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METHODS FOR EVALUATING THE DOE APPROPRIATE TECHNOLOGY PROGRAM: A REVIEW AND COMPILATION OF EVALUATION METHODS

Bart Lucarelli

July 1982

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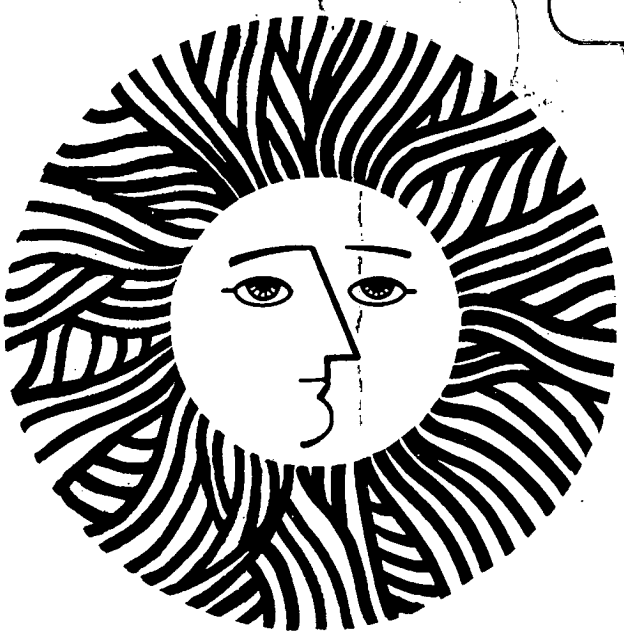

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Methods for Evaluating the DOE Appropriate Technology Program:

A Review and Compilation* of Evaluation Methods

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EXECUTIVE SUMMARY

This paper describes procedures for evaluating the energy impact of renewable energy resource projects funded by the Appropriate Technology (AT) Program of the U.S. Department of Energy (DOE). The report has one chapter and four appendices, compiled from two reports[1] published in 1979 and 1981 by the Lawrence Berkeley Laboratory (LBL) as well as from unpublished observations by LBL researchers.

Chapter 1 contains a discussion of the various evaluation approaches used by LBL over the past two years, definitions of key concepts such as direct and indirect energy impact and cost-effectiveness, and recommendations of a simplified evaluation approach for the future. Appendix A contains detailed procedures for evaluating the direct energy impact from six renewable energy resource systems: (1) wind electric, (2) hydroelectric, (3) anaerobic digestion, (4) active solar water and space heating, (5) passive solar, and (6) geothermal space and water heating as well as weatherization. Appendix B defines economic concepts and presents a simplified approach for computing the cost-effectiveness of small energy projects. Appendix C has blank data forms that DOE can use to collect data from specific AT projects. Appendix D contains a table to help estimate the direct impact of passive solar systems.

From these findings LBL makes four recommendations.

Based on a review of past studies, LBL has noted that AT Projects by definition are unique and energy savings are difficult to estimate and estimates can only be viewed as "best guesses." Moreover, consistent

guidelines for measuring the energy impact of other DOE programs are not in place and thus estimates of the energy savings for the AT Program and not comparable with those for other DOE programs. Finally, the AT Program is mandated to meet non-energy objectives such as creating new employment, reducing pollution and strengthening the social and economic structures of communities. An evaluation of these important objectives has not been accomplished by LBL but certainly deserves attention in future studies.

1) establish a common set guidelines for evaluating the energy impact of federal energy grant programs;

2) develop additional project evaluation methods;

3) use a simplified evaluation approach in the interim until the guidelines are set; and

4) analyze the non-energy impacts of the AT Program.

Establish Common Guidelines:

The guidelines should be generally applicable to all DOE grants programs yet simple and precise in their directions so that program managers can apply them in a standard and unambiguous manner. The guidelines should clearly define the types of impacts to be evaluated, direct, indirect, etc.; the time period over which impacts are to be qualified; and the economic and other limiting conditions for determining whether these impacts will occur.

Develop Additional Methods

Methods for analyzing only six energy systems are presented in Appendix A. Others are needed for alcohol fuel plants, photovoltaic cells, wood stoves, conservation devices and wind-powered water pumps. Moreover, the methods developed have not been field tested and may require further refinement. Next to establishing guidelines, DOE should give this task their highest priority.

Simplify the evaluation approach:

At this time, because the DOE lacks consistent guidelines for evaluating its energy programs, LBL recommends as an expedient measure that a simplified evaluation approach be adopted. The following four step approach should reduce costs of analysis and improve the credibility of the results:

1) select a sample of 30 projects that are judged to have a large energy savings potential;

2) evaluate each project for direct impact, using the data forms and methodologies in Appendix A, where possible;

3) estimate the maximum indirect impact for each project using only two limiting conditions; that the impact is quantifiable and that the project energy system is cost effective;

4) sum the two impacts for the entire sample, convert to primary energy and barrel of oil equivalent (BOE) units and use this estimate as a lower level estimate of program energy impact.

Analyze non-energy impacts:

Because the AT Program is mandated to achieve multiple objectives, i.e., employment, environmental, and social objectives, it should be evaluated, according to all of these objectives, not just energy impact. For example, the program is expected to fund projects that improve the environment and increase local self reliance and employment as well as save energy. Evaluations of employment and environmental impact for such small scale projects will most likely have to be qualitative, case study analyses. Nevertheless, they can document successes of the program beyond the issue of energy impact. In short, the success or failure of the program must be judged upon a more comprehensive set of impacts rather than on energy impact alone.

CHAPTER 1 : INTRODUCTION AND GENERAL APPROACH

In this report, Lawrence Berkeley Laboratory (LBL) presents a general approach and detailed methods for evaluating the energy impact of the Appropriate Technology (AT) Program of the U.S. Department of Energy (DOE). Its purpose is to create a framework for evaluating the energy impact of specific projects and for extrapolating from project to program impact. Since the start of the program in 1977, LBL has assisted the DOE in evaluating the energy impact of the program and has published two reports on the topic:

1) a 1979 study that evaluated 20 projects funded by the Region IX Program in fiscal year (F.Y.) 1977. (Lucarelli, et. al., 1979); and

2) a 1981 study that evaluated 57 of the 584 projects funded nationwide by the AT Program in F.Y. 1979. (Lucarelli, et. al., 1981).

Both studies pointed to the complexity and difficulty of evaluating the energy impact of the AT Program because of the diverse array of technologies and objectives of projects it has funded. This report synthesizes the methods used in the 1979 and 1981 studies and attempts to create a consistent conceptual framework and detailed methods for evaluating the energy impact of the program and specific AT Projects.

As already mentioned, developing the evaluation tool is hindered by the diversity of the program which, in turn, makes it difficult for DOE to determine the potential of the program to reduce U.S. oil imports.

Since 1977, the program has funded over 1500 projects to develop and encourage the use of small scale, renewable energy systems. In contrast to other federal grant programs, the AT Program, disburses its funds in amounts of $50,000 or less and awards grants to a vast and diverse constituency for many purposes. Technologies applied by the projects include anaerobic digesters, solar water heaters and new energy conservation devices. Stages of project development have ranged from concept and prototype development to commercial demonstration and marketing. Because of their differing development stages, the projects also have different objectives. Thus, managers of concept and prototype development projects conducted laboratory research and engineering tests while managers of commercial projects surveyed customer response to their systems with questionnaires and public demonstration for mass marketing.

The objectives of each project also varied according to the type of person or group managing the project. Five applicant types were eligible for funding: (1) individuals; (2) small business; (3) local public agencies; (4) Indian tribes and (5) non-profit organizations. Projects managed by small businesses tended to emphasize commercial development and prototype testing. Local agencies and non-profit organizations favored public demonstration, information dissemination and low income assistance projects.

The remainder of this chapter reviews the results of the 1979 and 1981 studies and concludes with a set of recommendations for conducting future impact studies. Following this chapter are four appendices. Appendix A presents detailed methods and data forms for assessing the energy impact of seven renewable energy systems. Appendix B contains a

methodology for evaluating the economic feasibility of small-scale, renewable energy systems. Appendix C consists of blank data forms for applying the project evaluation methodologies in future impact studies. Appendix D contains a brief description and a sample of a table of data required for computing energy savings from passive solar systems.

The research that has gone into this report is far from complete. In particular, the project methodologies in Appendix A, particularly the data collection forms, need to be field tested to determine whether the data are easily obtainable by a generalist or DOE project manager. Moreover, the number of technologies for which energy impact methods have been developed is very small and methods for additional technologies, such as alcohol-fuel plants, wind-powered, water pumps and photovoltaic systems need to be developed.

The general evaluation approach proposed for the AT Program also must be reconciled against methods used for evaluating the energy impact of other DOE programs. At present, DOE does not have a consistent approach for evaluating the energy impact of its grants programs and hence the results of impact studies for different programs cannot be used to determine the comparative effectiveness of the different programs.

Finally, the AT Program was established by Congress and DOE to do more than just save energy. The program is expected to improve environmental quality, increase employment and local self-sufficiency; thus any evaluation of the AT Program must consider the complete set of objectives the program is expected to achieve.

If this report stimulates discussion and activity to complete these unfinished items on the agenda of the AT Program, a large part of its objective will have been achieved.

Comparison of Evaluation Procedures Used in the 1979 and 1981 Studies.

This section describes the evaluation approaches used in the 1979 and 1981 studies. The evaluation approaches have been discussed under four headings: energy impact definition, sample selection, project evaluation and program impact analysis.

Energy Impact Definition:

Because no guidelines existed for evaluating DOE grant programs, LBL developed its own for the 1979 and 1981 studies. Defining key concepts and setting their operational limits quickly became a complex and confusing exercise, leading in some cases to the establishment of arbitrary limits. To start, LBL defined two types of energy impact: direct and indirect.

Direct energy impact is the energy savings from operating the energy hardware purchased with project funds. If no energy hardware was operated or if no activity was taking place over the course of the project to save energy, then LBL assigned a zero value to the direct impact of that project.

Indirect energy impact is the energy saving resulting from the replication of the project by other people. The replication effect can occur in 3 ways:

1) the successful results of a demonstration project could encourage others (individuals, small business, public agencies) to duplicate the project.

2) an energy device could be mass produced and marketed as a result of successful demonstration and testing.

3) information could be disseminated that encourages others to replicate an energy saving idea or device.

Both the 1979 and 1981 studies used the same approach in estimating direct impacts; i.e., a project had either to operate an energy device for a productive purpose or to implement an energy savings concept. To realize an indirect impact in the 1979 study, the project manager had to have a plan or clear intent to replicate his energy system and, of course, the data for making an estimate had to be available. For the 1981 study, two additional conditions were imposed; (1) the project manager had to market or demonstrate an energy system (concept) that was cost-effective, and (2) the maximum period for achieving the replication potential could not exceed five years.

Cost-effective systems were defined as those that would generate over their economic lifetimes a net present value of energy revenues or of reduced energy costs equal to or greater than net first costs*. As an indicator of cost-effectiveness, the savings-to-investment ratio (SIR), which is the ratio of discounted, before tax revenues to first cost was used. By definition, energy systems with a SIR greater than or equal to 1.0 are cost-effective. The cost-effectiveness condition added

*Definition of terms (revenues, first costs, economic life, etc.) and assumptions for estimating cost-effectiveness are presented in detail in Appendix B.

credibility to the estimates of indirect impact by increasing the certainty that others will find it advantageous to replicate a particular system.

The second condition, which sets a five-year limit to the time for replication, was added to control for various exogenous factors that might prevent a project from achieving its full potential. For example, high interest rates and technical advances by competitors may render a promising device obsolete. Moreover, establishing how much of the replication potential was due to the funding and how much to other courses was difficult. Therefore, if the grantee could provide a reasonable estimate of his annual market share, that amount was multiplied by five years and used to estimate indirect impact. When the grantee could not provide an estimate, LBL assumed that one percent of the total potential was achieved each year for five years.

Both studies expressed direct and indirect impacts as resource energy saved or produced. Resource energy includes the energy lost in generating and transporting a specific fossil fuel to a point of use as well as the amount of the fossil fuel saved at the point of use because of the projects' impact. LBL assumed that all projects displace oil, either directly or indirectly. For example, if in place of the project energy system, a particular market would use electricity to meet its energy needs, then LBL assumed the impacted electric power plant was oil fired and primary savings were the amount of oil that would have been burned in the power plant if the project were not funded. Finally, resource energy savings were initially expressed in billion of Btu and then converted to barrels of oil equivalents (BOE).

Sample Selection:

After defining key concepts and ways for dealing with ambiguous outcomes, LBL then selected a sample of projects for energy impact analysis. In the two prior studies, LBL experimented with two sampling approaches:

1) biased, non-random sampling of the best projects (1979 study); and

2) non-random sampling without reference to project quality (1981 study).

The two samples were selected and analyzed for different objectives and the results are not directly comparable. The objective of the 1979 study, which analyzed a sample of 20 projects drawn from the Region IX Pilot Program, was to develop consistent procedures for estimating the energy impact of individual projects. For this purpose, LBL selected 20 projects that were judged to have excellent prospects for successful completion and to have quantifiable energy savings. The objectives of the 1981 study, on the other hand, were to develop statistical methods for estimating the energy impact of the program as a whole and to expand the methods of project analysis to include all technologies funded by DOE. Thus LBL selected a 57-project sample, thought to be representative of the national program. In contrast to the 1979 study, project selection was not made with reference to project quality. In short, the sampling approach must be closely related to the approach used to estimate program benefits. If statistical methods are to be used to extrapolate program savings from a sample of project impacts then simple or

stratified random sampling must be used. This topic, approach to sample selection, will be discussed in greater detail in the recommendations section.

Project Evaluation:

Whenever possible, LBL estimated direct energy savings from a project from direct monitoring data collected by the grantee. In most cases monitoring data were either not available or collected in a flawed manners. As a result, LBL had to use a large number of methodologies and ad hoc procedure for estimating direct energy savings. This approach to project evaluation was required not only because of the lack of direct monitoring of projects but also because of the many different technologies and objectives being advanced by the projects. For some projects, most notably projects which demonstrated solar water heaters, anaerobic digesters, and wind electric machines, standard methodologies were used to evaluate direct energy impacts (discussed in Appendix A). Indirect impacts had to be evaluated on a case by case basis, leading to highly judgmental estimates. The general guidelines set by LBL to limit the subjectivity of indirect estimates were only partially successful. Furthermore, following the guidelines set in the 1981 study (see Section Indirect Energy Impact in this chapter) delayed the evaluation of indirect impacts without improving the accuracy of the analysis.

In both studies, four steps were followed to evaluate each project:

1) define project objectives and hardware capabilities

2) collect direct monitoring data concerning the proposed energy system or, if not available, detailed engineering data concerning the system (size, energy output, relevant weather data, cost, etc.)

3) apply methods for calculating direct energy impact and economic feasibility

4) interview project managers to determine their intent to replicate project elsewhere and size of outside market.

Defining project objectives (Step 1) was accomplished by thoroughly reading the project proposal and by contacting the project manager. Because monitoring data were not available, LBL had to rely on specific methods and ad hoc calculation procedures to compute energy savings. For these methods data collection (Step 2) was the most difficult step in the project evaluation process. For these methods to be used, detailed technical and cost data had to be obtained, such as, local weather data, design and operating features of a specific renewable energy system, as well as first and operating costs of mass produced systems. Thus, data collection (Step 2) became the most difficult step in the project evaluation process. The uniqueness of each project also required LBL to evaluate each project differently, adding to the data collection problem. Three sources were contacted to obtain the data: (1) the grantee; (2) engineers and manufacturers having experience with a particular technology, and (3) published technical reports. In cases

where data did not exist, LBL made reasonable assumptions about a system's features, cost, and other characteristics.

Program Impact Analysis:

Of the two studies, only the 1981 study attempted to estimate the energy impact of the AT program. The 1979 study merely quantified the direct and indirect impacts of 20 projects and did not estimate the program energy impact from the sample. The 1981 study, using statistical inference, provided some tentative estimates of program impact. The statistical method applied in the 1981 study was elementary and straightforward. First, each project's total impact (direct plus indirect) was converted into BOE and the ratio of total BOE to total funding for the 57 projects was computed and treated as the sample mean. The standard deviation of the sample mean was computed. Ranges of the energy impact of the program at different funding levels were computed at three different confidence levels.

The results were highly tentative because LBL did not select its sample randomly and statements about program impact could not be made with probabilistic certainty. Moreover, the intervals for confidence levels greater than 75% were extremely wide, reducing the value of the program estimates for program evaluation purposes. The wide intervals are not surprising given the highly diverse array of projects funded by the A.T. Program. Finally, it was noted in the 1981 study that over 95% of the program impact potential was generated by 9 projects, adding to the wide confidence intervals.

Recommendations:

From this review, two conclusions have emerged. (1) since DOE has not established guidelines for evaluating the energy impact of its programs, the estimates made by LBL in the two studies have no standard of comparison within DOE. Thus, the effectiveness of the A.T. Program, compared to other DOE grant programs, cannot be determined. (2) even with a set of general guidelines, estimates of the A.T. Program's energy impact will still be highly speculative because of the overriding importance of a project's indirect impact. In the 1981 studies, LBL estimated that 97% of the program's energy impact will occur as an indirect impact. Because the indirect impacts are based on highly speculative and unverifiable assumptions, we can not state with much confidence whether the program will ever achieve this potential. Because of the program's diverse nature, future impact studies for the A.T. Program will face the same dilemma. (3) the AT Program was not set up just to save energy, although that is DOE's prime objective. In addition to saving energy, the program is expected to fund projects that improve environmental quality, increase employment, and assist communities in developing their economies. With such a wide set of objectives, the program was legally obligated to fund a diverse array of small energy projects, creating a difficult condition for conducting an energy impact analysis.

Given these findings, LBL recommends that DOE:

1) establish a common set of guidelines for evaluating the energy impact of federal energy grant programs;

2) develop additional project evaluation methods;

3) use a simplified evaluation approach in the interim until the guidelines are set; and

4) analyze the non-energy impacts of the A.T. Program.

Establish Common Guidelines:

The guidelines should be generally applicable to all DOE grant programs, yet simple and precise in their directions so that program managers can apply them in a standard and unambiguous manner. The guidelines should clearly define the types of impacts to be evaluated, direct, indirect, etc.; the time period over which impacts are to be quantified; and the economic and other limiting conditions for determining whether these impacts will occur.

Develop additional methods:

Methods for analyzing only seven energy systems are presented in Appendix A. Others are needed for alcohol fuel plants, photovoltaic cells, wood stoves, conservation devices and wind-powered water pumps. Moreover, the methods developed have not been field tested and may require further refinement. Next to establishing guidelines, DOE should give this task the highest priority.

Simplify the evaluation approach:

If another energy impact study is required before the guidelines are set, DOE should use a simplified evaluation approach. LBL

recommends the following four step approach which should reduce costs of analysis and improve the credibility of the results:

1) select a sample of 30 projects that are judged to have a large energy savings potential;

2) evaluate each project for direct impact, using data forms and methodologies in Appendix A, where possible;

3) estimate the maximum indirect impact for each project using only two limiting conditions: that the impact is quantifiable and that the project energy system is cost effective;

4) sum the two impacts for the entire sample, convert to primary energy and BOE units and use this estimate as a lower level estimate of program energy impact.

The approach will help reduce the cost of future studies and lead to more credible estimates by:

1) not using statistical inference to derive estimates of program impact.

   The statistical approach has two serious drawbacks when applied to a diverse program: (a) the prohibitive size of the sample required to predict program impact with high levels of confidence, and (b) the fact that the largest energy impact of the program will result from indirect impacts. Since indirect impacts are largely speculative and based on ad hoc procedures, the statistical approach merely disguises the uncertainty of the estimates.

2) requiring only two conditions for estimating indirect impact.

In the 1981 study, four conditions were set for limiting indirect impact: cost effectiveness, quantifiability, intent to replicate, and 5 year replication limit. LBL recommends that only two be required: (a) that the impacts are quantifiable and (b) that the energy system is cost-effective. The other conditions did not improve accuracy; they only reduced the probability of overestimating indirect impacts and may have unfairly penalized the program. For example, although some project managers may not plan to commercialize their devices, other people might. DOE has the option to license others to produce a system if the original manager decides against commercialization. Similarly, the five-year limit is highly arbitrary. Thus, dropping these two conditions will reduce the time and cost of conducting future studies with no reduction in accuracy.

Analyze non-energy impacts:

Because the program is mandated to achieve multiple objectives, it should be evaluated according to all of these objectives, not just energy impact. For example, the program is expected to fund projects that improve the environment and increase local self reliance and employment as well as save energy. Evaluations of employment and environmental impact for such small scale projects will most likely have to be qualitative, case study analyses. Nevertheless, they can document successes of the program beyond the issue of energy impact. In short,

the success or failure of the program must be judged upon a more comprehensive set of impacts rather than on energy impact alone.

APPENDIX A.

METHODS FOR ASSESSING THE DIRECT ENERGY IMPACT OF SEVEN RENEWABLE ENERGY RESOURCE SYSTEMS

Appendix A describes methods for determining direct energy impacts of seven renewable energy resource systems:

(1) wind electric
(2) hydroelectric
(3) anaerobic digestion (biomass)
(4) solar water heating and space heating
(5) passive solar
(6) weatherization/conservation
(7) geothermal space and water heating.

These technologies do not exhaust the possibilities for renewable resource applications, of course. Wind and hydro energy can both be used to generate mechanical shaft power, which can power machinery directly or be converted into heat for space and water heating. Biomass can be converted into alcohol, heat, and electricity through a variety of conversion processes. Nevertheless, the technologies and end uses discussed in this appendix are the most common and those for which published information is most readily available.

The simple approaches presented here can be used by a generalist or a nontechnical program administrator to evaluate renewable energy systems. The data forms include only information that is relevant to the calculations and which all grantees should have before proceeding with their projects. The simplification will result in some reduction in accuracy in comparison with the accuracy possible using more detailed methods. However, for the purpose of providing a basis for assessing the energy impact of the AT Program, the methods will provide

reasonable, ball-park numbers.

The appendix is separated into seven systems. For each system, a computational example is provided. First, a completed data form is presented, followed by a discussion of the computational steps for converting these data into an estimate of direct impact. Blank data forms are available in Appendix C. Appendix D provides a sample table from a DOE publication that must be used to evaluate passive solar systems.

System A-1. - Wind Electric

Assume that the following data comes from a grantee who is funded to install and operate a small wind electric generator in San Francisco.

Data Form A-1: Wind Electric

1. Average wind speed data

Note: Please supply monthly wind speed data for the proposed site or from the nearest airport. Specify the height at which wind speed measurements were taken and years over which the data were compiled.

a. Source of wind data: S.F. Airport

b. Height at which wind measurements were taken: 30 ft.

c. Time period for collection: 5 yrs.

d. Wind speed data (specify units)(at 30 ft. height):

January	8.2 MPH	July	14.2
February	8.8	August	15.0
March	11.2	September	14.2
April	12.6	October	13.2
May	14.0	November	12.5
June	15.0	December	10.0

2. Wind electric system

a. Manufacturer and model of wind machine:

Merkhom Wind Energy Corp., Hamburg, PA.

If home-built system, attach detailed description.

b. Type of generator: alternator w/diode

DC generator other

c. Rated capacity of generator: 40 kW in 25 mph wind

d. Cut-in speed: 10 MPH

e. Cut-out speed: 40 MPH

f. Describe type of tower: height, dimensions, and materials used in the foundation:

Tower is 65', made of steel, and set in reinforced concrete foundation, which is 11' x 11' x 14' deep.

3. Energy storage system

a. Batteries (type and number, manufacturer and model number, and storage capacity)

11 lead-acid, 12 V dc, 500 amp-hours storage.

b. Other

c. Will invertor be used to convert DC to AC? If so, give make, model, and capacity.

Yes, Gemini Synchronous Invertor - 8 kW

4. Load

120,000 kWh/year

a. Describe end use that electricity will be used for. Supply water pumping information on monthly demand in kWh and peak demand.

	kWh		kWh		kWh
Jan.	10,000	May	10,000	Sept.	10,000
Feb.	"	June	"	Oct.	"
March	"	July	"	Nov.	"
April	"	Aug.	"	Dec.	"

b. How far will the wind generator be located from the load or point of energy use?

200 ft.

c. What type of wire (material and size) is being used?

#08 copper

Step 1. Compute the electrical output of the system by first adjusting the average wind speed data collected at 30 feet to the 65-ft. height of the tower.

$$\frac{V}{V_o} = \frac{H^{.4}}{H_o} = \frac{\text{variation in wind velocity}}{\text{with variation in tower height}} \qquad (1)$$

where:

v = wind velocity
$H^{.4}$ = height of tower = 65 feet
H_o = height wind data taken at = 30 feet
v_o = wind velocity at height of wind measurements

Step 2: Convert the average wind speed data into estimates of the electricity delivered (in kWh) from the wind generator. A graph adapted from Leckie (1975) (See Fig. 1) provides a shortcut to estimate electricity output per kW of capacity (see vertical axis) based on monthly average wind speed (see horizontal axis) and assumptions about the coefficient of performance of the wind generator. The rated wind speed refers to the wind speed at which the generator produces full power.

This example is an evaluation of a system with a rated wind speed of 25 mph [see data element 2(c)]. To compute energy output from the wind system, take the average wind speed for each month and match that against the same wind speed on the horizontal axis of Fig. A-1. Draw a vertical line to the curve that reads 25 mph rated wind speed, and read off the vertical axis the amount of electricity in kWh delivered. Sum these monthly estimates to obtain the annual output. The results for the example are expressed in Table A-1.

Table A-1: Electricity output from wind generator, 25 mph rated wind speed, located in San Francisco.*

	Average wind (mph)	Electricity output (kWh/kW)		Average wind (mph)	Electricity output (kWh/kW)
Jan.	11.2	85	July	19.3	365
Feb.	12.0	110	Aug.	18.0	310
March	15.2	205	Sept.	17.0	275
April	17.1	280	Oct.	13.6	145
May	19.0	355	Nov.	10.3	70
June	20.4	410	Dec.	11.4	90

Total 2,705 kWh/kW

*estimates assume 45' height.

Step 3: Next, adjust the estimates to account for losses caused by:

- transmission of power from the generator to the load;
- losses in battery storage; and
- invertor losses.

The following efficiency and loss factors are useful in accounting for these losses:

- invertor efficiency:
  rotary .60 or
  electronic .85;
- battery losses 0.1;
- transmission losses .05 to 0.1.

Transmission or line losses are a function of:

- the distance the electricity is transmitted;
- the type and size of wire used; and
- the voltage of the system.

Properly designed wiring systems permit a 4 percent voltage drop or loss. To allow for possible exceptions in the AT projects, LBL recommends that a higher voltage loss of 10 percent is used. Finally, assume a plant use factor (the percentage of the time that the machine is operating) of 80 percent or the applicant's estimate, whichever is lower.

To complete the computation, reduce the estimate in Table A-1 by 45 percent to account for a 15 percent invertor loss, a 10 percent battery loss, a 10 percent line loss, and an 80 percent plant use factor. The final figures are shown in Table A-2 for the 40 kW machine.

Table A-2: Electricity output from a 40 kW wind generator located in San Francisco (in kWh).

Jan.	1870	July	8030
Feb.	2420	Aug.	6930
March	4510	Sept.	6050
April	6160	Oct.	3190
May	7810	Nov.	1540
June	9020	Dec.	1980
		Total	59,510 kWh

Compare the monthly figures in Table A-2 with the load estimates in data element 4-a. Notice that the full monthly output can be used on site. If the monthly output exceeds the load estimates, simply use the monthly load as the estimate of monthly output unless excess output is being sold back to the utility.

System A-2 - Hydroelectric (Alward, 1979)

Assume that a grantee in northern California has built a hydroelectric project at a nearby stream and completes Data Form A-2.

Data Form A-2: Hydroelectric

1. Stream flow rate: 750 ft^3/min

2. Usable flow: 187.5 cfm

   Discuss method used to compute flow rate and usable flow:

   N.A.

3. Gross head (in feet): 120 ft.

   Describe how measured:

   N.A.

4. Piping - type: PVC Class 160 PSI

   Diameter: 6" Length: 100 ft.

5. Prime mover (type of turbine): reaction

6. Power drive: gear box

7. Generator type: alternator

8. Electricity demand (give monthly data on load requirement in kWh.) Will any power be sold back to utility?

	kWh		kWh		kWh
Jan.	5,000	May	5,000	Sept.	5,000
Feb.	5,000	June	5,000	Oct.	5,000
March	5,000	July	5,000	Nov.	5,000
April	5,000	Aug.	5,000	Dec.	5,000

9. Wiring - type: #8 Length: 200 ft.

10. Energy storage (if any): N.A.

Batteries:

Pumped storage:

Step 1. Compute theoretical power output (P_{th}), using the following formula:

$$P_{th} = \frac{62.4Q \times (h_g - h_1) \times .745}{33{,}000} = 31.3 \text{ kW} \qquad (2)$$

Q = usable flow in cfm = 187.5 cfm
h_g = gross head = 120.0 feet
h_1 = head losses due to friction based on piping used = 1.5 feet
33,000 = factor to convert ft-lbs/min to hp
62.4 = density of water in lbs/ft^3.

Step 2. Next, compute net power output by adjusting the P_{th} for the efficiencies of the turbine and power drive system. The following conversion efficiencies are recommended:

Prime Mover		Efficiency	Range
Water wheel -	undershot	35%	25-45%
	breast	50%	35-65%
	poncelet	50%	40-60%
	overshot	65%	60-75%
Turbine -	reaction	80%	80%
	impulse	80%	80-85%
	cross-flow	70%	60-80%
Power drives			
	belt drive	95%/belt	95-97%
	gear boxes	95%	95%
Alternator and generator		80%	--

For this example, net power output is:

$$P_{net} = Pth \times et \times eg \times ea \qquad (3)$$

P_{net} = net power output
Pth = gross power to turbine = 31.3 kW
et = turbine efficiency = .8
eg = gearbox efficiency = .95
ea = alternator efficiency = .8

$$P_{net} = 31.1 \text{ kW} \times .8 \times .95 \times .8 = 19 \text{ kW}$$

<u>Step 3:</u> Compare net power output with electricity demand. Concerning the load served by the system (see data element 8).

From the data given, the net energy output has been computed as follows:

$$A = P \times D_{hm} \times 12 \times e = 49{,}250 \text{ kWh/yr} \qquad (4)$$

where:

A = annual energy output in kWh
P = net power output of system = 19 kW
12 = mos
D_{hm} = hrs of demand/mo = 240 hrs/mo
e = line losses = .1

System A-3 - Anaerobic Digestion

Leckie et al.(1975) have developed a shortcut to compute energy output from anaerobic digesters and have compiled data, based on laboratory tests and field measurements, for the following:

- the daily output of manure from different animals,
- the composition of manure and other organic materials in percentages of total solids and volatile solids, and
- the amount of gas that will be produced from these materials digested (expressed as ft^3 biogas/lb total solids).

The data are summarized in Tables A-4, A-5, and A-6. The following example will illustrate their use with Data Form A-3. Assume that a small farmer who has constructed a digester on his farm for heating water, completes Data Form A-3 as follows:

Data Form A-3: Anaerobic Digestion

1. Feedstock source (give amount and type of feedstock or units of generating source) Example: 300 cows, averaging 500 lbs each.

   260 pigs

2. Moisture content of slurry: 92%

3. Slurry input: 585 gal/day (5075 lbs/day or 78 $ft.^3$)

4. Digester operating (slurry) temperature: 95^oF

5. Digester capacity: 11,700 gal.

6. Retention time: 20 days

7a. Use of methane: heating water

7b. If the methane is used to produce electricity, provide the following data:

N/A

(1) Monthly load:

(2) Size and type of generator:

(3) Wiring system: Type

Length of wire

8. Gas handling and storage (describe system):

Metal gas holder on top of digester.

Step 1. Estimate gas output from the digester by referring to Tables A-4 and A-5.

Table A-4 indicates that manure output from swine equals 1.8 lbs of solids per animal per day (11.5 x .13).

Table A-6 indicates that for each lb of pig manure solids added to the digester, 7 ft^3 of biogas with a methane content of 60 percent will be produced.

With 260 pigs, daily gas output will equal 1820 ft^3 of biogas, with a Btu content of 1.1 MBtu (1820 ft^3 x 600 Btu/ft^3).

If the digester operates 80 percent of the time, annual energy output will come to 320 MBtu/yr.

Step 2. Step 1 assumes that the raw materials are retained long enough to allow conversion to methane. To determine whether retention time has been adequate for the materials to digest and whether the digester is large enough to retain the daily slurry input for the stated retention period, compute the minimum solids retention time (SRT_m) for the material by the following equation:

$$SRT_m = \left[a \times f \left[1 - \left[\frac{K_c}{K_c + COD} \right]^{1/2} \right] - b \right]^{-1} \qquad (5)$$

where:

- a = constant showing how many bacteria produced per amount of COD (see below) = .04
- b = constant showing how fast bacteria die = .15
- f = factor for COD use by bacteria (temperature dependent)
- K_c = minimum amount of COD required before bacteria can start multiplying (temperature dependent)

Both f and K_c are temperature dependent and can be obtained from Table A-3.

Table A-3. Values for f and K_c at different temperatures.

Temperature	f	K_c
59°F	3.37	18,500
68°F	3.97	10,400
77°F	4.73	6,450
86°F	5.60	3,800
95°F	6.67	2,235

Since the digester will operate at 95°F, select 6.67 for f and 2,235 for K_c.

COD, or chemical oxygen demand, is the amount of oxygen required to oxidize or destroy the organic compounds in the raw material by chemical means. COD can be computed from:

$$COD = 12{,}000 \text{ ppm} \, ft^3/lb \times VScon \qquad (6)$$

where 12,000 ppm = a constant needed to express COD in parts per million and where:

$$VS\ con = \frac{VStotal}{VSL} = \frac{\text{(total weight of volatile solids)}}{\text{(volume of slurry in ft sup 3)}}$$

Therefore, in this example:

$$COD = 12{,}000 \text{ ppm } ft^3/lb \times \frac{345 \text{ lbs}}{78 \text{ } ft^3} = 53{,}077 \text{ ppm}$$

where 345 lbs = daily slurry input in lbs [5075 lbs x solids content of slurry (8%) x volatile solids content as percent of total solids (85%)] (See Table A-4 and data element A-3) 78 ft^3 = volume of daily slurry input.

Returning to equation 5, note that:

$$\frac{1}{SRT_m} = \left[.04 \times 6.67 \times \left[1 - \left[\frac{2,235}{2,235 + 53,077} \right]^{1/2} \right] - .15 \right] \qquad (5)$$

Therefore, SRT_m = 5 days.

Typically, the SRT is increased by a safety factor of 3 or 4 in case of fluctuations in temperature and pH that may upset the digestion process. In this example, the retention time should vary from 15 to 20 days.

The data form indicates that the digester has a capacity of 11,700 gallons, allowing a 20 day retention period for the 585 gal/day slurry input. The retention period is within safety limits. These secondary calculations give us confidence in the estimate of gas output. To be safe, use a factor of 4 to estimate the retention time (RT) for the digester contents. If the RT is less than 4 times SRT_m, scale down the gas output.

Table A-4. Manure output from different animals (lbs/animal day).

	Total Wet Manure lbs	Percent Total Solids	Volatile Solids (% TS)	C/N Ratio
Bovine (1000 lbs)	72	14	80	18
Horses (850 lbs)	44	16	80	25
Swine (160 lbs)	11.5	13	85	--
Sheep (67 lbs)	4.5	11	80	--
Humans (150 lbs)	2.7	10	78	7
Geese, Turkeys (25 lbs)	.5	35	65	--
Ducks (6 lbs)	.5	35	65	--
Layer Chickens (3.5 lbs)	.3	35	65	--

Table A-5. Total solids, volatile solids and carbon nitrogen ratio of organic materials.

	% of Total Solids (TS)	Volatile solids (% of TS)	C/N ratio
Green garbage	99.0	77.8	18
Kraft paper	94.0	99.6	--
Newspaper	93.0	97.1	813
Garden debris	75.2	87.0	--
Christmas trees	90.7	99.5	767
Average refuse	92.7	63.6	45

Table A-6: Biogas production* as a function of total solids (per lb of total solids)

	Biogas (ft^3)	Range	Methane Content	C/N ratio
Pig manure	7.0	6.0-8.0	65%	--
Cow manure	3.9	3.1-4.7	60%	18:1
Chicken manure	9.6	6.0-13.2	60%	7:1
Conventional sewage	7.5	6.0-9.0	60%	7:1
Newspaper & sewage sludge 10:90 proportion	7.9	---	67%	30:1
White fir & sewage sludge 10:90 proportion	7.4	---	70%	30:1

*Methane content will vary with C/N ratio.

System A-4 - Active Solar Space and Water Heating

To compute energy savings from an active solar system, use F-Chart Level 3. F-Chart is an interactive computer program that was developed by the University of Wisconsin Solar Energy Laboratory as a tool in the design of solar systems. Because LBL is recommending that an off-the-shelf computer program be used for active solar systems, we will not burden the reader with a detailed quantitative example. Instead, we have presented an overview description of the F-Chart Program along with an example of the computer data input and output forms. The F-Chart program computes water heating loads, space heating loads, and the fraction of the heating load that can be met by the specified solar system (Beckman et al. 1977).

These calculations are based on the size of the solar system, monthly insolation data, the type of system (air or liquid) and parameters that describe the efficiency curve of the collector and heat exchanger, if any.

The parameters for the efficiency curve can be obtained from product literature when available or from performance efficiency curves of generic solar systems. Figure A-2 represents a typical performance curve for a solar collector. The F-Chart program uses two parameters of the efficiency curve: the y intercept, $(F_r, [\alpha]_n)$, and the negative slope $(F_r U_1)$ of a plot of efficiency versus the input temperature minus the ambient temperature divided by the total incident solar radiation (Fig. A-2). These two values have complex definitions based upon characteristics of the specific solar collector. To avoid these complexities, the F-Chart program provides for its users default values that estimate the

efficiencies of generic collector types. LBL recommends that DOE use these default values.

Once on line, the program provides a list of questions which the user answers to guide himself through the program. Data Form A-4 (see Appendix C) lists in order the inputs to the F-Chart program. A copy of the data form should be sent to project managers developing active solar collectors for either space or water heating. However, not all of this information must be supplied by the grantee. For our purposes, default information supplied in the program, such as for collector efficiency, is sufficient. In some cases, therefore, for space heating systems, only questions #1, 2, 4, 8, 9, 10, 11, 12, and 17 require grantee response. For solar water heating projects, questions #1, 3, 4, 8, 9, 10, 11, 14, and 17 require grantee response. Questions 18 and 19 should be answered (1) and (2) respectively. Once the necessary data is compiled, firms in the Washington, D.C. area with access to the F-Chart program can conduct the runs.

Calculation of Water Heating Loads

To calculate the water heating load (question #14), the user must specify the number of gallons of hot water that are used per day and the input and output temperatures of the water. The daily hot water load is then calculated by equation (7).

$$LW = \frac{8.34\text{Btu} \times (\text{gal/day}) \times \Delta T\ ^{\circ}F)}{(\text{gal}) - {}^{\circ}F} \qquad (7)$$

Calculation of Space Heating Loads

The F-Chart program allows the user to calculate space heating loads in two different ways. The user can input monthly heating loads directly or can choose to use the degree-day method for calculating monthly heating loads. For most purposes the degree-day method will suffice.

The degree-day method for calculating space heating loads is based upon the effective building UA, or daily heat-loss coefficient, and the number of degree-days in the month. A heating degree-day is defined as a day during which the average temperature is one degree less than 65°F. F-Chart has degree-day data for 266 locations and will also allow the user to enter his or her own data.

For the degree-day method the monthly heating load is assumed to be equal to the product of the building UA and the number of degree-days in the month, 24 hrs/day.

On the following two pages the input data and resulting outputs for a sample project analyzed by F-Chart is presented. The tables are self-explanatory with the input data listed in the top half followed by the thermal analysis.

Table A-7: F-Chart data for solar water heating project.

Code	Variable description	Value units
1.	Air SH+WH=1, Liq. SH+WH=2, Air or Liq. WH only=3	3
2.	If 1, what is (Flow rate/Col. area)(Heat spec.)	0 Btu/h-^{o}F-ft^{2}
3.	If 2, what is (Epsilon)(Cmin)/UA	2
4.	Collector area	38.38 ft^{2}
5.	FR prime-Tau-Alpha product (normal incidence)	.69
6.	FR prime-UL product	1.53 Btu/h-^{o}F-ft^{2}
7.	Incidence angle modifier (zero if not available)	0
8.	Number of transparent covers	1
9.	Collector slope	45
10.	Azimuth angle (e.g. south=0, west=90)	0
11.	Storage capacity	12 Btu/^{o}F-ft^{2}
12.	Effective building UA	0 Btu/^{o}F-day
13.	Constant daily building heat generation	0 Btu/^{o}F-day
14.	Hot water usage	100 gal/day
15.	Water set temp. (to vary by month, input neg.)	140°F
16.	Water main temp. (to vary by month, input neg.)	55°F
17.	Site location	184
18.	Thermal printout by month = 1, by year = 2	1
19.	Economic analysis (yes = 1, no = 2)	2

Table A-8. Thermal analysis for solar water heater.

Time	Percent solar	Incident solar (MMBtu)*	Heating load (MMBtu)	Water load (MMBtu)	Degree days (°F/da)	Ambient temp (°F)
Jan	25.2	1.81	0.0	2.20	866	37.4
Feb	30.7	1.82	0.0	1.99	686	41.0
Mar	35.6	2.21	0.0	2.20	643	44.6
Apr	38.3	2.21	0.0	2.13	32	69.8
May	38.2	2.22	0.0	2.20	166	60.8
Jun	38.1	2.07	0.0	2.13	394	51.8
Jul	33.7	1.89	0.0	2.20	0	75.2
Aug	35.0	1.94	0.0	2.20	0	73.4
Sep	41.3	2.16	0.0	2.13	23	68.0
Oct	39.2	2.23	0.0	2.20	254	57.2
Nov	31.4	1.92	0.0	2.13	576	46.4
Dec	23.7	1.73	0.0	2.20	817	39.2
Year	34.2	24.23	0.0	25.92	4457	

*(MMBtu) = million Btu

Systems A-5 & A-6 - Passive Solar and Weatherization

To compute energy savings from passive solar systems and weatherization projects, use a simple three-step procedure developed by Mazaria (U.S. Dept. of Energy, 1980). Data Form A-5 lists the information required to compute energy savings with this method.

Estimating Energy Savings for a Passive Solar Building

The following three-step procedure provides a quick estimate of the annual energy savings for a passive solar building.

1. Estimate the building load coefficient (BLC), exclusive of the south glazing, and divide this by the total south glazed area to obtain the load collector ratio (LCR).

$$LCR = BLC/(\text{net south glazed area}),\ Btu/DD\ ft^2$$

2. Look up the estimate of solar savings fraction in Appendix D for the particular type of passive solar heating approach being considered.

3. Multiply BLC by the degree days for a specific location to obtain the annual heating load; multiply this number by the solar fraction; and then divide the number by the efficiency of the backup heating system to obtain an estimate of energy savings from the passive solar building.

The following example, taken directly from the DOE Passive Solar Design Handbook (1980), will illustrate the computational steps. Assume that a grantee in Dodge City, Kansas, is building a passive solar home. He completes Data Form A-5:

Data Form A-5 - Passive Solar Systems

1. Project location: (City) Dodge City (State) Kansas

2. Passive system type: (Total square feet of south glazing:

a. WW - water wall	234	sq. ft.
b. WWNI - water wall with night insulation (R9)	-	sq. ft.
c. TW - Trombe wall	-	sq. ft.
d. TWNI - Trombe wall with night insulation (R9)	-	sq. ft.
e. DG - Direct gain	156	sq. ft.
f. DGNI - Direct gain with night insulation (R9)	-	sq. ft.

3. Building parameters

a. Nonsouth window area 65 sq.ft. # of glazings 2

b. Unglazed wall area ([165x8)-65-390) R value R-19

c. Perimeter (describe)

165ft. slab on grade

Length 165 ft. R value of perimeter insulation R-12

d. Floor area 1500 ft^2 R value N/A

e. Basement N/A

Length of wall

R value of wall insulation

f. Roof area 1500 R value of roof R-25

g. Infiltration

Average air change per hour: .65/hr

Ceiling height: 8 ft

Combined area of all floors: 1500 sq.ft.

4. Heating backup

Type: Natural gas

Capacity:

Step 1: Compute the BLC and LCP

The BLC is the additional heating required to maintain an increase of one degree Fahrenheit in the interior temperature of a building (expressed in Btu/day-^{o}F). Mazaria has developed a set of simple equations that allow a person to calculate the BLC in parts. The equations are presented below along with calculations for the Dodge City example

using the data from Data Form A-5.

Walls

$$L_w = 24 \times \frac{\text{wall area}}{\text{R value of walls}}$$

$$L_w = 24 \times \left[(165x8)-65-390)\right]/19 = 1090\text{Btu/DD}$$

where wall area = (perimeter) x (ceiling height) - (nonsouth window area) - (south window area)

Nonsouth window

$$L_g = 26 \times \frac{\text{nonsouth window area}}{\text{number of glazings}}$$

$$L_g = 26 \times (65)/2 = 850 \text{ Btu/DD}$$

Perimeter (slab or grade)

$$L_p = 100x \frac{\text{length of perimeter foundation}}{\text{R value of perimeter insulation} + 5}$$

$$L_p = 100 \times (165)/(12+5) = 970\text{Btu/DD}$$

Floor (over vented crawl space)

$$L_p = 24 \times \frac{\text{area of ground floor}}{\text{R value of floor}}$$

(not applicable for this example)

Basement (heated basement or other fully bermed wall, including floor losses

$$L_b = 256 \times \frac{\text{length of wall}}{\text{R value of wall insulation} + 8}$$

(not applicable for this example)

Roof

$$L_r = 24 \times \frac{\text{roof area}}{\text{R value of roof}}$$

$$L_r = (24)x(1500)/25$$

Infiltration

L_i = (0.432) x (average air changes per hour) x (ADR) x (ceiling height) x (combined area of all floors)

where ADR is the air density ratio (assume 0.75 lb/ft.^{3}).

L_i = (0.432) x (.65) x (.9) x (8) x 1500 = 3070 Btu/DD

Finally, add the components to obtain the final BLC estimate*

$$BLC = L_w + L_g + L_r + L_i = 7420 \text{Btu/DD}$$

Next, calculate the load collector ratio:

$$LCR = \frac{7420 \text{Btu/DD}}{390 \text{ ft}^2} = 19 \text{ Btu/dd-ft}^2$$

Step 2: Estimating solar savings fraction (SSF)

The next step is to use the table in Appendix D to estimate the fraction of the building heating load that the passive solar system can

meet. The table lists these data for difference LCRs and passive systems in Dodge City. The table has been developed for only six system types:

(1) WW - water wall
(2) WWNI - water wall with night insulation (R9)
(3) TW - Trombe wall
(4) TWNI - Trombe wall with night insulation (R9)
(5) DG - direct gain
(6) DGNI - direct gain with night insulation (R9)

Because the table has been developed only for water wall, Trombe wall, and direct gain systems, the table for Trombe walls will have to be used for attached solar greenhouses.

For designs hybrid systems: (1) calculate a single LCR, based on the total load and the total combined collection area, (2) look up the resulting value of SSF for each of the system types, and (3) average between the table values for each type of system based on the relative proportions of glazed area of each.

The user of this method will have to obtain the Passive Design Handbook (U.S. Department of Energy, 1980) for a full list of LCR data for different locations in the U.S. If the location is not listed in the Design Handbook, then the value can be estimated from neighboring locations with similar heating degree-day conditions.

Table entries for Dodge City, Kansas were obtained from the Passive Design Handbook and are listed below:

SSF	0.5	0.6	0.7	0.8
WWNI	36.0	29.0	23.0	18.0

Step 3: Estimating annual heating load

After estimating the BLC and SSF, one can then estimate the energy savings for the solar home as follows:

Annual energy savings = BLC x heating degree days x SSF x eff. of backup heater.

Assume the following efficiencies for backups:

(1) electricity - 1.0

(2) natural gas/fuel oil/propane - .65

(3) wood and other - .5

The above example has a natural gas backup so that direct energy savings are:

$$AES = \frac{(7420 \text{ Btu/DD} \times 5046 \times .78)}{.65} = 45 \text{ MBtu}$$

Estimating Energy Savings from Building Weatherization Systems

The method outlined for passive systems can be used in modified form to estimate energy savings from weatherization projects. The following procedure is recommended with Data Form A-6 in Appendix A:

1. Compute BLC before and after weatherization.

2. Multiply BLC (before and after) by heating degree days for the location (Table A) to obtain annual heating load.

3. Calculate annual energy savings by taking the difference of the before and after heating load and dividing this by the efficiency of the backup.

System A-7 - Geothermal - direct application: (U.S. Department of Energy,)*

In this category come projects that use geothermal hot water to generate industrial process heat or to meet the space and hot water requirements of residential and commercial buildings. Assume that all applications use a closed-loop, water-to-water heat exchanger. To determine the energy savings from a geothermal system, a two-step calculation, is required.

Step 1 Compare the operating features of the heat exchange/energy delivery system against the flow rate of the geothermal well and the temperature of the water at the well head to insure that the system is properly sized.

Step 2 Convert the energy delivery from the heat exchange system into a fossil fuel equivalent by adjusting for conversion losses. Data Form A-7 contains the necessary information for computing energy savings for direct use of geothermal hot water.

The following example should illustrate how to use the data. Assume that an applicant owns a factory that dehydrates onions. Currently, the factory is using a natural gas boiler to supply the heat

* Source: U.S. Department of Energy, Rules of Thumb for Geothermal Direct Applications, Undated publication.

to dry the onions. He submits a proposal to retrofit the factory with a heat exchange system and to install a transmission pipe from the well to factory. He completes Data Form A-7.

Data Form A-7: Geothermal hot water system - direct use

1. Well Data

   a. depth of well: 500 ft.

   b. diameter of well: 10 inches

   c. temperature of water at well head: 200°F

   d. flow rate (gpm): 200 gpm

   e. transmission pipe: 8" diameter (in.) 300' length (distance from well to end use)

   f. pump horsepower: 40

2. Energy delivery/heat exchange system

   a. detailed description of unit and flow diagram:

      Closed loop water-to water heat exchanger counts flow

   b. heat requirement of system

      (heat flow in Btu/hr.): 42.5 MBtu/hr

   c. temperature drop (ΔT°F): 50°F

d. operating head (ft.): 100 ft

e. flow rate of load water into heat exchanger -

3. Backup: natural gas boiler

4. Operation use (hrs/yr): 3600 hrs/yr

Compute the required flow rate $\dot{w}$ using the following equation:

$$\dot{w} = \frac{E}{T_L \; T} \qquad (7)$$

where:

$\dot{w}$ = required flow rate
E = energy required in Btu/hr. = 42.5 MBtu
T_L = length of transmission pipe = 5 00 ft.
T = temperature drop system water = 50°F
$\dot{w}$ = 42.5/(500 x 50) = 1700 gpm

As you can see from the data supplied by the applicant, the system has a flow rate of only 200 gpm or 12 percent of the total required. Thus the system can deliver only 5.1 MBtu/hr of the energy required. To convert this into a fossil energy equivalent, the following fuel to energy conversion factors should be used:

Natural gas, propane, diesel - .80
Electricity 1.0
Coal or other solid fuel .6

The onion factory uses natural gas as a backup. Thus, the system will save 22.7 billion Btu of natural gas each year.

The data will also allow you to check the horsepower of the pump for proper sizing by the following formula:

$$HP = (8.33\ \dot{w}\ H/33{,}000)\ 6i\ .8$$

where:

HP = pump horsepower
8.33 = weight of gallon of water in lbs. at 40C
w = flow rate of well = 200 gpm
H = total head = depth of well (500 ft.) + system head (100 ft.) + frictional head loss (N.A.) = 600 ft.
33,000 = conversion factor ft-lbs/min. to horsepower
HP* = 39

*.8 = Pump Efficiency

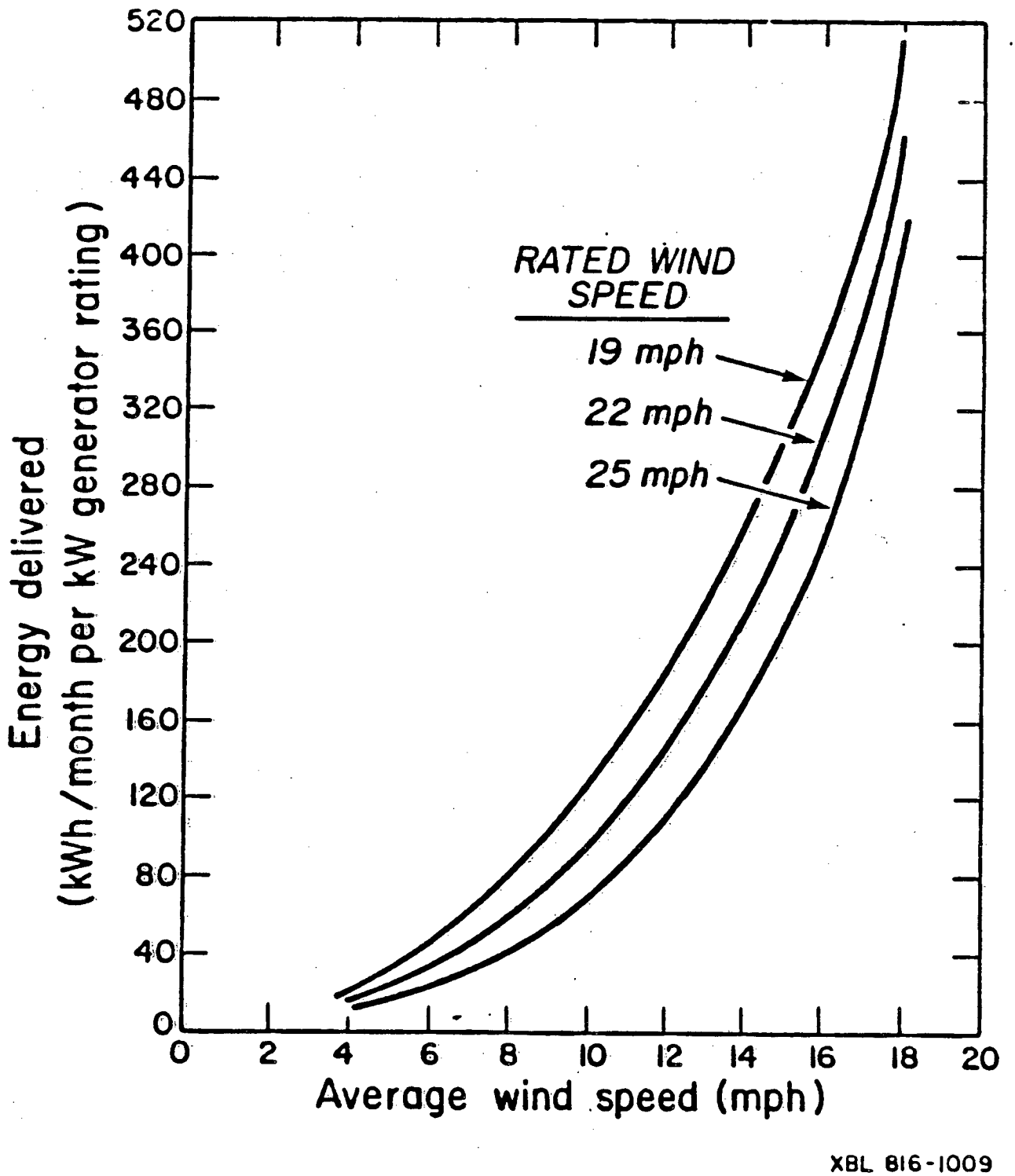

Figure A-1: Power Chart for Difference Wind Systems

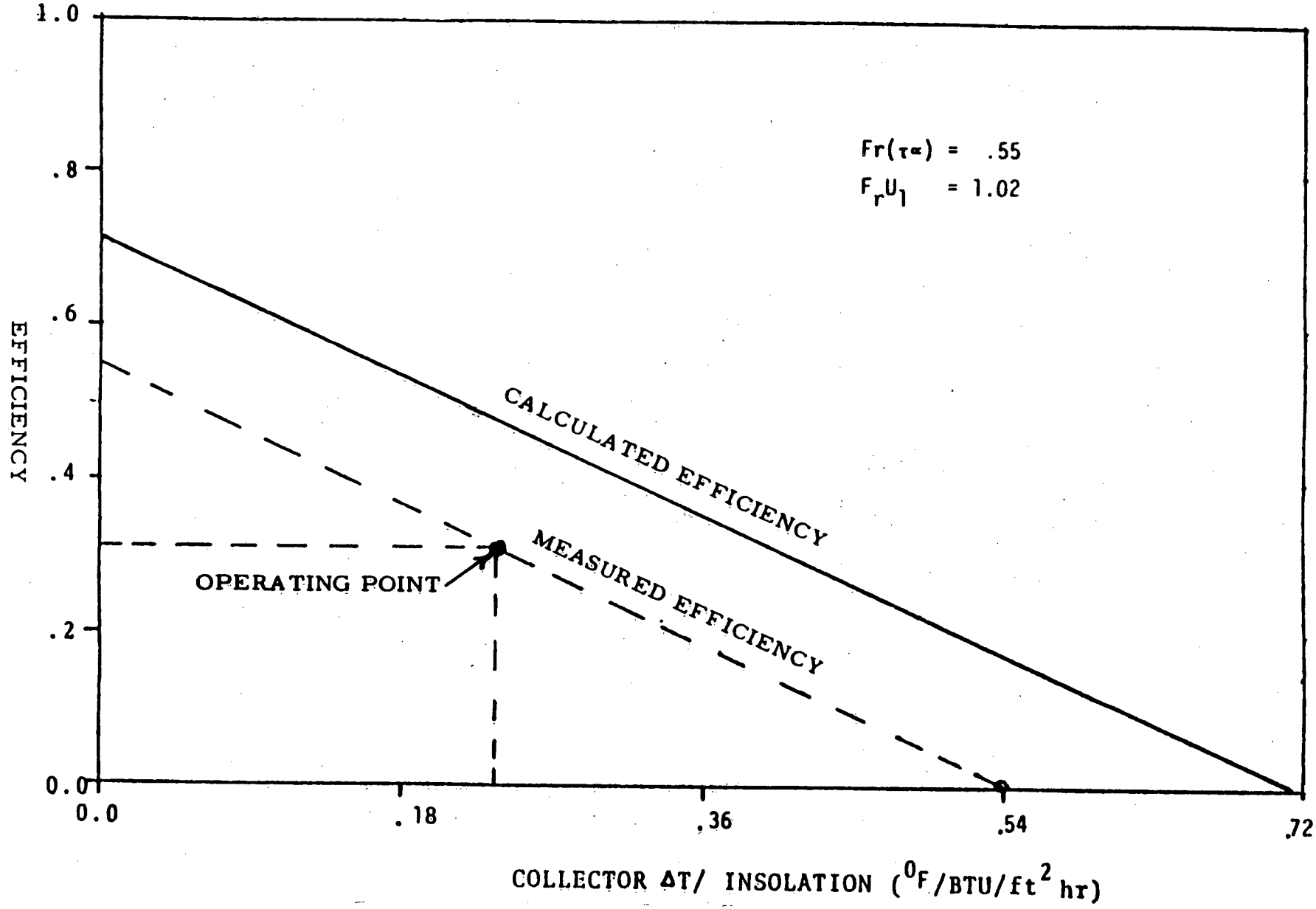

Figure A-2: Collector Efficiency Curve

APPENDIX B - Estimating the Cost-effectiveness of an Energy System

In this appendix, the methodology for estimating the cost-effectiveness of an energy system is presented. Data Form B-1 lists the data required to determine whether an energy system is cost-effective. The method proposed for evaluating the cost-effectiveness of an energy system was developed by the National Bureau of Standards (Ruegg, et al., 1981) and used by Lawrence Berkeley Laboratory (Lucarelli, et al., 1981) to evaluate projects funded by the AT Program. Definitions of key concepts and a description of the general methodology are provided below, followed by a computational example. An energy system is cost-effective if it generates over its life, net revenues equal to or greater than its capital or first cost. Life cycle costing (LCC) is the method for evaluating all relevant costs and revenues for an energy system over its economic life. The LCC method is applied in four steps.

(1) Estimation of first costs. First costs include the costs of purchasing and installing an energy system less any capital savings from not using a fossil fuel system. Whenever possible, base the first cost of a system on the actual cost or expected cost of the system in the commercial market. In the case where the project is applying a commercial system, the capital costs should be those claimed by the applicant on Data Form B-1. In cases where projects are developing prototype systems, first costs are estimated either from the applicant's best estimate of what his system will cost when commercially available or from comparisons to similar systems already being marketed. The cost of a commercial system will usually be less than a project grant to develop a prototype, which in many cases includes cost of design, development, and

testing.

(2) Estimation of annual net revenues Net revenues are the dollar value of energy or other output produced or saved over the life-cycle of a system minus operating, maintenance, and replacement costs. Similar to capital costs, these revenues are computed on a net basis, taking into account any additional savings and/or costs incurred by the prospective user for not using a fossil fuel alternative.

(3) Conversion of costs and revenues to present values The costs and revenues estimated in (1) and (2) occur at different times. To convert these values into time-equivalent amounts, future costs are discounted by a real rate of interest that reflects the time value of money. In other words, future benefits resulting from an investment are worth less to an investor today because he could have invested his funds in an immediate investment and generated an immediate return.

In estimating life-cycle costs for each project, assumptions must be made about future energy and nonenergy costs. The following assumptions are suggested for conducting the LCC analysis:

- All future costs and revenues should be expressed in real 1980 dollars: that is, they are net of inflation.[13]
- Nonenergy costs and revenues increase annually at the rate of inflation, i.e., at a 0 percent real rate of increase.
- The real discount rate is 10 percent.[14]
- Base year energy prices are either the actual price per unit paid by the grantee or are regional DOE estimates of energy

prices for 1980.[15]*

- o Energy prices escalate at a real annual rate of 5 percent.

(4) Determination of cost-effectiveness Once life-cycle costs are computed, cost-effectiveness can be determined. A system is deemed cost-effective if on a life-cycle basis the net present value of before-tax revenues equals or exceeds first costs. As an indicator of cost-effectiveness, the savings to investment ratio (SIR), which is the ratio of the net present value of before-tax revenues to first costs, is recommended as an indicator of effectiveness. By definition, energy systems with a SIR equal to or greater than 1.0 are cost-effective.

The before-tax SIR roughly indicates whether a specific energy system that relies on renewable energy resources can compete against the fossil fuel alternative without government subsidies. It does not imply any certainty about investment. To determine whether anyone will invest in an energy system requires a detailed analysis of economic sectors with their applicable investment criteria and tax laws. Because many systems can be applied in more than one sector, economic analysis on an after-tax basis is unduly cumbersome. Therefore, use the simpler, before-tax approach, which still allows you to rank projects according to their relative cost-effectiveness.

System B-1: Economic Analysis Return to the San Francisco Wind Electric System (System A-1) as an illustration of how this methodology is used. The applicant completed Data Form B-1, suppling the following economic data:

Data Form B-1: Economic Analysis Data

1. Capital cost

Equipment:	$34,000
Materials:	3,000
Labor:	3,000
Other:	
Total:	$40,000

2. Capital savings (Itemize savings resulting from not installing the alternative to the above system.)

NA

3. Annual operating and maintenance cost (Itemize)

$600/year

2 year service contract with manufacturers.

4. Annual cost of parts replacement (Itemize)

5. Life of energy system (years) 25

6. Fuel being displaced and cost

Electricity $ .11 /kWh

Natural gas	/therm
Propane	/gallon
Distillate	/gallon
Other	/

The grantee says that capital costs are $40,500. The next step is to compute the present value of revenue and O&M costs over the life of the project. In System A-1, we estimated annual energy output at 59,510 kWh/yr. Given an 11¢/kWh charge in 1980, the value of the base year energy savings will be $6,546. To simplify the process of computing the present value of revenue and O&M costs, use Table B-1, which lists uniform present worth (UPW) factors based on a 10 percent discount rate and different rates of fuel price escalation. With this table, the present value of energy revenue can be determined easily by selecting the UPW factor for the relevant project life (25 years) and energy and price escalation (5 percent). The UPW for this case is 14.4367 and is circled on Table B-1. Multiplying this factor (14.4367) by the value of base year energy revenues ($6546) gives the present value of energy revenues over the life of the project ($94,500). Similarly, the present value of O&M costs can be determined by selecting the UPW factor under year 25 and a fuel price escalation rate equal to 10 percent (9.077) (assuming that nonenergy costs increase at the rate of inflation) and multiplying this factor by annual O&M costs ($600 per year), which yields $5446. Subtracting energy revenue ($94,500) from O&M costs ($5446) gives a net revenue of $89,054.

To compute the SIR of the system, divide net revenue ($89,054) by the capital cost of the system $40,500. This yields a SIR of 2.2 which by definition makes the system cost-effective. The SIR can be used to rank projects according to their relative cost-effectiveness and enables one to select for funding those with the highest level of cost-effectiveness.

Table B-1

Uniform Present Wort for Energy Price Escalation Rate from 0% to 10% (Based Upon a 10% Discount Rate

	Energy Price Escalation Rates										
Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9091	0.9182	0.9273	0.9364	0.9455	0.9546	0.9636	0.9727	0.9818	0.9909	1.0000
2	1.7355	1.7612	1.7871	1.8131	1.8393	1.8657	1.8921	1.9188	1.9457	1.9727	2.0000
3	2.4868	2.5353	2.5844	2.6340	2.6844	2.7354	2.7869	2.8391	2.8921	2.9456	3.0000
4	3.1698	3.2460	3.3237	3.4027	3.4834	3.5656	3.6492	3.7344	3.8213	3.9097	4.0000
5	3.7907	3.8986	4.0092	4.1225	4.2388	4.3581	4.4801	4.6053	4.7336	4.8650	5.0000
6	4.3552	4.4978	4.6449	4.7966	4.9531	5.1146	5.2808	5.4524	5.6294	5.8117	6.0000
7	4.8684	5.0480	5.2344	5.4278	5.6284	5.8367	6.0524	6.2765	6.5089	6.7498	7.0000
8	5.3449	5.5521	5.7810	6.0188	6.2669	6.5260	6.7959	7.0780	7.3723	7.6793	8.0000
9	5.7590	6.0159	6.2878	6.5722	6.8705	7.1839	7.5124	7.8577	8.2201	8.6004	9.0000
10	6.1445	6.4417	6.7577	7.0903	7.4411	7.8118	8.2028	8.6161	9.0524	9.5130	10.0000
11	6.4930	6.8328	7.1935	7.5755	7.9807	8.4113	8.8682	9.3539	9.8696	10.4174	11.0000
12	6.8137	7.1919	7.5977	8.0299	8.4909	8.9837	9.5095	10.0717	10.6722	11.3138	12.0000
13	7.1034	7.5216	7.9725	8.4553	8.9733	9.5300	10.1274	10.7698	11.4601	12.2020	13.0000
14	7.3667	7.8243	8.3199	8.8536	9.4293	10.0513	10.7227	11.4487	12.2335	13.0819	14.0000
15	7.6061	8.1022	8.6421	9.2266	9.8604	10.5490	11.2964	12.1092	12.9929	13.9539	15.0000
16	7.8238	8.3574	8.9408	9.5758	10.2680	11.0240	11.8492	12.7516	13.7384	14.8178	16.0000
17	8.0216	8.5918	9.2179	9.9029	10.6535	11.4776	12.3821	13.3767	14.4706	15.6742	17.0000
18	8.2014	8.8069	9.4747	10.2090	11.0177	11.9103	12.8953	13.9844	15.1891	16.5223	18.0000
19	8.3649	9.0044	9.7129	10.4957	11.3622	12.3235	13.3900	14.5757	15.8947	17.3630	19.0000
20	8.5135	9.1857	9.9337	10.7641	11.6878	12.7178	13.8666	15.1507	16.5873	18.1958	20.0000
21	8.6486	9.3512	10.1385	11.0154	11.9957	13.0942	14.3259	15.7101	17.2674	19.0211	21.0000
22	8.7715	9.5042	10.3285	11.2509	12.2870	13.4537	14.7688	16.2546	17.9355	19.8394	22.0000
23	8.8832	9.6446	10.5046	11.4714	12.5623	13.7968	15.1955	16.7841	18.5913	20.6501	23.0000
24	8.9847	9.7735	10.6679	11.6777	12.8225	14.1241	15.6065	17.2989	19.2349	21.4531	24.0000
25	9.0770	9.8919	10.8193	11.8710	13.0686	14.4367	16.0026	17.7998	19.8670	22.2490	25.0000

APPENDIX C

Data Forms for Seven Energy Systems

Data Form 1: Wind Electric

1. Average wind speed data:

Note: Please supply monthly wind speed data for the proposed site or from the nearest airport. Specify the height at which wind speed measurements were taken and years over which the data were compiled.

a. Source of wind data:

b. Height at which wind measurements were taken:

c. Time period for collection:

d. Wind speed data (specify units):

January	July
February	August
March	September
April	October
May	November
June	December

2. Wind electric system

a. Manufacturer and model of wind machine:

If home-built system, attach detailed description.

b. Type of generator: alternator w/diode

DC generator other

c. Rated capacity of generator: kW in mph wind

d. Cut-in speed:

e. Cut-out speed:

f. Describe type of tower: height, dimensions, and materials used in the foundation:

3. Energy storage system

a. Batteries (type and number, manufacturer and model number, and storage capacity)

b. Other

c. Will inverter be used to convert DC to AC?
If so, give make, model, and capacity.

4. Load

a. Describe end use that electricity will be used for. Supply information on monthly demand in kWh and peak demand.

Jan.	May	Sept.
Feb.	June	Oct.
March	July	Nov.
April	Aug.	Dec.

b. How far will the wind generator be located from the load or point of energy use?

c. What type of wire (material and size) is being used?

Data Form 2: Hydroelectric

1. Stream flow rate:

2. Usable flow:

   Discuss method used to compute flow rate and usable flow.

3. Gross head (in feet):

   Describe how measured.

4. Piping - type:

   Diameter: Length:

5. Prime mover (type of turbine):

6. Power drive:

7. Generator type:

8. Electricity demand (give monthly data on load requirement in kWh.

   Will any power be sold back to utility?

Jan.	May	Sept.
Feb.	June	Oct.
March	July	Nov.
April	Aug.	Dec.

9. Wiring - type: Length:

10. Energy storage (if any):

Batteries:

Pumped storage:

Data Form 3: Anaerobic Digestion

1. Feedstock source (given amount and type of feedstock or units of generating source) Example: 300 cows, averaging 500 lbs each.

2. Moisture content of slurry:

3. Slurry input:

4. Digestion operating (slurry) temperature:

5. Digester capacity:

6. Retention time:

7. Use of methane:

   If the methane is used to produce electricity, provide the following data:

   a. Monthly load:

   b. Size and type of generator:

   c. Wiring system: Type

   Length of wire

8. Gas handling and storage (describe system):

Data Form 4: F-Chart Version 3.0 Worksheet - S1 Units

1. Air SH+WH = 1, Liq. SH+WH = 2, Air/Liq. WH only = 3 Btu/h-^{o}F-ft^{2}

2. If 1, what is (Flow rate/Col.area)(Spec.heat)?

3. If 2, what is (Epsilon)(CMin)/(Ua)?

4. Collector area (f^{2})

5. FR Prime-Tau-Alpha Product (Normal Incidence)

6. FR Prime-Ul Product Btu/h-^{o}F-ft^{2}

7. Incidence Angle Modifier (Zero if not avail.)

8. Number of transparent covers

9. Collector slope (degrees)

10. Azimuth angle (south = 0; west = 90°)

11. Storage capacity (Btu/^{o}F-ft^{2})

12. Effective building UA (Btu/^{o}F-day)

13. Constant daily building heat generation (Btu/day)

14. Hot water usage (gal)

15. Water set temp. (to vary by month, input neg.#)
^{o}F

16. Water main temp. (to vary by month, input neg.#)
    ^{o}F

17. City call number

18. Thermal print out by month = 1, by year = 2

19. Economic analysis? yes = 1, no = 2

Data Form 5 - Passive Solar Systems

1. Project location: City State

2. Passive system type: (Total square feet of south glazing:

   a. WW - water wall ft^2

   b. WWNI - water wall with night insulation (R9) ft^2

   c. TW - Trombe wall ft^2

   d. TWNI - Trombe wall with night insulation (R9) ft^2

   e. DG - Direct gain ft^2

   f. DGNI - Direct gain with night insulation (R9) ft^2

3. Building parameters

   a. Nonsouth window area # of glazings

   b. Wall area R value

   c. Perimeter (describe)

      Length R value of perimeter insulation

   d. Floor area R value

   e. Basement

      Length of wall

      R value of wall insulation

   f. Roof area R value of roof

   g. Infiltration

      Average air change per hour:

      Ceiling height:

      Combined area of all floors:

4. Heating backup

   Type:

   Capacity:

Data Form 6 - Weatherization*

1. Project location: City State

2. Building parameters

   a. Nonsouth window area # of glazings

   b. Wall area R value

   c. Perimeter (describe)

      Length R value of perimeter insulation

   d. Floor area R value

   e. Basement

      Length of wall

      R value of wall insulation

   f. Roof area R value of roof

   g. Infiltration

      Average air change per hour:

      Ceiling height:

      Combined area of all floors:

3. Heating backup

   Type:

   Capacity:

   Efficiency:

---

*User should fill out two forms; one for house before weatherization and one for house after weatherization.

Data Form 7: Geothermal Hot Water - Direct Use

1. Well Data

   a. depth of well:

   b. diameter of well:

   c. temperature of water at well head: ^{o}F

   d. flow rate (gpm):

   e. transmission pipe: diameter (in.) length (distance from well to end use)

   f. pump horsepower:

2. Energy delivery/heat exchange system

   a. detailed description of unit and flow diagram:

   b. heat requirement of system (heat flow in Btu/hr.):

   c. temperature drop (Δ T):

   d. operating head (ft.):

3. Backup:

4. Operation use (hrs/yr):

Data Form 8: Economic Analysis

1. Capital cost

   Equipment:

   Materials:

   Labor:

   Other:

   Total:

2. Capital savings (Itemize savings resulting from not installing alternative to above system.)

3. Annual operating and maintenance cost (Itemize)

4. Annual cost of parts replacement (Itemize)

5. Life of energy system (years)

6. Fuel being displaced and cost

Electricity	$	/kWh
Natural gas		/therm

Propane	/gallon
Distillate	/gallon
Other	/

APPENDIX D

Tables of Load Collector Ratios and Solar Savings Fraction for Different Passive Systems

This table is presented for use with the Load Collector Ratio method. It is based on Solar Load Ratio calculations, using the weather data tabulated in Appendix A of the DOE Passive Solar Design Handbook (U.S. Department of Energy, 1980).

For Dodge City, two sets of numbers are tabulated for each six system types and for values of SSF ranging from 0.1 to 0.9. In the upper set, values of LCR (in Btu/DD ft^2) are tabulated for use with the Load Collector Ratio method. In the lower set of numbers, value of D are tabulated for use in the economic optimization procedure. D is the derivative of SSF with respect to 1/LCR and has units of Btu/DD $ft.^2$ (The physical significance of D is that it represents the equivalent additional load, in Btu/DD, that can be fully satisfied by one additional ft^2 of solar collection area.)

The six system types are abbreviated as follows:

WW - water wall
WWNI - water wall with night insulation (R9)
TW - Trombe wall
TWNI - Trombe wall with night insulation (R9)
DG - direct gain
DGNF - direct gain with night insulation (R9)

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