J \times K \times L \times hrs - N}{M}$$

- J = System utilization rate, 0.85 (The Program assumes this value as the average for a mature well operated system)¹⁵
- K = Heat generation of engine in therm per hour (obtained from manufacturer) (Specific information about the installation may indicate that the heat generation of the engine may represent the heat recovery from the water jacket, the exhaust manifold or both.)
- L = Heat exchanger efficiency (obtained from manufacturer)
- M = Average efficiency of a gas boiler, 0.80 (the Program assumes this value for gas boilers). Use a value appropriate for the specific boiler or heating system used.
- N = Average waste heat supplied to the biodigester. This estimate depends on the digester type and design, the type and collection method of influent, and many other factors. A standard calculation method is not feasible for this value. Provide calculations and supporting documentation for this estimate.
- hrs = The annual hours of operation for the engine-generator. The value is 8760 for systems that operate year round, but may vary by location.

Since the system is providing natural gas savings for heating, the estimate is divided by the average efficiency of a natural gas fired boiler. The 0.8 figure is used as the average efficiency of a traditional natural gas fired boiler heating system. The heat generation of the engine-generator and the efficiency of the heat exchanger will depend on the type and operating power of the engine. Finally, the average waste heat supplied to the biodigester must be subtracted from the available waste heat. The heat supplied to the biodigester will be unavailable to offset existing heating loads. Please document all values and assumptions.

This calculation is based on the assumption that all waste heat produced can be utilized. When the waste heat available will exceed the waste heat utilized, the waste heat utilization equals the waste heat demand. The program should track only the waste heat that will be utilized. In the following sections, we provide recommendations for estimating waste heat utilization for two overall situations: when historical heat demand data is available and when it is not.

¹⁵ The system utilization rate accounts for factors such as generator downtime, maintenance, and other practical considerations affecting generation. Based on experience, existing installations have an average system utilization rate of 0.85.

C. *HISTORICAL HEAT DEMAND DATA AVAILABLE*

i. *Space Heating Applications*

1. Determine annual (12-month) fossil fuel usage (when more or less than a full year of historical usage data are provided Focus should annualize the data and document the approach).
2. Convert the quantity of fossil fuel into therms using standard conversion factors available from DOE and other sources.
3. Determine space heating usage by removing non-space heating uses of fossil fuel.
 - a. Use average usage for June, July, and August as monthly non-space heating use (if this approach is not appropriate then identify why not and calculate using a different and documented approach).
 - b. Multiply monthly non-space heating use by 12 and subtract from annual usage.
4. Weather normalize space heating usage using 30-year average HDD =
Space heating use * (avg HDD)/(actual HDD for period of data).¹⁶
5. Determine percentage of space heating use that will be displaced (e.g., percentage of floor space heated with waste heat) to estimate savings.
6. Waste heat utilized (therms) = Weather normalized annual therms x percent of space heating use that will be displaced.

ii. *Non-space Heating*

1. Determine annual (12-month) usage.
2. Determine non-heating usage as described above.
3. Determine percentage of non-space heating displaced. Describe how this amount was determined. The amount of non-space heating displaced can be less than or greater than 100 percent. It would be greater than 100 percent for situations in which the non-space heating system was not only switched to utilize captured waste heat, but was expanded to include additional natural gas consuming applications. It would be less than 100 percent for situations when only a portion of the specific non-space heating load is replaced with captured wasted heat, or there is a reduction in use for this application.
4. Multiply annual non-heating usage by percentage displaced. This is the non-space heating waste heat utilized.

iii. *Waste Heat Utilized for Space and Other Heating*

1. Estimate space heating waste heat utilization as described above.

¹⁶ 30-year averages and annual heating degree days can be found at <http://www.doa.state.wi.us/degreedays>.

2. Estimate non-space heating waste heat utilization as described above.
3. Add results of 1 and 2.

D. NO HISTORICAL HEAT DEMAND DATA AVAILABLE

Some systems to utilize waste heat are installed in new facilities, as an expansion to an existing facility, or for a new purpose or process. In these cases, there is no historical data available from which to estimate waste heat utilization.

For grant applications on projects requiring Wisconsin Commercial Code and HVAC plan review, the applicant shall provide a complete copy of the submitted heating and cooling package to be included as an attachment to the grant application. For grant applications for small commercial space heating applications that do not require Wisconsin Commercial Building Code and HVAC Plan review, Focus should require the applicant to supply and Focus to review the heat load calculations consistent with Manual J.¹⁷

By “consistent with Manual J,” we are referring to calculations that estimate heating load for the space that will be heated with the biogas system. This calculation must take into account:

- The overall U-value and area of the ceiling, walls, windows, and floor
- Heating system efficiency (assume, at a minimum, an 80 percent AFUE)
- Average heating degree days during the heating season (indicate what months were included in the heating season – e.g., October through April).

The applicant should provide and Focus should review in its documentation all input values for the calculations, clear documentation of the calculation approach, and the basis for the input values. For example, provide the assumed R-values for windows, walls, floors, and windows, and assumptions about infiltration loss. Make sure that calculations are accurate and clear.

For non-space heating loads, the applicant should provide and Focus should review, complete documentation of the analysis conducted to estimate savings. The analysis should be consistent with generally accepted engineering practices and documented so that all input data and assumptions are identified.

In cases for which historical data are unavailable, we recommend that an engineer or HVAC contractor complete them.

For non-residential applications, the applicant should provide the contractor’s calculations of the estimated waste heat utilized, documenting how the waste heat will be utilized. Calculation content and format should be consistent with industry practice. The evaluation team will review these calculations to determine if they meet industry practices.

¹⁷ Air Conditioning Contractors of America (ACCA). *Manual J Residential Load Calculation*. It is important to ensure the procedure used by the contractor follows Manual J.

2.1.5 Information required

In order to calculate the estimates of kWh and kW the program must include in the application or project documentation the information listed below. The intent is to provide a comprehensive list of the necessary items for calculation. It does not include other information that may be necessary for implementing the program. It includes many items that the program currently collects. Grant applications and all supporting documents should be included in the folder provided to the Focus program evaluator.

The intent of these information requirements is twofold: first, that the program collects the necessary information to accurately determine the amount of methane and consequently kWh produced by the system and, second, that the program files contain sufficient documentation of the calculation approach for review and verification of these calculations. The process of documenting the approaches may also result in more consistency across similar projects.

To perform the calculations, the project documentation (most likely supplied by the bio-digester design consultant as part of a feasibility report) should include:

- Farm digester production information
 - Type of animals
 - Number of each type of animal
 - Quantity of manure (lb/animal/day)
 - Manure collected in influent (percentage)
 - Digester efficiency (percentage)
 - COD destroyed (ft^3 biogas/lb COD corrected for temperature and pressure)
 - Methane content of biogas (percentage)
 - Estimated annual biogas production (ft^3/yr)
 - Lower heating value of methane used (BTU/ft^3 corrected for temperature and pressure).
- Industrial digester production information
 - Gallons of influent per day
 - Lbs COD/gallon influent. This value should represent the COD/gallon of dissolved solids, suspended solids and solids (sludge).
 - Digester efficiency (percentage)
 - COD destroyed (ft^3 biogas/lb COD corrected for temperature and pressure)
 - Methane content of biogas (percentage)
 - Estimated annual biogas production (ft^3/yr)
 - Lower heating value (LHV) of methane used (BTU/ft^3 corrected for temperature and pressure). Where the engine manufacturer provides the heat rate based on the higher heating value (HHV), include the HHV of methane used and the derating factor from HHV to LHV.
- Equipment information
 - Generator or boiler manufacturer

- Generator or boiler model number
 - Number of generators or boilers
 - Generator rated capacity (KW)
 - Thermal conversion efficiency (percentage)
 - System utilization rate (percentage)
 - Heat rate of engine (therm/hr) for water jacket and for exhaust.
 - Heat exchanger efficiency (percentage)
 - Boiler efficiency
 - Heat energy uses. Since it is possible that waste heat production will exceed waste heat utilized, the applicant shall provide monthly heat load estimates or a thermal modeling spreadsheet to document heat energy uses.
- Evaluation outputs
 - Annual kWh production (kWh/yr)
 - Peak kW (kW)
 - Annual therm output
 - Negative parasitic kWh
 - Negative parasitic peak kW.

2.2 BIOMASS SYSTEMS

In this section, we discuss the calculation of therms displaced by biomass. Biomass projects implemented by Focus on Energy vary in the biomass inputs, the heating use (space, water, and other) for the biomass, and the presence of prior consumption data. Because of the variation across these projects, we provide standard calculations for several situations and emphasize the importance of providing thorough documentation regarding the calculation assumptions and data sources.

2.2.1 Therms displaced by biomass

We provide recommendations for estimating therms displaced by biomass for two overall situations: when historical usage data is available and when it is not.

A. HISTORICAL USAGE DATA AVAILABLE

i. Space Heating Applications

1. Determine annual (12-month) fossil fuel usage (when more or less than a full year of historical usage data are provided Focus must annualize the data and document the approach).
2. Convert the quantity of fossil fuel into therms using standard conversion factors available from DOE and other sources.
3. Determine space heating usage by removing non-space heating uses of fossil fuel.

- a. Use average usage for June, July, and August as monthly non-space heating use (if this approach is not appropriate then identify why not and calculate using a different and documented approach).
 - b. Multiply monthly non-space heating use by 12 and subtract from annual usage.
4. Weather normalize space heating usage using 30-year average HDD.¹⁸

$$\text{WeatherNormalizedSpaceHeating} = \frac{\text{SpaceHeatingUse} \times \text{HDD}_{\text{Avg}}}{\text{HDD}_{\text{Actual}}}$$

5. Determine percentage of space heating use that will be displaced (e.g., percentage of floor space heated with biomass) to estimate savings.
6. Therms displaced = Weather normalized annual therms x percentage of space heating use that will be displaced.

ii. Non-space Heating

1. Determine annual (12-month) usage.
2. Determine non-heating usage as described above.
3. Determine percentage of non-space heating displaced. Describe how this amount was determined. The amount of non-space heating displaced can be less than or greater than 100 percent. It would be greater than 100 percent for situations in which the non-space heating system was not only switched to biomass, but was expanded. It would be less than 100 percent for situations when only a portion of the specific non-space heating load is replaced with biomass, or there is a reduction in use for this application.
4. Multiply annual non-heating usage by percentage displaced. This is the non-space heating displaced.

iii. Space and Other Heating Displaced

For situations in which both space and non-space heating is displaced.

1. Estimate space heating displaced as described above.
2. Estimate non-space heating displaced as described above.
3. Add results of 1 and 2.

¹⁸ 30-year averages and annual heating degree days can be found at <http://www.doa.state.wi.us/degreedays>.

B. NO HISTORICAL USAGE DATA AVAILABLE

i. Space Heating Applications

Some biomass systems are installed in new facilities, as an expansion to an existing facility, or for a new purpose or process. In these cases, there is no historical data available from which to estimate therms displaced.

For projects requiring Wisconsin Commercial Code and HVAC plan review, Focus on Energy should include a complete copy of the submitted heating and cooling package in the program files. For biomass projects for small commercial space heating applications that do not require Wisconsin Commercial Building Code and HVAC Plan review, the project documentation should include heat load calculations consistent with Manual J.¹⁹

By “consistent with Manual J,” we are referring to calculations that estimate heating load for the space that will be heated with the biomass system. These calculations are necessary for two purposes. First, to assure that the system is properly sized, and second, to estimate savings. This calculation must take into account:

- The overall U-value and area of the ceiling, walls, windows, and floor
- Heating system efficiency (assume, at a minimum, an 80 percent AFUE²⁰)
- Average heating degree days during the heating season (indicate what months were included in the heating season – e.g., October through April).

The program documentation should include all input values for the calculations, clear documentation of the calculation approach, and the basis for the input values. For example, provide the assumed R-values for windows, walls, floors, and windows, and assumptions about infiltration loss. Make sure that calculations are accurate and clear.

ii. Non-space Heating

Biomass systems may also be used for energy savings on non-space heating loads. For these loads, the program records should include complete documentation of the analysis conducted to estimate savings. The analysis should be consistent with generally accepted engineering practices and documented so that all input data and assumptions are identified. In cases for which historical data are unavailable, we recommend that an engineer or contractor complete them.

2.2.2 Information required

In order to conduct the estimates of therms displaced, the program must include in the application or project documentation the information listed below. In some cases, not all information is required. In other cases, there will be a need for more detailed information.

¹⁹ Air Conditioning Contractors of America (ACCA). *Manual J Residential Load Calculation*. It is important to ensure the procedure used by the contractor follows Manual J.

²⁰ The efficiency of the biomass system should be used to estimate the size of the biomass system.

The intent of these information requirements is twofold: first, that the program collects the necessary information to accurately determine the amount of fossil fuel displaced by the biomass system; and second, that the program files contain sufficient documentation of the calculation approach for review and verification of these calculations. The process of documenting the approaches may also result in more consistency across similar projects.

Focus on Energy program staff agreed to establish checklists that would cover the data and approach discussed above to assure that the appropriate data are collected and that calculations are consistent. We recommend that this be done.

- Biomass equipment specifications
 - Approximate square footage of facility to be serviced by biomass system
 - Facility type (retail, manufacturing, residential, etc.)
 - Burner size, manufacturer, and model
 - Fuel to be used (biomass source such as waste wood, green wood, pellets, chips or saw dust)
 - Cost of fuel to be used per ton (or some other unit)
 - Heating value of biomass fuel source
 - BTU output of burner
 - Estimated efficiency
 - New use or replacement
 - Intended use (space heating, processes, water heating, others specified)
 - What other systems and fuels will supplement the biomass system in its task (if any)
 - Percentage of total uses supplied by biomass system
 - What systems will be available for backup in case of biomass system failure (if any).
- Existing equipment specifications
 - Fuel used (e.g., natural gas, propane)
 - Type of system (e.g., forced air furnace, boiler)
 - Size of existing system (in BTUs per hour)
 - Estimated efficiency of existing system
 - Existing fuel usage
 - Dates and quantity of fills for propane or fuel oil (a minimum of 12 months data)
 - Indication of data used for above estimates (include bills in project folder)
 - Dates of meter reading and quantity of electricity or natural gas used (12 months).
- When no existing equipment (new construction or expansion)
 - Intended use of equipment
 - For space heating
 - Percentage of heating to be displaced

- Heat loss or other calculations estimating space heating load for new or expanded space
- Non-space heating
- Documentation of biomass load needed to meet requirements.

2.3 PHOTOVOLTAIC (SOLAR ELECTRIC)

Focus on Energy estimates of solar energy (kWh) transmitted by the photovoltaic (PV) system to the grid are performed using PVWatts, an online software package provided by the National Renewable Energy Laboratory (NREL).²¹ PVWatts has become the industry standard for estimation of PV system performance and should continue to be used by the program.

Peak kW in the current contract period (and going forward) is based upon kW capacity during peak electrical use in the summer. This requires a different calculation approach, provided below, than the approach used previously.

2.3.1 kWh savings estimate

PVWatts requires the following inputs:

1. A reference city
2. PV panel rated DC capacity
3. Panel orientation
4. Panel tilt
5. A derate factor between 0.0 and to 1.0.

The first four inputs are straightforward. The reference city is the closest relevant weather station to the system's location and is used to determine solar radiation. The PV panel rated DC capacity is provided by the manufacturer. The panel orientation and tilt are easily measured and this information is provided in the rebate application.

The base derate factor is the combination of multiple system component factors that affect the efficiency of the system and thus the kWh production. PVWatts uses a default base derate factor of 0.77, whereas Focus uses a base derate factor of 0.80. An analysis of actual PV production versus Focus estimates indicates that 0.80 is a reasonable base value to use in the Wisconsin Program.²²

²¹ <http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/> (accessed August 11, 2009).

²² For FY07, KEMA compared the inverter readings of kWh production for 14 participants to Focus program estimates. Although the actual performance of the systems varied by as much as 26 percent relative to the Focus estimate, the overall ratio of Focus estimated to annualized inverter readings was 1.01.

To arrive at an overall system derate factor, the base derate factor should be multiplied by factors for shading and snow cover shading. These factors are not included in the base derate factor. The calculation is performed as follows:

$$\text{System derate factor} = \text{Base derate factor} \times \text{Shade factor} \times \text{Snow factor}$$

Where:

System derate factor = Value entered into the PVWatts calculator to derate PV panel DC rating to an AC rating

Base derate factor = 0.80 for the Focus program

Shade factor = 100 percent minus percentage shading (decimal value)

Snow factor = 100 percent minus percentage snow cover (decimal value)

It is important that the shading and snow factors be included in the calculations of the system derate factor (as opposed to multiplying them times the final kWh output). This is so that the monthly AC energy values are correctly calculated in the PVWatts output, which is important for the calculation of peak kW, as explained below.

Shading factors are determined using a shade measurement tool. Percentage snow cover is an assigned value based on the tilt angle of the panel (see Table 2-2). Additional snow cover may be assigned for systems in the Lake Superior snow belt or when empirical data provide evidence of a difference from the table. The Focus PV Cash-Back Reward Pre-Approval Application currently gives the following percentage values for shading from snow cover.

Table 2-2. Shading from Snow Cover

Tilt Angle	≥ 35°	≥20° and <35°	≥14° and <20°	≥10° and <14°	≥5° and <10°	≥2° and <5°	<2°
Annual snow cover shading	1%	2%	3%	4%	6%	8%	12%

To calculate annual production accurately if a rack is adjusted seasonally, each season must be calculated separately in PVWatts.²³ PVWatts calculation results show that about five percent more energy is produced annually if a rack is adjusted two or four times a year.²⁴ PVWatts calculations must be performed for each panel tilt angle adjustment, and then the applicable monthly AC kWh production for each tilt angle added together to arrive at a twelve month annual kWh production. Focus program staff should first assess the likelihood that an “adjustable” system will indeed be adjusted seasonally before calculating for multiple tilt

²³ The evaluations have found that few households with adjustable racks make seasonal corrections.

²⁴ There is not a substantial difference in annual kWh production between panels adjusted two and four times per year.

angles.²⁵

In instances where arrays of panels at a site are at different tilt angles, orientations, or have different shading, the PVWatts calculations must be performed separately for each array.

2.3.2 kW savings estimate

The definition of kW in the current contract period (and going forward) is associated with kW savings at peak summer periods.²⁶ The kW savings is calculated based on the average hourly load displaced between 1 pm and 4 pm weekdays from June through August.

To estimate the peak kW savings for a fixed array system with a tilt angle of 30–45 degrees and an azimuth angle of 180 degrees, the peak kW is based on the sum of the site's PVWatts kWh AC output for the months of June, July, and August, multiplied by a coefficient²⁷:

$$Peak\ kW = 0.0013\ hr^{-1} \times (kWh_{June} + kWh_{July} + kWh_{August})$$

To more accurately estimate peak kW estimates for arrays that do not have a fixed tilt angle of 30 to 45 degrees and an azimuth angle of 180 degrees, PVWatts v1 should be used to find the hourly production for the year. Using the hourly data, the system designer can directly calculate the peak kW by summing the kWh production during the peak period (1 pm to 4 pm DST) during the months of June, July, and August and dividing the sum by 276 hours or [3 hours * (30 days + 31 days + 31 days)].

²⁵ Only three of the seven FY07 adjustable systems evaluated were adjusted seasonally, according to Focus participants. All three participants that make adjustments had a specific interest in renewable energy that made them more inclined to make the effort required for the adjustment. Adjustments are also more likely for pole mounted system (versus roof mounts), which are designed for easier adjustments.

²⁶ See *BP OPS Manual*, "Revised Peak KW Reduction Description," p. 57, April 1, 2008. Peak kW in this definition is being used as a measure of power load on the grid displaced by the photovoltaic system.

²⁷ The above formula for peak kW is a simplification of the fixed coefficients used in the following equation:

$$Peak\ kW = \frac{(A \times B) \times C_{June} + (A \times B) \times C_{July} + (A \times B) \times C_{August}}{D \times E}$$

Where:

- A = Average percent daily radiation between 1 pm and 4 pm (12 pm and 3 pm solar time) on weekdays for peak months. These data are available on the Solar Pathfinder measurement disc for 43–49 degrees N. Latitude (June = 36 percent, July = 36 percent, August = 37 percent)
- B = PVWatts estimate of kWh AC monthly energy for June, July, and August
- C = Number of days in the months of June, July, and August
- D = Number of hours in peak period = 3 hours
- E = Number of months in peak period = 3 months

The PV system designer must be aware of two issues and correct the calculation accordingly. First, PVWatts hourly output is based on solar time. Therefore, the time period coinciding with peak on PVWatts output is 12 pm to 3 pm. Second, PVWatts hourly output is based on the irradiation during the preceding hour (e.g., output for 1 pm is based on incident solar radiation from 12 pm to 1 pm.).

System installers or designers can readily use this method since users can obtain these data directly from PVWatts v1. In addition, system installers and designers may use this method for fixed mounted systems facing due south although the results will be similar to those obtained through the method described earlier.

2.3.3 Information required

In order to calculate the estimates of kWh and peak kW, the program must include in the application or project documentation the information listed below. The intent is to provide a comprehensive list of the necessary items for calculation. It does not include other information that may be necessary for implementing the program; but it does include many items that are currently being collected by the Focus Program. The PVWatts output form contains much of the information below and should be part of the applicant's evaluation folder.

- System site
 - Complete names and address
 - Type of facility (residential or nonresidential, for profit or not for profit, individual/sole proprietor, corporation, partnership, government, school, church, other)
 - Percentage annual shading—(indicate measurement tool)
 - Percentage snow cover—(from program chart).
- System specifications
 - Manufacturer of panel, inverter, rack, charge controller, batteries
 - Number, rated capacity (kW) of each component and total system capacity
 - Type of rack—fixed, manually adjustable, single axis tracking, dual axis tracking
 - Orientation(s) (compass direction with respect to north)
 - Tilt angle(s) of panels with respect to horizontal (degrees).
- PVWatts outputs
 - Reference city
 - Base derate factor
 - Derate factors applied for shade, snow shading
 - System derate factor
 - Annual AC energy production estimate (kWh)
 - AC energy production for the months of June, July, and August (kWh)
 - Peak kW estimate (kW).

2.4 SOLAR WATER HEATING

Focus uses RETScreen Version 4²⁸ to calculate production from solar water heating (SWH) systems. RETScreen is an online design tool for the installers of solar hot water and other energy systems.

We found RETScreen to be a reasonable tool for estimating SWH production and recommend that the program continue using RETScreen for Solar Water Heating loads. Versions 4 of RETScreen provides conservative estimates of solar water heating.

2.4.1 Energy and demand displaced by solar water heating system

The RETScreen 4 models can evaluate three basic applications: domestic hot water (DHW), industrial process heat, and swimming pools. Users should be cautious when using these models due to the assumptions²⁹ incorporated into them. These assumptions include:

1. The service hot water model assumes that the daily volumetric load is constant for each user-defined time period (which can be one or more months).
2. The model assumes a constant application and temperature. Separate estimates are required for components of systems that use service hot water for two different applications or at two different temperatures.
3. The model assumes that all the energy collected is used. For systems with storage this is a reasonable assumption. For systems without storage, some energy may get lost during periods when hot water is not in use.

The RETScreen model requires various operational parameters of the SWH installation and the load. Examples of data include inputs about the solar panel used, a reference city for climate data, system design parameters, and the quantity of water heated. The model calculates the estimated thermal savings due to the installation of SWH systems for service hot water with storage, service hot water without storage, and swimming pools, as applied to residential, commercial, and industrial applications.

The model has a database and algorithms to assist with most data input and calculations. In situations where the Focus program does not use the RETScreen database information or model calculations (e.g., hot water load), the project folder should include complete documentation of the assumptions and calculations to arrive at the estimate. For residential systems, the program should use a value of 15.8 gallons (60 liters) per person per day unless there is evidence to support a different value. Where appropriate, the data source and methodology should also be clear. When RETScreen is used, RETScreen output worksheets should be included with each application, and Focus staff should review the inputs for reasonableness.

²⁸ RETScreen[®] is a registered trademark of Natural Resources Canada and is available for free download from www.retscreen.net.

²⁹ RETScreen[®] International. *Clean Energy Project Analysis, RETScreen Engineering & Cases Textbook*, 3rd ed. www.retscreen.net.

A. NATURAL GAS (THERMAL) ENERGY DISPLACED

Solar water heating systems provide natural gas energy savings, measured in therms, when replacing a natural gas water heater. The RETScreen software will provide an estimate of energy production by the SWH system in MWhs. To calculate the natural gas therms replaced (saved) by the system convert the RETScreen MWh production estimate to therms³⁰ and then divide this estimate by 0.8.³¹ The 0.8 figure is used as the average efficiency of a gas fired water heating system. When the production estimate exceeds the known usage, use the known usage as the total energy displaced by the system.

B. ELECTRIC ENERGY DISPLACED

Solar water heating systems provide electric energy savings when replacing or supplementing an electric water heater. The RETScreen software provides an estimate of energy production by the SWH system.³² The production estimate is the total thermal energy, in MWhs, displaced by the system. When the production estimate exceeds the known usage, use the known usage as the total energy displaced by the system.

C. SPACE HEATING SAVINGS

Focus does not explicitly fund space-heating applications. Sometimes a DHW system may be part of a larger system that includes space heating, or the size of the solar thermal system is larger than needed to meet water heating needs and is tied into the space heating system. In these instances, RETScreen does not readily calculate space-heating contributions for solar water heating systems. We developed a method to estimate the systems contributions to space heating load.

We recommend the following method for calculating space heat savings provided by solar hot water systems. First, calculate solar energy available in therms (or kWh for electric heating customers) from the SHW system during the heating season (October 1 to April 30), $SEA_{Oct-April}$. Second, calculate therm savings (or kWh) based on annual hot water load, $therms_{DHWAnnual}$. Third, calculate therm savings (or kWh) based on summer hot water load (May 1 to September 30), $therms_{DHWSummer}$. Then, subtract the summer hot water load savings from the annual hot water load savings to determine the winter hot water load (October 1 to April 30), $therms_{DHWWinter}$. Finally, subtract the winter hot water therm savings (or kWh) from the solar energy available during heating season. For clarity, we show the equation (based on therm savings):

³⁰ Therms = MWh * 34.121 therms/MWh.

³¹ This calculation assumes that tank and distribution losses for SWH systems and what it is replacing are roughly the same.

³² This calculation assumes that tank and distribution losses for SWH systems and what it is replacing are roughly the same.

$$therms_{SpaceHeating} = SEA_{Oct-April} - (therms_{DHWAnnual} - therms_{DHWSummer})$$

$$therms_{SpaceHeating} = SEA_{Oct-April} - (therms_{DHW inter})$$

Where:

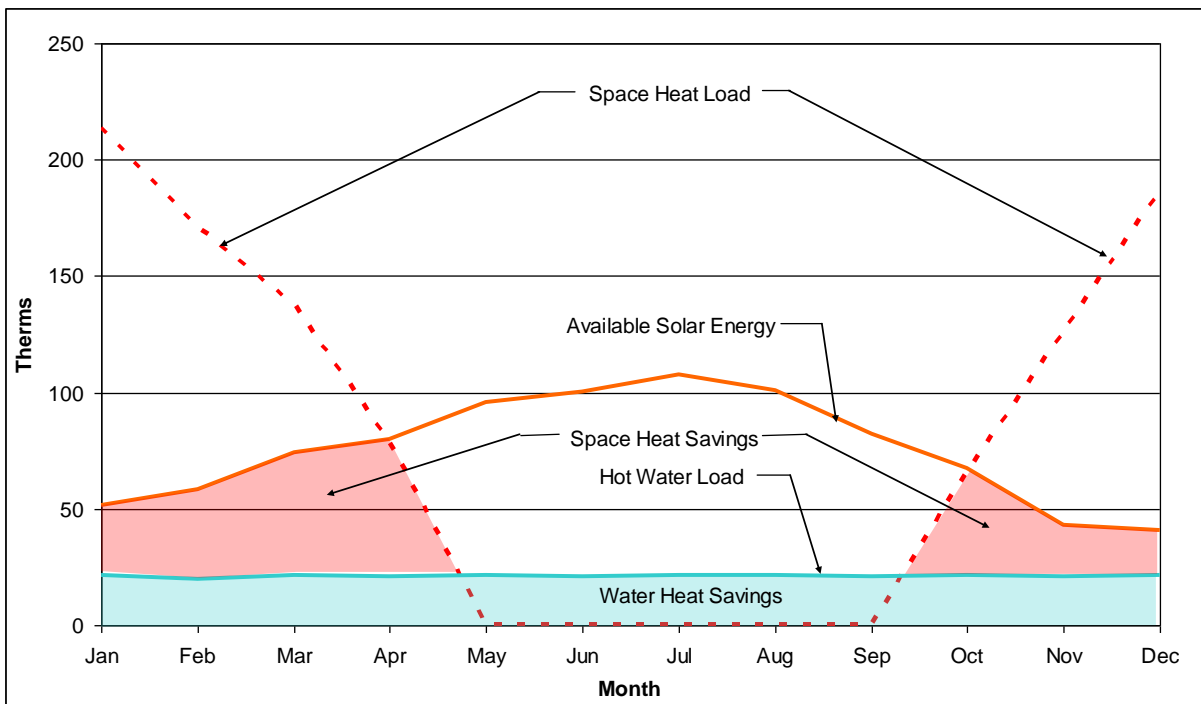
$SEA_{Oct-April}$ = Solar energy available (in therms) from October 1 to April 30. To estimate this value, use a supply water temperature of 80° F. This value is the assumed temperature of hot water returning from a heating loop. In addition, estimate the water usage assuming constant flow throughout the day. For a system using ½ inch pipe pumped at 4.2 gallons per minute, this is approximately 6000 gallons per day usage. This value shall not exceed the space heat load over the period of October 1 to April 30.

$therms_{DHWSummer}$ = therm savings for domestic hot water usage from May 1 to September 30

$therms_{DHWAnnual}$ = therm savings for annual domestic hot water usage

Figure 2-1 shows the relationship between solar energy available and water heating savings for a solar water heating system.

Figure 2-1. Solar Space Heating Estimates



The program is working to develop alternate methods for estimating space heat savings. If alternate methods are used, the project file must include the calculations, assumptions and supporting documentation.

D. ELECTRIC DEMAND DISPLACED

When the SWH system is replacing an electric water heater the program should estimate and track the Peak kW displaced. Focus on Energy defines peak kW as the hourly average power load or output (kW) of an electrical system between 1 pm and 4 pm weekdays in June through August.

We assume the SWH system will operate coincident with utility peak. Therefore, calculate the Peak kW with the following formula:

$$kW_{Peak} = \frac{kWh_{SummerDay} \times UCP}{3hrs}$$

$kWh_{SummerDay}$ = Hot water kWh usage for a summer day.

For residential, we assume the usage will be constant over the year. Therefore, for residential applications use:

$kWh_{SummerDay}$ = RETScreen, heating delivered (in kWh) / 365 days

For commercial, agricultural, or industrial applications, provide the $kWh_{SummerDay}$ used and the supporting documentation

UCP = Hot water usage coincident with peak (in percentage)

For residential,

UCP = 11.2 percent³³

For commercial, agricultural, or industrial applications, provide the UCP used and the supporting documentation

3 hrs = Peak hours (1 pm to 4 pm)

E. PARASITIC ENERGY AND DEMAND

RETScreen also estimates the energy used by the SWH circulation pump, which is a parasitic load. The model estimates an annual electricity usage (MWh) for the pump based on an entered value for pump power per unit area of solar panel. The Focus program database should track the energy and demand of the system pumps as a negative value in the kWh and kW column when only therm savings are tracked. The program should subtract the

³³ Average UCP for high water use and low water use homes from hot water use profiles in *Domestic Hot Water System Modeling for the Design of Energy Efficient Systems*, Prepared for NREL by NAHB Research Center, Inc.

parasitic energy and demand usage from total production and peak demand (and track the net values in the kWh and kW columns of the database) when electric energy is displaced. Include the values and approach used to calculate peak parasitic kW in the project documentation.

Thermostats on the holding tank and collector panel are likely to control the pump. As a result, the pump will only operate during hours when the sun is heating the panel and when hot water is used. The pump will occasionally cycle to maintain the temperature of the tank during non-use periods, but this operation will be minimal and we have ignored this minor associated load. Therefore, parasitic kW coincides with hot water use during the day.

The peak parasitic kW coincides with hot water use during utility peak. As mentioned earlier, the Program defines peak kW as the hourly average power load or output (kW) of an electrical system between 1 pm and 4 pm during the period June through August. Therefore, calculate the peak parasitic kW with the following formula:

$$kW_{Peak} = \frac{kWh_{Pump} \times UCP}{3hrs}$$

kWh_{Pump} = Pump kWh usage for a summer day.

For residential, we assume the pump usage will be constant over the year. Therefore, for residential applications use:

kWh_{Pump} = RETScreen annual parasitic estimate (in kWh) / 365 days

For commercial, agricultural, or industrial applications, provide the kWh_{Pump} used and the supporting documentation

UCP = Hot water usage coincident with peak (in percentage)

For residential,

UCP = 11.2 percent³⁴

For commercial, agricultural, or industrial applications, provide the UCP used and the supporting documentation

3 hrs = Peak hours (1 pm to 4 pm)

Use the pump size determined though a site assessment as the RETScreen input. When the pump size is unknown, use RETScreen recommendations provided in the help section for pump sizing and power ranges per collector aperture area. For residential systems, the value

³⁴ Average UCP for high water use and low water use homes from hot water use profiles in *Domestic Hot Water System Modeling for the Design of Energy Efficient Systems*, Prepared for NREL by NAHB Research Center, Inc.

will be small, but not insignificant, if an AC pump is used. For industrial operations, the value can be sizeable. Enter zero for pump W/m^2 in RETScreen for the following instances³⁵:

- Thermosiphon systems, as a solar loop pump is not required
- Systems with photovoltaic-powered pumps, as the required electric energy is produced by photovoltaic panels
- Outdoor swimming pool systems when the filtration system pump can be used for the solar loop; when solar loop requires a high head (e.g., collectors placed too high above pool level, a booster pump may be required)
- Industrial-type systems where water is simply diverted through the collectors before being delivered to the load.

2.4.2 Information required

The project file must include the information used to calculate the estimate of therms, kWh, and/or kW displaced. This information includes, but is not necessarily limited to, the items in the list below. The intent is to provide a comprehensive list of the necessary items for calculation by the RETScreen model. Most of this information are required entries in the model and appear in the spreadsheet output. Additional information may be necessary for implementing the model.

Typically, the SWH design consultant or installer determines and supplies the information necessary for the calculations. Where values are assumed, are different from a model default, or are not part of the equipment specifications, provide supporting documentation. For example, if hot water usage is based on hours of operation (instead of measured), provide the operating hours, the calculations and the rationale for using this approach.

In addition, explain any alteration of the model (e.g., specifying monthly use percentages to approximate occupancy), and indicate these in the model inputs and outputs.

- Site reference conditions
 - Climate reference city relevant to site location
- Load characteristics
 - Application type (hot water or swimming pool)
 - Building or load type
 - Occupants or units serviced
 - Occupancy (%)
 - Hot water load (gallons/day) (include supporting documentation)
 - Hot water temperature (°F)
 - Operating days per week

³⁵RETScreen® International. *RETScreen Software Online User Manual, Solar Water Heating Model*. www.retscreen.net.

- Percentage of months used
- Supply water temperature – minimum (°F)
- Supply water temperature – maximum (°F)
- Resource assessment
 - Slope of panel (degrees from horizontal)
 - Azimuth of installation (degrees from true south)
- Solar water heater
 - Type (unglazed, glazed, evacuated, other)
 - Manufacturer and model number of solar panel
 - Number of panels to be installed
 - Panel's gross and aperture areas (ft²)
 - Panel Fr, FR UL, and temperature coefficients
 - Miscellaneous losses (%)
- Balance of system
 - Storage capacity/solar collector area (gallons/ft²)
 - Heat exchanger efficiency (%)
 - Miscellaneous losses (%)
 - Pump power per solar collector area (W/ft²)
- Model outputs
 - Annual heating delivered (MWh and therms)
 - Annual pump electricity use (MWh and kWh)
 - Solar fraction (%).

2.5 WIND SYSTEMS

Focus on Energy leases the Seventh Generation Energy Systems, Inc. (7th Generation) model that calculates energy generation of wind systems. Focus provides this model to the site evaluation companies for assessment of Focus on Energy projects. The model is periodically updated by Sagrillo Power and Light (SPL) and 7th Generation as new information about the performance of various turbine models becomes available. Site assessors use a second model developed by AWS Truewind to help determine average wind speed for a prospective site. The general operation and assumptions of these models and their use is outlined below. This approach uses the best available information at this time.

Peak KW in the current contract period (and going forward) is based upon kW capacity during utility summer peak electrical use.

2.5.1 kWh savings (offset) estimate

Estimating energy (kWh) production from wind systems requires a measure of wind speed and the use of a model to estimate system production. Below we discuss the

recommendations for estimating wind speed in the absence site specific wind metered data and the use of the 7th Wind™ Wind Turbine Performance Model v10.72 to estimate system output.

A. WIND SPEED CALCULATION

Static maps are available from the Focus website³⁶ for reference heights between 30 and 100 meters. In addition, wind site assessors have access to a GIS database. A range of average annual wind speeds are read off the color-coded map for the particular location being studied. An average annual wind speed is then selected from the range by the site evaluator as a result of his or her best assessment of the site's characteristics. For a selected turbine hub height a value for the annual average wind speed is estimated using the Power Law equation:

$$\text{Wind Speed}_{(\text{site})} = \text{Wind Speed}_{(\text{ref})} \times (\text{Height}_{(\text{site})} / \text{Height}_{(\text{ref})})^{\alpha}$$

where α is the wind shear exponent (see Table 2-3) based on the site assessor's evaluation of the terrain.

Table 2-3. Wind Shear Estimate based on Surface Description³⁷

Surface Description	Wind Shear α
Smooth hard ground, lake, or ocean	0.20
Level country with foot-high grass Tree lines > 1,000 feet away	0.25
Level and uniform open terrain with crops with Occasional trees and buildings 500 – 1000 feet	0.30
Terrain is open with scattered Trees/buildings less than 500 feet	0.35
Terrain is less open, not densely wooded; Trees/buildings less than 500 feet or Mixed densely wooded areas & open areas; Tree lines greater than 500 feet away	0.40
Mixed densely wooded areas & farm fields; Trees/buildings less than 500 feet	0.45
Densely wooded	0.50
Urban areas with tall buildings	0.60

Experienced users of the GIS wind map recommend extrapolating a reference height higher than the turbine height. Extrapolating down provides a good approximation of wind speed at tower height, whereas extrapolating up will overestimate wind speed.³⁸ Therefore in the equation above, the height_(ref) selected should be greater than or equal to height_(site).

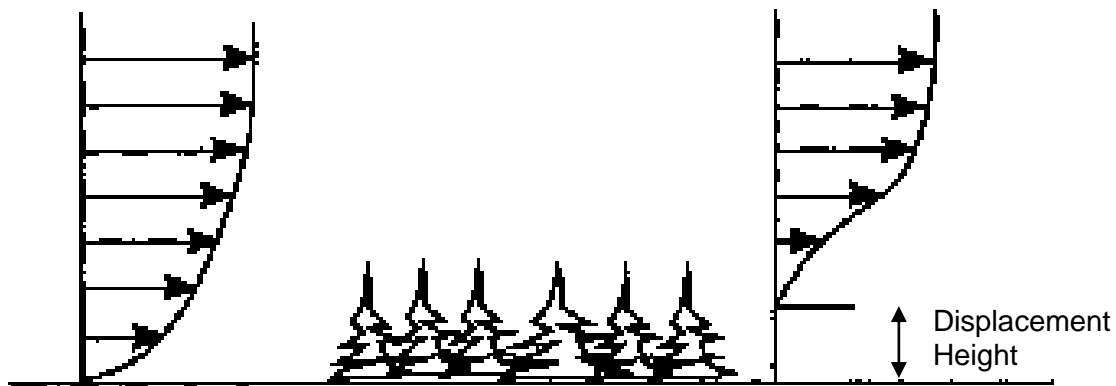
³⁶ <http://www.focusonenergy.com/Information-Center/Renewables/Wind-Maps-Data/>.

³⁷ M. L. Ray, A.I. Rogers, and J.G. McGowan, *Analysis of Wind Shear Models and Trends in Different Terrains*, AWEA Wind Power 2005 Conference, Pittsburgh, PA, June 2006.

³⁸ Mick Sagrillo, Sagrillo Power and Light.

Localized obstructions can also affect wind speed at hub height. Obstructions such as trees or buildings located in the direction of the prevailing wind can reduce the wind speed at the height of the tower. To account for site-specific obstructions, the Program adds a displacement height that increases the reference height for wind speed. A 100-foot tower that is surrounded by open plains will see a different wind speed than the same 100-foot tower that is surrounded by large groves of 50-foot trees. Figure 2-2 illustrates the effect.

Figure 2-2. Displacement Height



The wind speed estimate should include a displacement height adjustment:

- If obstructions in *a prevailing wind direction* have a depth of 50 feet or more, and
- If the obstruction is closer than ten times the average height of the obstruction. For example, if an obstruction has a 50-foot average height, the obstruction must be 500 feet away to negate its effect.

Calculating the displacement height varies depending on the surrounding environment as follows:

Rural Displacement Height	= $\frac{2}{3}$ x prevailing mature tree height for deciduous trees
Rural Displacement Height	= $\frac{3}{4}$ x prevailing mature tree height for evergreen trees
Residential Displacement Height	= Height halfway between the eaves and the peaks of the surrounding houses (if trees are not causing displacement)
Industrial Displacement Height	= Prevailing height of flat roofed buildings

The effective wind reference height then is:

$$\text{Effective Wind Reference Height} = \text{Wind Reference Height} + \text{displacement height}$$



For example, if there is a 50 foot displacement height and the reference wind speed is 14 mph at 120 feet, then the effective wind reference speed is 14 mph at 170 feet.

B. WIND TURBINE PERFORMANCE MODEL

The 7th Wind™ Wind Turbine Performance Model v10.75 provided by Seventh Generation Energy Systems is currently used to calculate the annual energy output (kWh) for a selected wind turbine manufacturer and size. Stored in the model are over 20 turbine manufacturers’ power output curves, and a probability distribution of wind speeds based on a calculation of a Weibull function using a particular site’s annual average wind speed. The model’ assume a Rayleigh wind distribution and the user should use a shape factor of $k = 2.3$ for best estimation of Wisconsin conditions. Other factors in the model include hub height, site elevation (to account for air density), wind shear and turbulence intensity. Corrections to turbine output due to ambient temperature are minimal, vary seasonally, and therefore are not factored into this calculation.

The model also requires a turbulence factor to account for output losses and deviations from manufacturer’s specifications. An experienced wind turbine performance assessor should determine this factor based on judgment using Table 2-4.

Table 2-4. Turbulence and Derate Factors

Site Quality (relative to Turbulence)	Terrain	Turbulence Derate Factor
Good	Well exposed	15 %
Average	Some ground clutter, scattered trees, buildings	20 %
Poor	Many trees or buildings, lower elevation than surroundings	25 %
Very poor	Urban or wooded	30 %

In addition, users should include an additional five percent derating to account for inverter based systems. Thus, the model derates annual energy output by 15 percent to 35 percent to account for turbulence (based on site conditions) and inverter losses.

Historically, both Focus and KEMA calculations resulted in substantial overestimates of kWh production. For the last three evaluation periods (FY07, 18MCP, CY09) Focus and KEMA engineering estimates were between XX and YY lower than estimates based on inverter readings of production. While we do not know the reason for the discrepancy, we do know that it was not due to downtime for maintenance or other reasons. KEMA expects that improvements made by the program to site assessments, namely changes to the wind shear exponential and Weibull shape factor, will result in annual kWh estimates that are closer to annual metered kWh production.

We also suspect the discrepancy may be partly due to the statistical wind speed distribution assumptions. Generally, practitioners in the industry apply a Rayleigh distribution function to understand the variability of the wind speed. The Rayleigh distribution defines the probability of wind speeds from zero to infinity based on the average wind speed and is a standard assumption in the industry. Since wind power is proportional to the cube of the wind speed, the assumption of high wind speeds can have a substantial effect on predicted energy production.

Metering data from three installations that received funding through the Focus on Energy Program for FY07 showed output from these turbines to be an average of 52 percent of estimated output. Metering data from five installations for the 18MCP showed output from these turbines to be, on average, 63 percent of the estimated output.

We verified these findings using an additional method to adjust for annual and seasonal wind variation at each turbine in the FY07 and 18MCP evaluations. With this method, we used Wisconsin State Climatology Office data (from ASOS stations) to determine the average wind resource experienced over the time period of turbine production. We compared this average wind resource to the long term annual average. If ASOS stations experienced higher than average wind speeds over the production period, we assumed that the turbine experienced proportionally higher wind speeds as well. Wind speeds used in the wind map are based on long term averages; that is, if an ASOS station experienced a wind speed five percent higher than average, we assumed the turbine will also experience a wind speed five percent higher than average. If the turbine wind speed was assumed to be 14 mph (based on the wind map) and the average wind speed experienced during the sample period was five percent less, we used an assumed wind speed of 13.3 mph in the 7th Wind™ model to determine an adjusted annual estimate. We compared this adjusted estimate to the annualized meter data to calculate a verified gross adjustment factor. Using this method, the verified gross adjustment factor is 68 percent.³⁹

Access to the State Climatology Office, data is no longer available. The evaluation team now uses Weather Underground⁴⁰ wind speed data to compare annualized metered data to 7th Wind™ Wind Turbine Performance Model calculator estimates.

2.5.2 Peak kW estimate

The definition of kW in the current contract period is associated with kW savings at system peak.⁴¹ This is a different definition than used in the past. The kW savings is calculated based on the average hourly load displaced between 1 pm and 4 pm weekdays from June through August. To calculate this estimate of peak kW:

$$Peak\ kW = \frac{estimated\ kWh}{8760\ hours}$$

³⁹ Earlier versions of this document recommended a 0.65 derate factor to account for overestimation of energy production from 7th Wind™ Wind Turbine Performance Model calculator. The changes to the default wind shear constant, α , and the Rayleigh shape factor, k , make this additional derate factor unnecessary.

⁴⁰ <http://www.weatherunderground.com>.

⁴¹ See *BP OPS Manual*, "Revised Peak KW Reduction Description," p. 57, April 1, 2008. Peak kW in this definition is being used as a measure of power load on the grid displaced by the photovoltaic system.

An inspection of meteorological data from wind resource measurement stations throughout Wisconsin indicates that wind speeds tend to be lower during the summer months.⁴² Offsetting this effect is the fact that wind speeds also tend to be higher in the middle of the day. A spot inspection of wind speeds between 1 pm and 4 pm during June through August does not show a consistent trend towards lower wind speeds during this period. Therefore, the average annual wind speed is assumed to be a viable estimate of early afternoon summer wind speeds for the purpose of calculating capacity factor, until such time as more data and analysis become available.

2.5.3 Information required

In order to conduct the estimates of kWh and kW the program must include in the application or project documentation information listed below. Many of these items will be provided by a site evaluator as part of a feasibility study or are part of the 7th Wind Model output. The intent is to provide a comprehensive list of the necessary items for calculation. It does not include other information that may be necessary for implementing the program. It includes many items the program is currently collecting.

- Turbine data
 - Turbine manufacturer, model number
 - Turbine rated capacity (kW) at a standard 11 meters per second wind speed
 - Rotor diameter (ft)
 - Turbine percentage efficiency rating vs. wind speed (when available) and/or capacity factor
 - Manufacturer's estimated kWh output vs. wind speed table or chart
 - Manufacturer's power curve.
- Site data
 - The feasibility study including the input values and underlying assumptions including the manufacturers' power curve and Rayleigh distribution data. Documenting these assumptions will allow the evaluators to better understand actual values as opposed to assumed values
 - Site address and geographic coordinates
 - Turbine hub height (ft)
 - Displacement height (if applicable)
 - Estimated wind shear exponent (α) based on local terrain
 - Site elevation above sea level (ft)
 - Reference wind speed (mph), elevation (m), and information source
 - Assumed Weibull k value
 - Assumed turbulence intensity value (%)
 - Assumed system derate value (%)

⁴² Global Energy Concepts. *Wisconsin Wind Resource Assessment Program, 1997–2001*. 2002.



- Model outputs
 - Average annual wind speed at hub height (mph and m/s)
 - Annual energy output (kWh/yr)
 - Net turbine capacity factor
 - Peak kW
 - The 7th Wind™ Wind Turbine Performance Model output sheets.
 - Version No. of 7th Wind™ Wind Turbine Performance Model calculator.