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ALTERNATIVE ENERGY SOURCES FOR WASTEWATER TREATMENT PLANTS

Roy F. Weston, Incorporated
West Chester, PA

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ALTERNATIVE ENERGY SOURCES FOR WASTEWATER TREATMENT PLANTS

by

Roy F. Weston, Inc.
Designers-Consultants
West Chester, Pennsylvania 19380

Contract No. 68-03-3055

Project Officer

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WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

This technology assessment provides an introduction to the use of several alternative energy sources at wastewater treatment plants. This document assumes that the reader has little or no knowledge of the technologies presented. The report contains fact sheets (technical descriptions) and data sheets (cost and design information) for the technologies. Cost figures and schematic diagrams of the technologies are included. Case histories of seven treatment plants that have used one or more of the alternative technologies are presented.

Based on this assessment the following alternative energy technologies appear to be potentially cost effective:

1. Heat pumps which use influent or effluent wastewater as their heat source, forsupplying process or building heat.
2. Geothermal direct-use systems for large energy loads when geothermal source is adequate.
3. Wind power systems for large electrical loads when annual wind flux is adequate.
4. Passive solar systems where they can be cost-effectively integrated into the overall architectural design of a facility.
5. Low-head hydro systems may be appropriate for smaller plants which have an available head greater than three meters.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Laboratory is that component of EPA's research and development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; with establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and with assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product use. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document discusses the applicability and economic feasibility of various technologies that can make use of alternative energy sources to reduce reliance on conventional energy sources for municipal wastewater treatment facilities.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

This technology assessment provides an introduction to the use of several alternative energy sources at wastewater treatment plants. This document assumes that the reader has little or no knowledge of the technologies presented. The report contains fact sheets (technical descriptions) and data sheets (cost and design information) for the technologies. Cost figures and schematic diagrams of the technologies are included. Case histories of seven treatment plants that have used one or more of the alternative technologies are presented.

Based on this assessment the following alternative energy technologies appear to be potentially cost effective:

1. Heat pumps which use influent or effuent wastewater, as an alternative to distilled oil, residual oil, and natural gas for supplying process or building heat.

2. Geothermal direct-use systems for satisfying large energy loads (greater than 10^8 kJ/d) when the geothermal temperature gradient is 45^oC/km or greater, and sufficient geothermal well flows exist.

3. Wind power systems for satisfying electrical loads greater than 1,000 kWh/d, when the annual wind flux is approximately 4,000 kWh/m^2-yr or greater.

4. Passive solar systems where they can be cost-effectively integrated into the overall architectural design of a facility.

5. Low-head hydro systems may be appropriate for smaller plants which have an available head greater than three meters.

This report was submitted in fulfillment of Contract No. 68-03-3055 by Roy F. Weston, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period of October 1981 to August 1983, and the work was completed as of August 1983.

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ACKNOWLEDGMENT

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SECTION 1

INTRODUCTION

This technology assessment provides an introduction to the use of several alternative energy sources at wastewater treatment plants. The report assumes that the reader has little or no knowledge of the technologies presented.

Section 2 of the report presents the conclusions reached by the technology assessment. Section 3 contains brief general discussions of energy requirements at wastewater treatment plants, and other energy use considerations.

Section 4 contains fact sheets (technical descriptions) and data sheets (cost and design information) for the technologies. Cost figures and schematic drawings of the technologies are in this section. Data collection for the report was done in 1982, therefore, the costs presented should only be used to gauge the relative costs of the various technologies. Current cost information should be obtained from equipment vendors or other current sources for actual cost estimating.

Section 5 presents the case histories of seven treatment plants that have used one or more of the alternative technologies discussed.

SECTION 2

CONCLUSIONS

HEAT PUMPS

Heat pumps are commercially available. The temperature of the alternative energy source is the principal potential technical limitation on the application of these systems in POTW's; however, the use of the wastewater itself as the alternative energy source minimizes the impact of this limitation. The use of influent or effluent wastewater heat pumps is generally cost-effective in comparison to distilled oil, residual oil, and natural gas for supplying process or building heat to the POTW.

ACTIVE SOLAR HEATING AND COOLING SYSTEMS

Active solar heating and cooling systems are commercially available. The available solar insolation rate and system cost are the principal limitations on the application of these systems in POTW's. Active solar heating and cooling systems are not cost-effective alternatives to the use of conventional energy supplies in POTW's due to the hiqh capital investment.

PHOTOVOLTAIC SYSTEMS

Photovoltaic systems are commercially available. The available solar insolation rate, system energy conversion efficiency, and system cost are the principal limitations on the application of these systems in POTW's. Because of the high initial capital investment photovoltaic systems are not cost-effective alternatives to the use of conventional electrical energy supplies in POTW's.

GEOTHERMAL -- DIRECT USE SYSTEMS

Geothermal direct use systems are commercially available. Geographical limitations, associated with the geothermal temperature gradient and available well flow, as well as site investigation and well construction costs, are the principal limitations on the application of these systems in POTW's. Geothermal direct use systems appear to be cost-effective in comparison with the use of conventional fuels for satisfying thermal energy loads greater than 10^8 kJ/d when the geothermal temperature gradient is approximately 45^oC/km or greater, and when well flows are of a sufficient magnitude. Locations with geothermal gradients in excess of 45^oC/km are predominantly limited to the Rocky Mountain states.

WIND POWER SYSTEMS

Wind power systems are commercially available. Geographical limitations, associated with the available wind flux regimes, as well as overall system costs, are the principal limitations on the application of these systems. Wind power systems appear to be cost-effective in comparison with the use of conventional fuels for satisfying energy loads greater than 1,000 kWh/d, when the annual wind flux is approximately 4,000 kWh/yr-m^2 or greater.

Locations with annual wind flux greater than 4,000 kWh/yr-m^2 are predominantly limited to areas in the following states:

- Maine
- Vermont
- New Hampshire
- New York
- Virginia
- North Carolina
- Kansas
- Oklahoma
- Colorado
- Wyoming
- Montana
- Idaho
- Utah
- Nevada
- Washington
- California

LOW-HEAD HYDRO SYSTEMS

Low-head hydro systems are commercially available. Geographical limitations, associated with the available head for these systems, and the fraction of the total POTW energy requirements satisfied, are the principal limitations on the application of these systems in POTW's. From the standpoint of satisfying a significant portion of a POTW's electrical requirement, these systems appear to be more appropriate for smaller POTW's. The use of these systems should be seriously considered in any application that has an available head greater than 3 m.

PASSIVE SOLAR SYSTEMS

Passive solar systems are commercially available. These systems have been used previously to reduce the consumption of conventional heating fuels in POTW's, as well as many other architectural applications. The principal technical limitations of passive solar systems are possible site-specific limitations on available solar insolation, and the integration of the passive system into the overall architectural plan. Potential economic limitations are primarily associated with the incremental costs for construction of the passive solar system, instead of a conventional architectural design. These incremental costs must be considered, along with the amount of alternative energy supplied, on a case-by-case basis to potentially justify the use of a passive solar system in specific applications. In light of the rising costs for conventional fuels, these systems should be seriously considered in future construction at POTW's throughout the United States.

GEOTHERMAL -- POWER SYSTEMS

Geothermal power systems are commercially available. However, current technological limitations on minimum system size, as well as the limited availability of acceptable sites exhibiting the necessary geothermal characteristics, will likely prevent the use of these systems in POTW's.

FUEL CELLS

Fuel cells are not expected to be commercially available until approximately the year 2000.

ACTIVE SOLAR SYSTEMS FOR POWER GENERATION

Active solar systems for power generation are not expected to be commercially available until the mid 1990's. In addition, these systems can only use direct sunlight, and, therefore, their applications would be primarily limited to arid regions of the southwest.

SECTION 3

CONVENTIONAL ENERGY REQUIREMENTS IN POTW's

In order to evaluate the usefulness of "alternative energy sources" in meeting the demand for energy in publicly owned treatment works (POTW's), it is necessary to understand the energy requirements for these wastewater treatment facilities. The purpose of this section is to characterize typical energy requirements. The factors included in this analysis of energy requirements in POTW's include:

1. The types and amounts of energy required by treatment facilities.

2. The extent of daily, seasonal, and yearly variations in these energy requirements.

3. The geographic and local availability of the sources of conventional energy.

TYPES AND AMOUNTS OF ENERGY REQUIRED

The energy requirements of POTW's have been discussed in a variety of places in the literature. For example, two comprehensive sources of information are reports (1, 2) published by EPA on the total energy consumption for municipal wastewater treatment.

In addition, estimates of the primary energy requirements for over 100 different municipal wastewater treatment plant operations have been published. (2) Likewise, summaries and detailed estimates of the numbers of these unit operations in existence today and forecasted for the future (year 2000), are available in the EPA Needs Survey. (3)

Table 1 presents estimates of the total energy budget for three sizes of municipal wastewater treatment plants. The energy requirements in this table are expressed in terms of kWh/3,785 m^3/d (kWh/mgd). For the treatment plant as a whole, these estimates range from 0.426 kWh/m^3-d (1614 kWh/mgd) to 0.390 kWh/m^3-d (1477 kWh/mgd). The greatest demand for energy at a POTW is for electrical energy. For the type of POTW's shown, the demand for electrical energy represents 60 to 70 percent of the total energy demand of the facility. However, this percentage can change significantly depending on the types of unit operation and method of sludge disposal.

The information presented in Table 2 breaks down the estimated electrical energy consumption into the energy requirements for specific unit operations. As shown in Table 2, the greatest consumption of electrical energy is associated with the aeration equipment for secondary treatment of the wastewater. In order of descending magnitude, this demand is followed by that for influent (and trickling filter recycle) pumping, anaerobic digestion mixing, and then other less significant demands.

TABLE 1. ESTIMATED TOTAL ENERGY BUDGET FOR MUNICIPAL WASTEWATER TREATMENT PLANTS*

Item	3,785 m^3/d (1 mgd)	37,850 m^3/d (10 mgd)	378,500 m^3/d (100 mgd)
Electrical energy	1,100 (68%)	903 (59%)	835 (56%)
Chemicals	158 (10%)	158 (10%)	158 (11%)
Digester heating (supplementary fuel)	168 (10%)	168 (11%)	168 (11%)
Building heat	168 (10%)	59 (4%)	86 (6%)
Sludge hauling	20 (1%)		
Sludge incineration		230 (15%)	230 (16%)
Total energy consumption	1,614	1,508	1,477

* In terms of kilowatt-hours per 3,785 m^3 (million gallons) of wastewater treated. Estimates are based on activated sludge plants with anaerobic digestion. Sludge disposal is by incineration in the 37,850 m^3/d (10 mgd) and 378,500 m^3/d (100 mgd) sizes, and by hauling dewatered sludge 64 km (40 miles) one-way to land spreading at the 3,785 m^3/d (1 mgd) size. Heat energy has been converted to electrical energy by assuming that 1 kWh is equivalent to 11,100 kJ.

Source: Reference 1, p.4.

TABLE 2. ELECTRICAL ENERGY CONSUMPTION FOR MUNICIPAL WASTEWATER TREATMENT PLANTS

Process	Energy consumption, kWh/d		
	3,785 m^3/d (1 mgd)	37,850 m^3/d (10 mgd)	378,500 m^3/d (100 mgd)
Preliminary treatment			
Bar screens	1.53	1.53	10.7
Comminutors	15.3	61	204
Grit removal	1.7	3.4	34
Influent pumping (9m, 30ft TDH)	152	1,451	12,933
Primary sedimentation (12 $m^3/m^2 \cdot d$, 300 gal/d/ft²)	30.6	122	734
Trickling filters			
Recirculation pumping (Q_r/Q = 3.0)	183	1,740	15,519
Final sedimentation	30.6	122	734
Activated sludge process			
Diffused air (AEF* = 6%)	532	5,320	53,200
Mechanical aeration 0.338 kg O_2/MJ (2 lb O_2/hp-hr)	404	4,040	40,400
Recirculation pumping (50%, 5.3 m, 17.5 ft TDH)	45	423	3,131
(33 $m^3/m^2 \cdot d$, 800 gal/d/ft²)	30.6	122	734
Chlorination	0.72+	0.72+	265
Sludge handling and disposal			
Sludge pumping	2.65	26.6	266
Gravity thickeners	10.2	20.4	40.9
Air flotation thickeners			
Anaerobic digesters			
Mixing	106	334	1,122
Heating	17.6	122.4	788
Vacuum filtration	57	246	3,325
Multiple-hearth incineration	54	245	1,905
Lights and miscellaneous power	57	210	2,400

* AEF - Aeration efficiency in percent for diffused air and KgO_2/MJ (lb O_2/hp-hr) for mechanical aeration.

\+ Energy requirements approximately the same for 400- and 2,000-lb/d chlorination units.

Note: KWh/d x 3.6 = MJ/D.

Source: Reference 4, p. 15.

DAILY, SEASONAL, AND YEARLY VARIATIONS IN ENERGY REQUIREMENTS

Among the demands for electrical energy, the greatest demands are associated with influent/recycle pumping, and secondary aeration equipment. For this reason, the factors which influence periodic variations in energy requirements, i.e., hourly, daily, seasonal, or yearly, are those factors which influence either the organic or hydraulic loading on the facility.

Variation of the Organic Loading

Among the factors which influence the organic loading on a facility are:

1. Variations in the magnitude of the industrial contribution of organic wastes to the POTW, for example:

    a. Variations due to shift changes in industrial or commercial operations, and clean-up activities -- a daily effect.

    b. Response to market demands, e.g., fruit canning operations after the harvest season -- a seasonal effect.

    c. Industrial growth within the service area -- a yearly trend.

2. Treatment of periodic, high strength sidestreams generated within the POTW itself, e.g., from solids-handling equipment -- an hourly, daily, or weekly effect.

3. Septage disposal at the treatment plant -- a daily or seasonal effect.

4. Temperature variations due to seasonal weather changes, resulting in either poorer performance of the oxygen transfer equipment (a summer effect), or increased recycle and mixing to compensate for reduced kinetic performance (a winter effect).

The Water Pollution Control Federation Manual of Practice No. 8 (5) provides a discussion of the variations in wastewater characteristics.

Variation of the Hydraulic Loading

Among the factors which influence the hydraulic loading on a POTW are:

1. The diurnal variation typically associated with the generation of domestic wastewater.

2. Variations in the amount of industrial wastewater discharged to the facility, for example:

    a. Process and clean-up wastewaters generated on a batchwise or semi-continuous basis -- a daily effect.

    b. Sources of noncontact cooling water -- a seasonal or yearly effect.

3. Sidestreams, generated on an intermittent basis, within the POTW, such as from solids dewatering or filter backwash -- a daily or weekly effect.

4. Excessive inflow or infiltration associated with the sewerage system -- daily, seasonal, or yearly effect.

Manual of Practice No. 9 (6) provides a discussion of the variations in sanitary wastewater flow.

GEOGRAPHIC AND LOCAL AVAILABILITY OF CONVENTIONAL POWER SOURCES

The most convenient way to evaluate the geographic and local availability of conventional power sources is to analyze the costs of providing that power. A variety of periodical reference sources are available which provide estimates of the current prices of conventional power on a regional basis throughout the United States. Two of these sources are:

1. Federal Register publications and updates of 10 CFR Part 436, "Federal Energy Management and Planning Programs; Methodology and Procedures for Life Cycle Cost Analyses" (average fuel costs). (7) This publication is updated on an approximately annual basis.

2. Energy User News, (8) a weekly newspaper by Fairchild Publications of New York City.

The variations in the prices for natural gas, electricity, and No. 2 fuel oil for eight metropolitan areas scattered throughout the U.S. have been estimated (8) as follows:

1. Natural gas -- $2.67 to 4.09/$10^6$ kJ

2. Electricity -- $0.0328 to 0.0795/kWh

3. No. 2 fuel oil -- $0.269 to 0.293/L

These prices are based on May 1981 dollars.

Estimates (7) of the average U.S. prices and escalation rates for various fuels are presented in Table 3. These estimates are also expressed in mid-1981 dollars, and have been broken down for various sectors of the economy. Also included in this table are Department of Energy (DOE) forecasts of the prices in mid-1985, mid-1990, and mid-1995. It should be noted that, in addition to these countrywide average estimates, this publication (7) also provides similar estimates for each of the 10 DOE regions.

REDUCING ENERGY COSTS

The reason for considering alternative energy sources is usually to reduce energy costs. Two items which greatly affect energy costs are electrical rate structures and energy conservation. A detailed discussion of these topics is

TABLE 3. ENERGY PRICES AND ESCALATION RATES (UNITED STATES AVERAGE)

Fuel type	Current and projected energy prices (in mid-1981 dollars): Mid-1981 base-year (Dollars per sales unit)*	Mid-1981 base-year (Dollars per 10^6 Btu)	Mid-1985 (dollars per 10^6 Btu)	Mid-1990 (dollars per 10^6 Btu)	Mid-1995 (dollars per 10^6 Btu)	Projected energy price escalation rates (percentage change compounded annually): Mid-1981-mid-1985	Mid-1985-mid-1990	Mid-1990-mid-1995 and beyond
		Residential sector						
Electricity	0.057 (kWh)	16.74	20.56	20.81	20.62	5.28	0.24	-0.19
Distillate	1.334 (gal)	9.62	10.62	12.05	16.25	2.51	2.55	6.16
LPG	0.900 (gal)	9.42	10.41	11.69	15.65	2.52	2.35	6.00
Natural gas	0.004 (ft^3)	4.42	6.21	6.62	7.45	8.88	1.28	2.38
		Commercial sector						
Electricity	0.058 (kWh)	17.10	21.01	21.10	20.86	5.28	0.09	-0.23
Distillate	1.262 (gal)	9.10	10.05	11.47	15.66	2.51	2.69	6.42
Residual	0.949 (gal)	6.34	8.94	10.19	12.29	8.99	2.64	3.82
Natural gas	0.004 (ft^3)	3.98	5.59	6.01	6.82	8.85	1.46	2.58
Steam coal	39.375 (ton)	1.75	2.22	2.42	2.49	6.11	1.77	0.59
		Industrial sector						
Electricity	0.042 (kWh)	12.32	15.13	15.58	15.48	5.27	0.58	-0.12
Distillate	1.266 (gal)	9.13	10.08	11.50	15.69	2.51	2.66	6.42
Residual	0.949 (gal)	6.34	8.96	10.13	10.92	9.02	2.50	1.52
Natural gas	0.004 (ft^3)	3.52	4.94	5.12	5.89	8.84	0.72	2.83
Natural gas -- MFBI	0.005 (ft^3)	4.52	6.35	5.10	5.83	8.89	-4.32	2.72
Steam coal	39.800 (ton)	1.68	2.82	3.19	3.35	13.80	2.51	0.96
		Transportation						
Gasoline	1.622 (gal)	12.97	15.92	17.09	21.92	5.26	1.42	5.11

*Note that these prices are equivalent to those in the adjacent column (both for mid-1981), but they are stated in different units of energy. Price per sales unit of energy is derived from price per million Btu by dividing the price by a million and multiplying by the Btu content of a sales unit of energy, assuming the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 95,500 Btu/gal of LPG; 1,016 Btu/ft^3 of natural gas; 149,690 Btu/gal of residual; 22,500,000 Btu/ton of steam coal; and 125,071 Btu/gal of gasoline. For example, in DoE Region 1, for electricity, \$0.086/kWh = \$24.82/1,000,000 Btu x 3,412 Btu/kWh.

Source: Reference 7, p. 56733.

beyond the scope of this report but they will be discussed briefly. Many other sources discuss these items and should be consulted for more information (1, 2, 3, 9, 10, 11).

Rate Structures

The effect of the electrical rate structure is very significant. Electric company bills usually include charges for both how much energy is used and when the energy is used. There are typically different rates for on-peak and off-peak usage, maximum demand charges which reflect all-time peak energy usage, ratchet clauses which can escalate minimum demand charges based on yearly 15 minute peaks, and penalties for low power factors on motors. Understanding the billing structure of the electric company and the energy usage profile of the POTW is an essential first step in reducing energy costs. Energy savings can often be achieved by just changing the schedule of electrical energy usage rather than reducing the amount of electrical energy used.

Energy Conservation

Although altering energy scheduling can reduce electrical energy usage, energy conservation is also an important step in reducing energy costs. Many conservation measures have low capital costs and short pay-back periods. Some conservation techniques require no capital expenditures at all, such as, improving pump and motor performance through improved maintenance procedures, running efficient pumps more frequently than inefficient pumps, and properly matching pumping equipment to demand loads. Energy conservation steps should be considered in any cost-effective analysis that compares conventional and alternative energy sources.

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SECTION 4

TECHNICAL DESCRIPTIONS

This section contains overall technical descriptions for the following alternative energy systems:

1. Heat pumps.
2. Active solar systems for heating and cooling.
3. Photovoltaic systems.
4. Geothermal--direct use systems.
5. Wind power systems.
6. Low-head hydro systems.
7. Passive solar systems.
8. Geothermal--power generation systems.
9. Fuel cells.
10. Active solar systems for power generation.

These descriptions provide a summary of the overall technical status of each alternative energy technology with respect to its design, construction, costs, and constraints on its application. These descriptions are presented in a fact/data sheet format, with supplementary figures (including process diagrams) and costs, where appropriate. This overall format was chosen in order to permit both an overall assessment of the technologies, and where possible, an estimate of system size and costs. The information is presented to allow for a preliminary assessment for comparing these technologies with conventional energy supplies. Appropriate references are included for additional information regarding these technologies.

The information presented in this section has resulted from a review of the literature and vendor/manufacturer contacts to confirm design bases and costs.

Table 4 summarizes the type of information needed to use the data sheets to size the various alternative energy systems, and to develop preliminary estimates of the capital and operation/maintenance costs for the systems.

Data sheets were not prepared for geothermal power generation systems, fuel cells, and active solar systems for power generation because, based on the technology review, extremely limited potential currently exists for their application in POTW's. These limitations are summarized in the fact sheets. Also, a data sheet was not prepared for passive solar systems. While potential applications for this technology exist in POTW's, a generalized data sheet was not prepared due to the significant variations in possible solar applications, which result from the variations in building architecture and corresponding passive solar systems and costs. In the case of passive solar systems, the fact sheet identifies specific literature references for guidance on system design.

TABLE 4. INFORMATION NEEDED TO SIZE THE VARIOUS ALTERNATIVE ENERGY SYSTEMS

System	PARAMETER
Heat pumps	Annual ambient temperature profile of heat source --°C
Active solar for heating and cooling	Solar insolation rate -- kJ/d-m^2 or kJ/yr-m^2
Photovoltaic	Solar insolation rate--kWh/d-m^2
Geothermal -- direct use	Earth thermal gradient--°C/km Well yield (flow-rate)--m^3/hr
Wind power	Wind flux -- kWh/m^2-yr
Low-head hydro	Available head -- m Available flow -- m^3/d
Passive solar	Solar insolation rate -- kJ/d-m^2

FACT SHEET FS-1--HEAT PUMPS

Description - A heat pump is a thermodynamic refrigeration cycle machine which moves heat from a low-temperature source to a higher temperature sink by the addition of work. When high-temperature heating applications are desired, the heat pump supplies this energy by drawing it from a low-temperature source. The useful heat output is a function of that extracted from the cold region, plus the energy added to the heat pump. Therefore, the total heat output, usually expressed as the coefficient of performance (COP), is always greater than unity. Typically the COP ranges from 3 to 4, where the COP is defined as total heat output divided by the energy added (See Fig. 1). Common types of heat pumps include water-to-water, water-to-air, and air-to-air (See Figure 2.).

Technical Status - Heat pumps were widely used for residential and light commercial building applications as early as the 1950's. Recent improvements in design and components have resulted in a dramatic growth in heat pump applications including some applications in wastewater treatment plants. Recent interest has focused on the recovery of heat from wastewater effluent.

Applications - Heat pumps can supply heat for domestic hot water, space heating, and process heat (e.g., anaerobic digester, sludge drying).

Technical Data	Primary source of energy	- Electricity.
	Alternative source of energy	- Directly driven by internal combustion engine utilizing anaerobic digester gas or fossil fuels.
	Nature of output	- Varies with the temperature of heat source
	Comments	- A standby or auxiliary heating system is required when the source temperature falls below 4°C.

Design Considerations - Total and maximum heat load requirements, coefficient of performance (COP) of heat pump, and temperature data of heat source.

Performance - The performance of the heat pump, as measured by COP, varies with source temperature (see Figure 1). In general, the heat pump becomes inefficient if the source temperature drops below 4°C. Maximum heat load may occur at minimum COP, e.g., heating an anaerobic digester in cold weather.

Reliability - Heat pumps have been used widely in the HVAC field with no history of operational or design problems other than the installation of these units in unsuitable geographic (climatic) locations. Heat pumps are generally considered low O&M equipment. Potential concerns for use at a POTW include corrosion for installations using a chlorinated effluent, and scaling and biological fouling which adversely affect the efficiency of the heat exchanger.

Limitations -

- Geographical - Operation of air-to-air heat pumps in nothern climates (35° north latitude and above) requires consideration of a heat energy wheel, air-to-air preheat exchanger, or Z duct to increase the COP. There are no geographical limitations for water-to-water and water-to-air heat pumps using wastewater effluent because the wastewater is relatively warm (10°C) throughout the year.

- Production/distribution - None.

- Environmental effects - None other than the possible release of fluorocarbons to the atmosphere due to leakage.

- Legal, social, or institutional barriers - None.

References - 1 through 6.

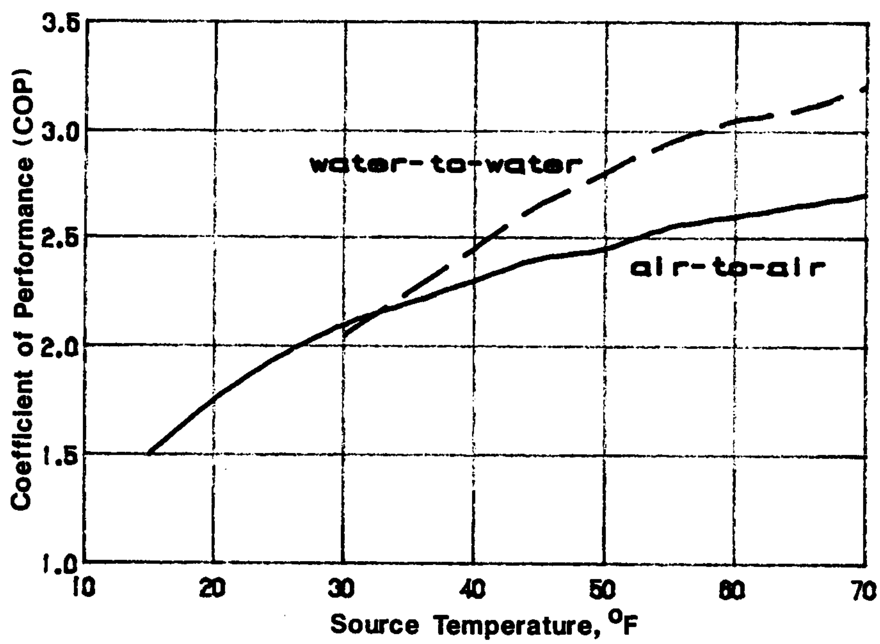


Figure 1. Heat pump coefficient of performance. (Adapted from Ref. 3)

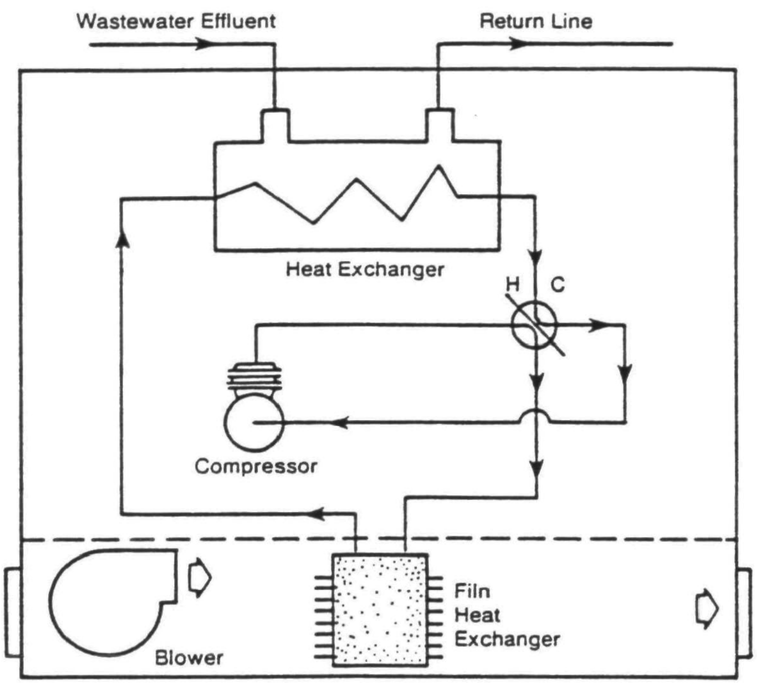


Figure 2. Heat pump schematic diagram.

DATA SHEET DS-1--HEAT PUMPS

Step 1. Heat Load Requirement - The maximum heat load for specific process operations can be estimated from information provided in references 1, 2, and 3.

Heat Load __________kJ/hr

Step 2. Selection of Heat Pump - Select type of heat pump (water-to-water, water-to-air, air-to-air) and use Fig. 1 to determine the COP. COP should be based on minimum source wastewater or air temperature. COP for air-to-air can be increased if source air is preheated.

Type of heat Pump ____________________ COP __________

Step 3. Estimated Costs

Installed capital costs --

Use the heat load from Step 1 and Figures 3 and 4 to estimate the total installed capital costs

Annual O&M Costs --

a) Electricity:

Total service hours		Total load (Step 1)		Conversion factor		Electrical unit cost		1/COP (Step 2)
________ (hr/yr)	x	________ (kJ/hr)	x	0.000278	x	________ ($/kWh)	x	________

=(a)$__________

b) Other O&M costs: =(b)$__________
(usually 0.04-0.08 of total installed capital costs)

Total Annual O&M costs (a & b) =(c)$__________

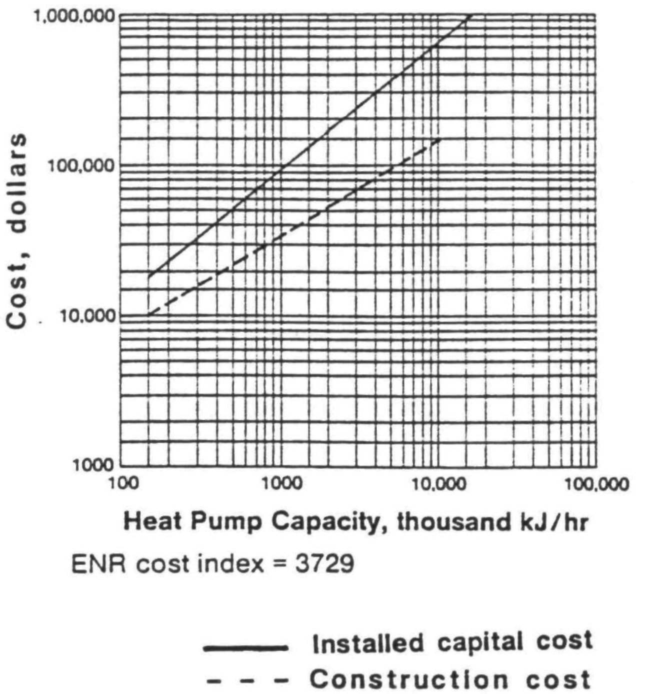


Figure 3. Water-to-water/water-to-air heat pump costs. (Adapted from Ref. 3)

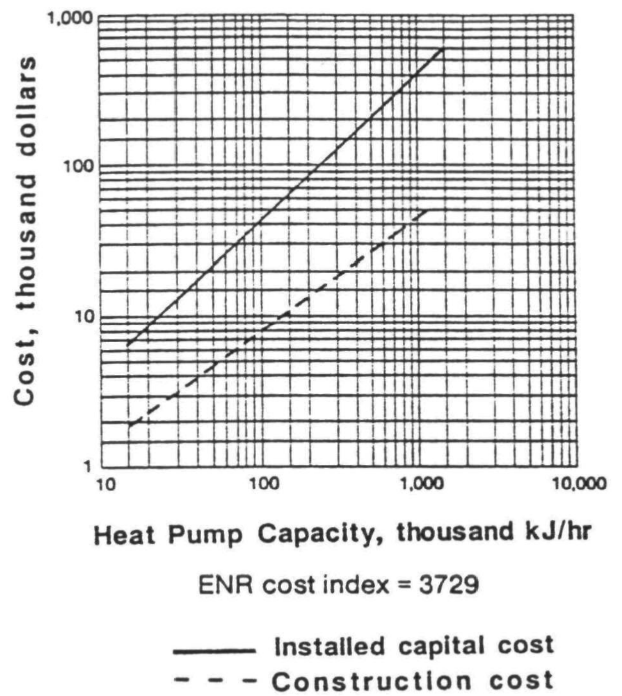


Figure 4. Air-to-air heat pump costs. (Adapted from Ref. 3)

FACT SHEET FS-2
ACTIVE SOLAR SYSTEMS FOR HEATING AND COOLING

Description - Solar energy is collected as heat for heating or cooling. A solar collector converts incident solar radiation (insolation) to usable thermal energy by adsorption on a suitable surface. A heat storage reservoir is used so that energy can be supplied during evening hours and cloudy days. A distribution system distributes energy from the collector or storage to the point of consumption. Solar cooling is typically accomplished by using solar heat to operate a thermal refrigeration cycle. There are three basic heat-activated refrigeration cycles: absorption cycle, organic Rankine cycle, and desiccant cycle. (See Figures 5 and 6.)

Technical Status - The basic concepts are well established and many designs are available commercially. Active solar systems have been installed in wastewater treatment plants.

Application - Active solar systems can supply heat for domestic hot water, space heating, sludge drying, and space cooling. Active solar systems do not appear to be cost-effective for anaerobic digester heating.

Technical Data - Primary source of energy - Sunlight.

Alternative energy source- None

Nature of output - Output varies with seasonal and daily sunlight cycle and with cloud cover variation; sufficient heat storage can adequately buffer most heat fluctuations.

Comments - Connection to auxiliary heating or cooling systems is required.

- Heat storage for night time and cloudy periods is required.

Design Considerations - Heating requirements (domestic hot water and space heating), cooling requirements, storage requirements, system efficiencies, local insolation data, and weather/climate conditions.

Performance - The performance of an active solar system is primarily dependent on geographical location and local weather conditions. Studies indicate that local weather conditions limit the optimum performance (output) of the active solar system. A solar heating system typically has an efficiency of 20-30 percent, while a solar cooling system has an efficiency of only 6-12 percent.

Reliability - The reliability of the solar heating and cooling system over the life expectancy of the unit is questionable (21). A recent national study of 12 active solar units showed only one provided the expected solar energy. A number of problems were reported as causing poor system performance: air leakage, water leakage, freezing problems, control problems, storage heat loss problems, severe weather, lower energy requirement than design load, and supplemental heat problems.

Limitations -

- Geographical - The application of active solar heating and cooling is feasible throughout the United States.
- Production/distribution - There is no evidence currently available to show any reduction in costs for active solar heating and cooling in the near future.
- Environmental effects - Active solar heating and cooling systems have relatively minor environmental impacts. The major concerns are the potential hazards associated with a toxic working fluid and storage media (contamination of water and direct human impacts from inhalation or contact), collector overheating, and degradation of living space air quality (e.g., stagnant air, accumulation of airborne contaminants, buildup of molds, fungus, and bacteria) in storage system.
- Legal, social, and institutional barriers - Large-scale glare, sunrights, local codes, installation expertise, land availability and acquisition, and public acceptance of the removal of tree canopy.

References - 7 through 21, 25, 101.

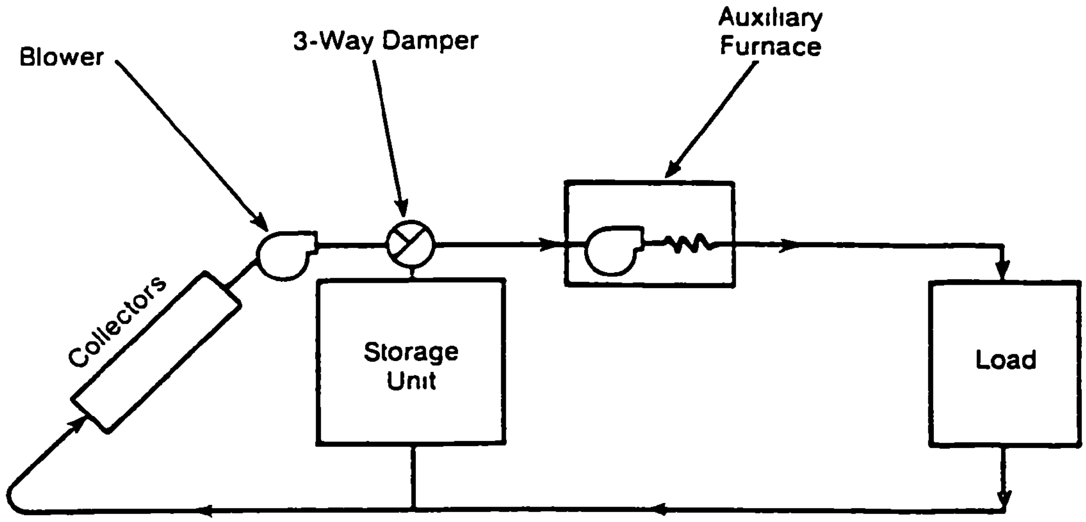


Figure 5. Typical air flat-plate solar energy collection system. (2)

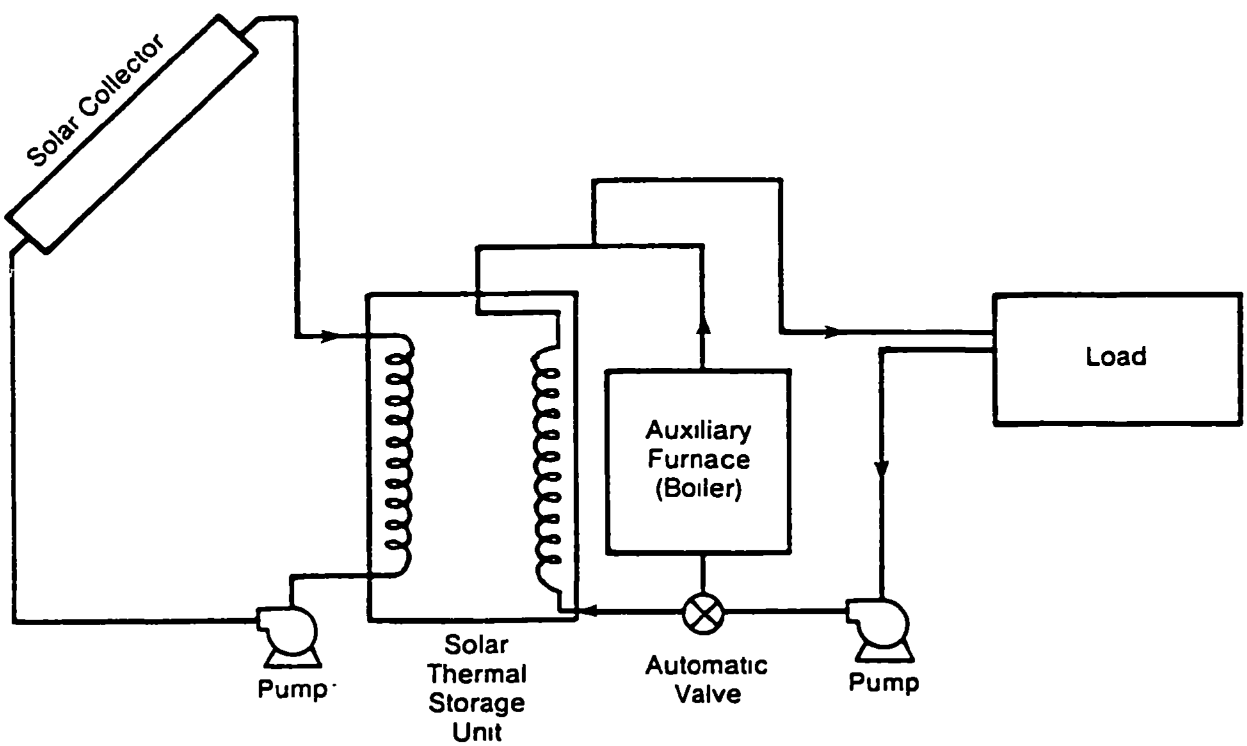


Figure 6. Typical liquid flat-plate solar energy collection system. (2)

DATA SHEET DS-2
SOLAR HEATING AND COOLING SYSTEMS

Step 1. Heating and Cooling Requirements - Heating and cooling loads can be estimated from references 1, 2, and 3.

Specific Load (Heating or Cooling)

Hot water (domestic)	________kJ/hr
Space heating	________kJ/hr
Space cooling	________kJ/hr
Process heat (e.g. sludge drying)	________kJ/hr
Other	________kJ/hr

Step 2. Isolation Calculation for Specific Heating or Cooling Requirement - Insolation data can be obtained from reference 1 or Figure 7. Number of months of insolation for heating and cooling season is a function of location; it can range from 3-8 months. (To convert average daily insolation rate to a yearly rate, the average daily insolation rate for a particular month is multiplied by the number of days per month to obtain a total monthly insolation rate, then the monthly totals are summed to obtain the yearly insolation rate.)

For each application noted in Step 1 there is an average insolation based on location, time of year, and number of months the application is in operation.

Application	Insolation	
Hot water (domestic)	- Average annual insolation (12 months)	______kJ/yr-m^2
Space heating	- Winter average insolation (3-8 months)	______kJ/yr-m^2
Space cooling	- Summer average insolation (3-8 months)	______kJ/yr-m^2
Process heat	- Average annual insolation (12 months)	______kJ/yr-m^2

Step 3. Efficiencies (Total System) -

Hot water (domestic) (usually 0.2-0.3)	________
Space heating (usually 0.2-0.3)	________
Space cooling (usually 0.08-0.12)	________
Process heat (usually 0.2-0.3)	________

Step 4. Array Area Requirements -

$$\text{Area } (m^2) = \frac{\text{Specific load}}{\text{Efficiency x insolation}} =$$

Hot water area	________m^2
Space heating area	________m^2
Space cooling area	________m^2
Process heat area	________m^2

Where: Area = Collector area in m^2
Specific load = Heating or cooling load for application in kJ/yr (Step 1).
Insolation = Step 2, in kJ/yr-m^2 for specific application.
Efficiency = Total system efficiency (Step 3).

Step 5. Economic Considerations -

Installed capital costs* (including storage) -

Item	Unit costs	Array area	Installed capital costs
Hot water (domestic)	450 (\$/m^2)	x__________(m^2) =	\$__________
Space heating	540 (\$/m^2)	x__________(m^2) =	\$__________
Space cooling	1,100-1,700(\$/m^2)	x__________(m^2) =	\$__________
Process heat	540 (\$/m^2)	x__________(m^2) =	\$__________
Net credit+	140 (\$/m^2)	x__________(m^2) =	\$(__________)
		Total	\$__________
Annual operation and maintenance costs* (usually 0.01-0.03 of total capital costs) -			\$__________yr

* Costs supplied by equipment vendors (1982 costs)

\+ If both space heating and cooling are included in the solar design, a net credit (\$) is given for the redundancy in the collection system. This credit equals the smaller of the space cooling and space heating area x collector costs (\$140/m^2).

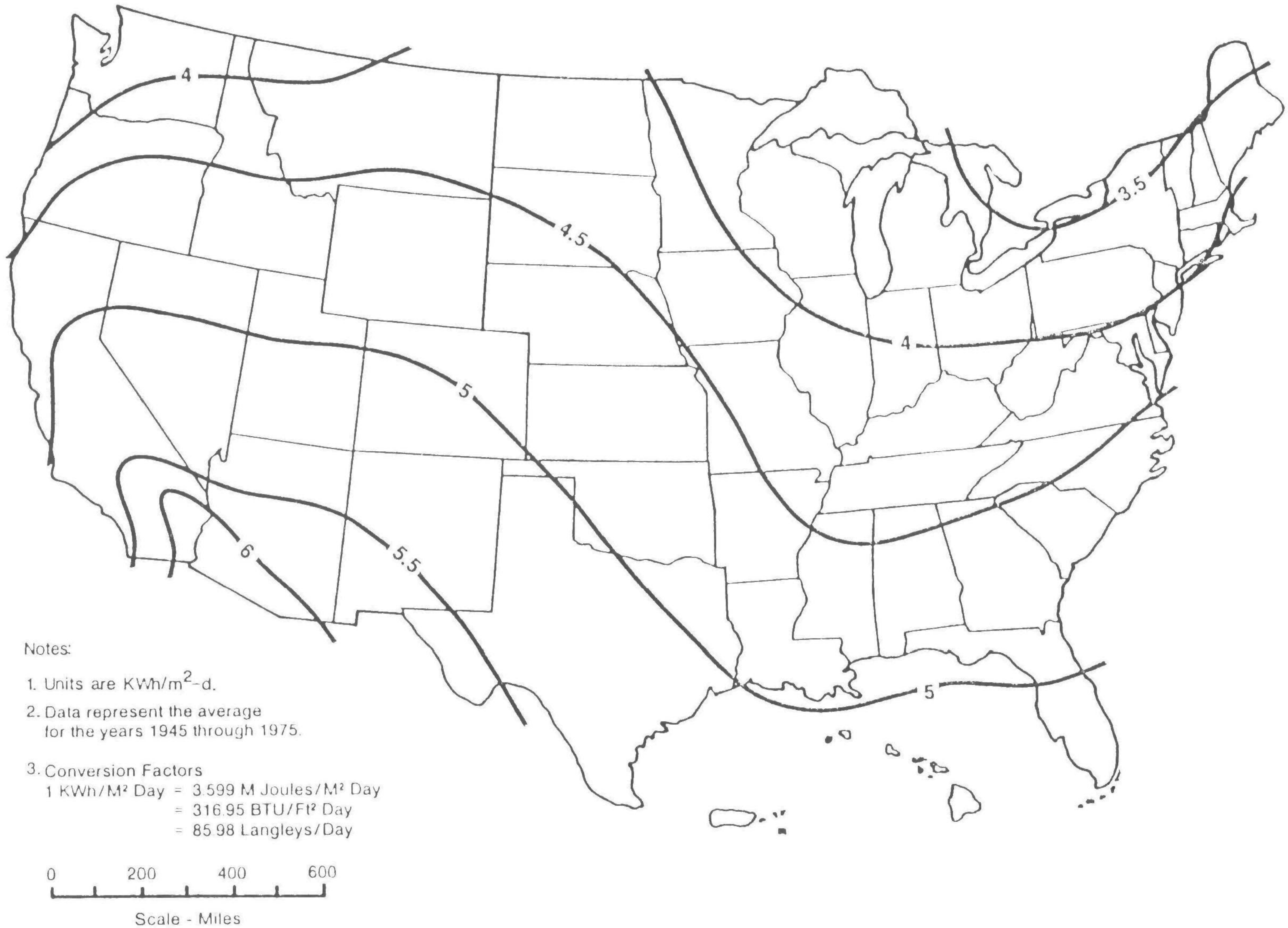


Figure 7. Solar insolation - total horizontal annual average day values. (101)

FACT SHEET FS-3--PHOTOVOLTAIC SYSTEM

Description - Photovoltaic power systems convert sunlight directly to electricity. The system consists of a solar array using flat plate or concentrating-type collectors, a power conditioning system (dc or ac conversion and voltage regulation), an energy storage system, and/or a utility tie-in or standby generator. (See Figure 8.)

Technology Status - Single-crystal photovoltaic cell systems are the state-of-the-art technology. The technology is well advanced for silicon and gallium arsenide cells. Several photovoltaic demonstration projects are in operation using single-crystal silicon cells. Low-cost photovoltaic manufacturing technology for polycrystalline and thin-film materials is still in the development stages. Typical efficiencies of commercially-available cells range from 10-14 percent.

Application - Photovoltaic power systems can supply electricity to the POTW.

Technical Data -

Primary source of energy	-	Sunlight
Alternate energy source	-	None.
Nature of output	-	Seasonal and daily sunlight cycle and cloud cover variation.
Comments	-	Connection to auxiliary electrical system required, i.e., batteries, central utility, or standby generator.
	-	Energy storage for night time and cloudy periods is required.

Design Considerations - Power requirements, siting requirements, local insolation data, storage requirements, array and system efficiency, and local weather/climate conditions.

Performance - The performance of a photovoltaic system is primarily dependent on geographical location and weather conditions. Studies have shown that the local weather pattern is the most critical component limiting performance (output) of the photovoltaic system. Overall system efficiencies range from 8-10 percent.

Reliability - The photovoltaic system is generally considered very reliable. The system has no moving parts and requires only periodic maintenance. However, reliability data over the life of the photovoltaic system are currently not available. The photovoltaic system will have to be subjected to long-term testing under actual field conditions before sufficient data are obtained to determine the actual reliability of the system.

Limitations

- Geographical - All areas of the United States to latitude 60° north have sufficient annual insolation to be potentially suitable for photovoltaic power, with the southwestern region of the United States having the optimal insolation rates.

- Production/distribution - Current production and system costs do not reflect the large-scale manufacturing of these units. Increasing demand for photovoltaic systems and optimization of production processes will ultimately reduce the capital costs of these units.

- Environmental effects - The environmental impacts regarding installation and use of photovoltaic systems are minimal. Areas of concern are predominantly safety-related: off-gasing of the array, power conditioner, and batteries.

- Legal, social, and institutional barriers - Utility interconnection, insolation rights, large-scale glare, and installation area availability and acquisition.

References - 1, 6, 7, 13, 22 through 31, 101.

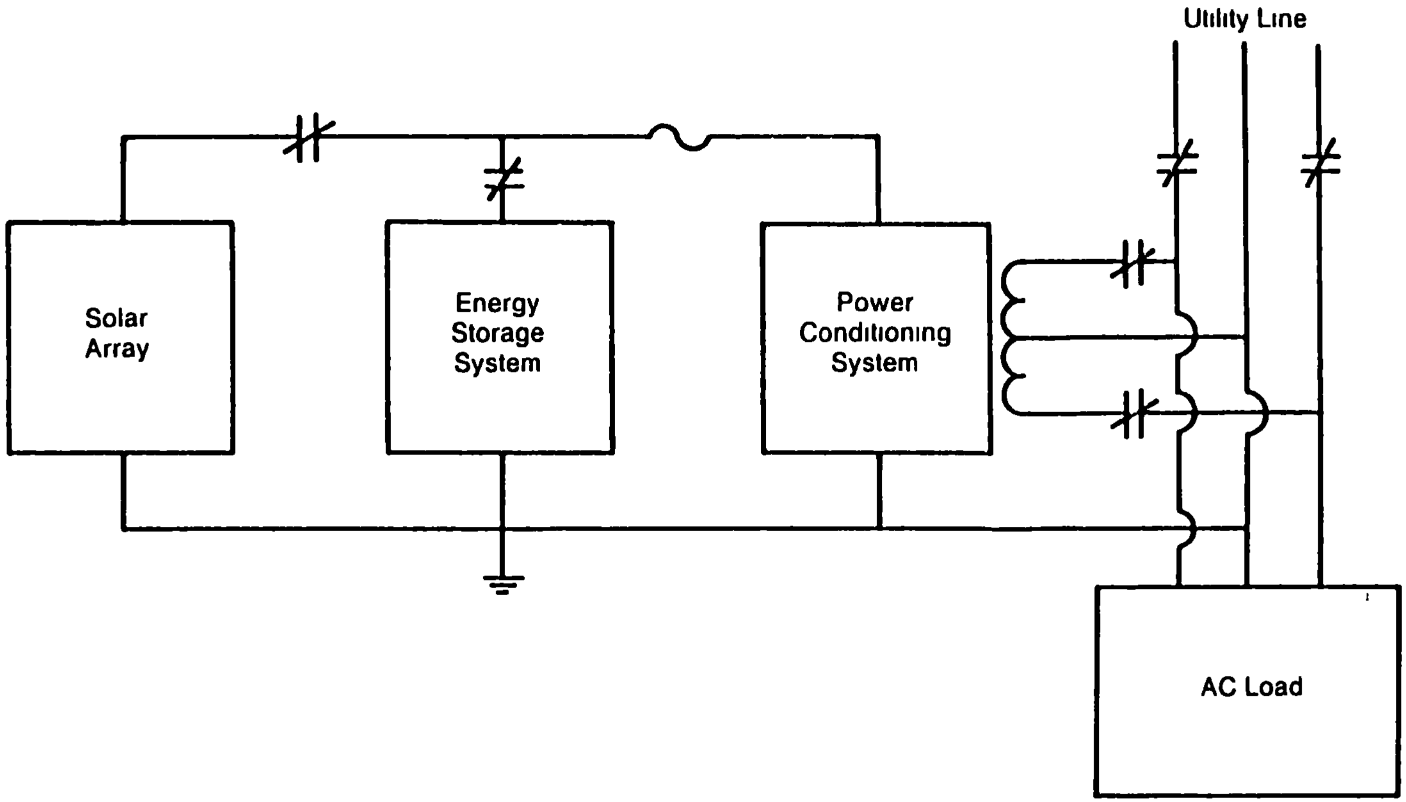


Figure 8. Simplified block diagram of the photovoltaic electrical system. (26)

DATA SHEET DS-3--PHOTOVOLTAIC SYSTEMS

Step 1. Load or Fraction of Load Requirements - The load requirements for specific process operations can be estimated from references 2 and 3. ________kWh/yr

Step 2. Insolation Data - Insolation data can be obtained from reference 1 or Figure 7. (See step 2 of Data Sheet DS-2.)
Average annual insolation at proposed location ________kWh/m^2-yr

Step 3. Array Area Requirements -

$$\text{Array area } (m^2) = \frac{\text{Load requirements}}{\text{Cell efficiency x average insolation}} = \_\_\_\_\_\_ m^2$$

Where: Load requirements = Step 1 in kWh/yr.
Average insolation = Step 2 in kWh/m^2-yr.
Cell efficiency = 0.10 to 0.14

Step 4. Peak Power Output (kW) - ________kW

P peak (kW) = Array area x system efficiency x peak insolation

Where: P peak = Peak power output in kW.
System efficiency = Usually 0.08 - 0.10.
Array area = Step 3.
Peak insolation = Typically 0.75-0.95 kW/m^2.

Step 5. Economic Considerations -

Total installed capital costs* -

Typical 1982 unit costs - based on peak power output (kW) from Step 4:

Photovoltaic array	= $10,000/kW	X P peak (Step 4)	= $________
Support structure	= $ 1,000-$5,000/kW	X P peak (Step 4)	= $________
Power conditioner	= $ 500-$1,000/kW	X P peak (Step 4)	= $________
Batteries (if req.)	= $ 500-$2,000/kW	X P peak (Step 4)	= $________
		Total	$________

Annual operation and maintenance costs* (typically 0.02-0.03) of installed capital costs. $________/yr

---

* Costs supplied by equipment vendors (1982 costs)

FACT SHEET FS-4--GEOTHERMAL - DIRECT USE SYSTEMS

Description - Direct use systems pump hot geothermal fluid through a heat exchanger transferring the geothermal energy to a secondary thermodynamic fluid. This fluid then transmits the heat energy from the geothermal fluid to the thermal load. (See Figure 9.)

Technology Status - Direct use systems have been employed in the United States for approximately the last 20 to 30 years. Geothermal systems have been considered for POTW's but have not been used.

Applications - Direct use systems can be applied to space heating, anaerobic digestion, and sludge drying.

Technical Data -

Primary source of energy - Geothermal energy
Nature of output - Thermal energy

Design Considerations - Heating and/or power requirements, local geothermal temperature gradient (see Figure 10), available local geothermal data (including depth to source), geothermal fluid quality (including temperature) and quantity data, and geothermal test well data.

Performance - Geothermal sources have been known to produce constant and continuous output from 20 to 50 years. System efficiency for direct use is 90-95 percent.

Reliability - The reliability of direct use systems has been proven both in the United States and Europe. Direct use systems must be periodically shut down for heat exchanger maintenance. This maintenance consists of scale prevention and gasket replacement. This will be especially true for POTW applications if wastewater is the secondary fluid in the heat exchanger (greater potential for scaling and biological fouling).

Limitations -

- Geographical - For successful application, the site must be located near a suitable geothermal resource. This resource must be verified by both available data and actual well testing.

- Production/distribution - Direct use systems are commercially available.

- Environmental impacts - The impacts from waste heat are minimal for direct use systems. A major concern is the proper disposal of spent geothermal fluids to avoid upsetting the local aquatic environment. Spent geothermal fluids are typically disposed of by reinjection.

- Legal, social, and institutional barriers - None.

References - 32 through 47, 77, 102.

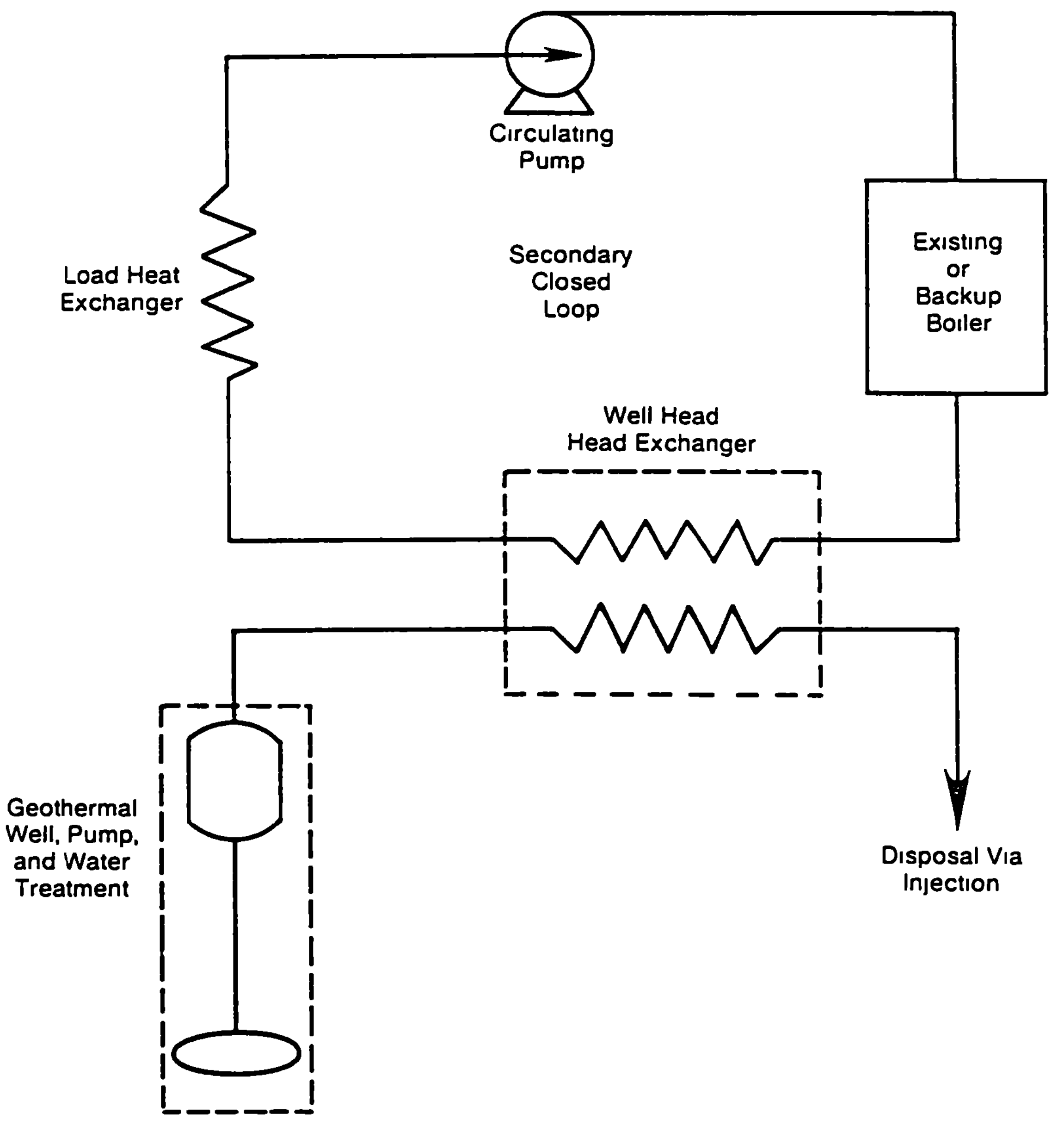


Figure 9. Typical geothermal direct use system. (43)

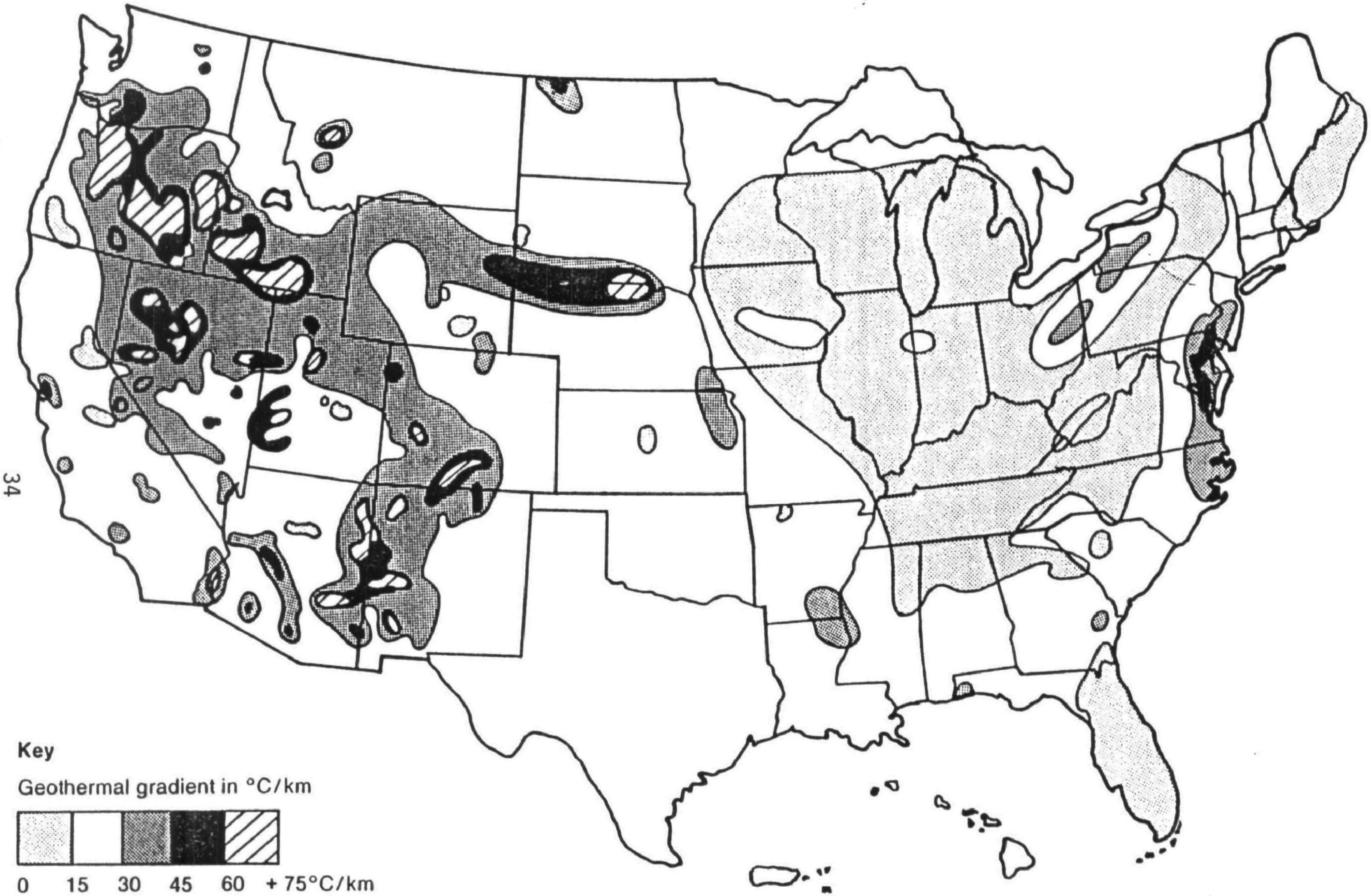


Figure 10. Geothermal gradient map of the conterminous United States. (41)

DATA SHEET DS-4--GEOTHERMAL - DIRECT USE SYSTEMS

Step 1. Heat Load (HL) Requirements - Head loads for specific unit operations can be estimated from the data provided in references 1, 2, and 3. ______________ KJ/hr

Step 2. Geothermal Temperature Gradient at Site (Fig. 10) (A) __________ ^{o}C/km

Step 3. Highest Required Source Temperature for a given application (Figure 11). (B) __________ (^{o}C)

Step 4. Total Required Well Depth

$$\text{Well Depth} = \left(\frac{(B) - 12.8}{(A)} + 0.05\right) 1.5 = \quad (C) \_\_\_\_\_\_\_\_\_\_$$

Step 5. Wellhead Pump Size and Flow Rate[a]

The well flow rate is calculated as follows:

$$\text{Required well flow rate (W)} = \frac{\text{HL (kJ/hr)}}{\text{T } (^{o}\text{C}) \text{ 4184}} =$$

______________ m^3/hr

Where: HL - Heat load requirements in kJ/hr (Step 1.)
T = Overall geothermal temperature drop in ^{o}C; generally 11^{o}C for space heating and domestic hot water, and 20^{o}C for an anaerobic digestion and sludge drying application.

$$\text{Pump kilowatts (kW)} = \frac{W \times H}{360\ e}$$

______________ kW

Where: W = Well flow rate in m^3/hr.
H = Pumping head in meters (m) which can be assumed to be 300 m (1,000 ft) for a preliminary estimate.
e = Pump efficiency, typically 0.60-0.85.

Step 6. Transmission Distance -

Estimated transmission distance from wellhead to thermal load in meters. (D) __________ m

Step 7. Economic Considerations -

Installed capital costs+ --

Well and wellhead heat exchanger costs from Figure 12 (1982 dollars)

(E)$__________

Wellhead pump costs ($/kW) from Figure 13 (1982 dollars) x kW (in Step 5) =

(F)$__________

Transmission piping costs (1982 dollars): (D) x $95/m =

(G)$__________

Total engineering and related capital costs

(E) + (F) = (G) = (H)$__________

Engineering design: (H) x 0.15 = (I)$__________

Site investigation and overhead: (H) x 0.03 = (J)$__________

Resource exploration and test wells (typically $100,000) (K)$__________

Total capital direct heating installed costs

(H) + (I) + (J) + (K) = Total (L)$__________

Annual operating and maintenance costs (usually 0.02-0.04 of total capital costs (L)). $__________/yr

---

* Due to very limited information of this type, it is recommended that the evaluator contact the following office for site-specific test well flow data:
U.S. Department of Energy
Division of Geothermal Energy, Resource Applications
Federal Building - MS3344
12th and Pennsylvania Avenue, N.W.
Washington, DC 20461

\+ Does not include reinjection well costs

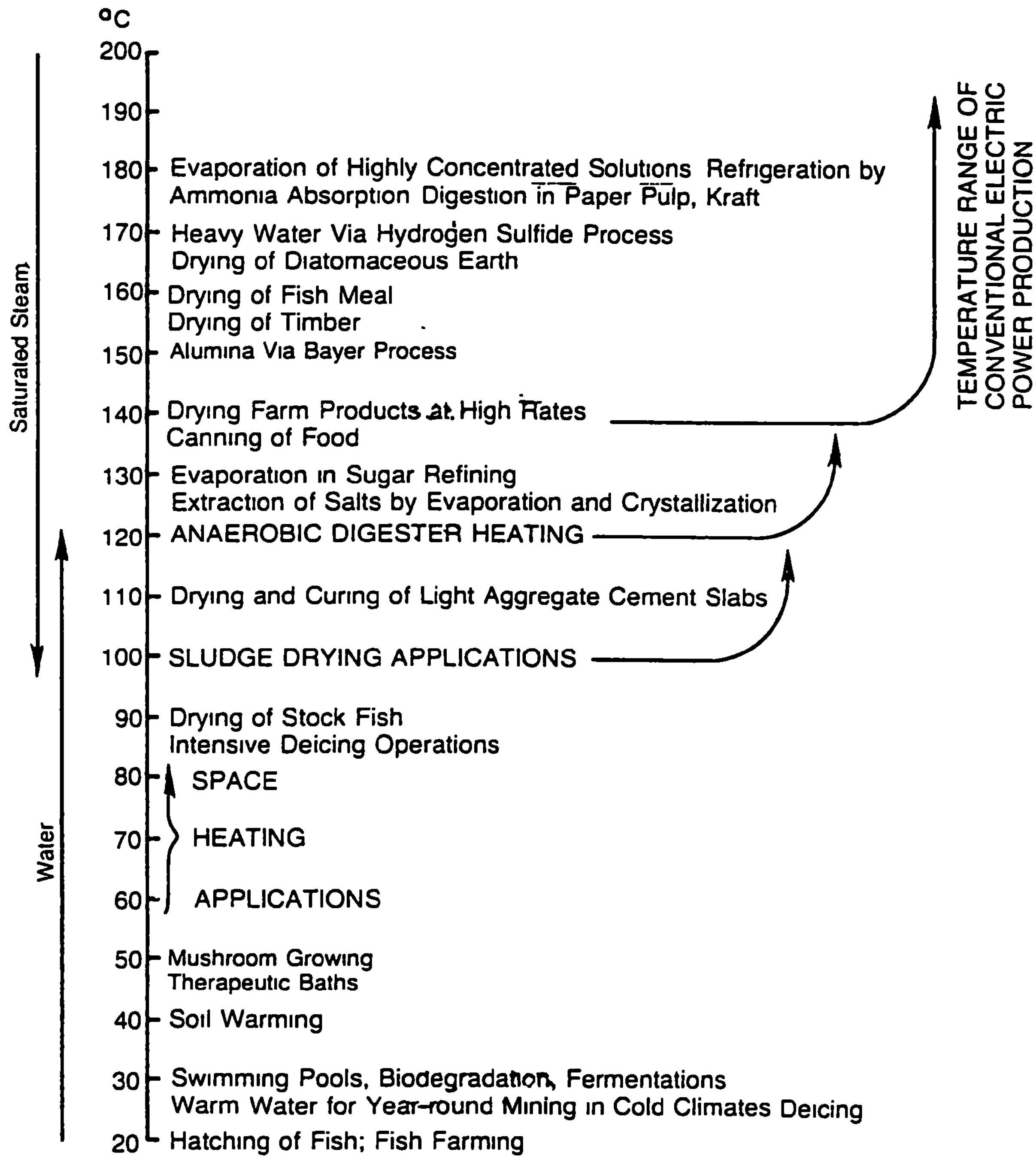
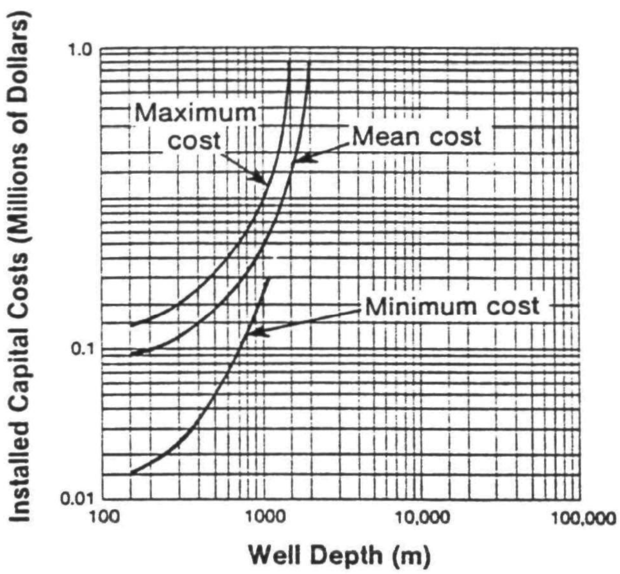


Figure 11. Applications versus source temperature range of geothermal water and steam.(38)



ENR cost index = 3729

Figure 12. Typical well and wellhead heat exchange installed capital costs for geothermal well. (44) (Reinjection well costs not included.)

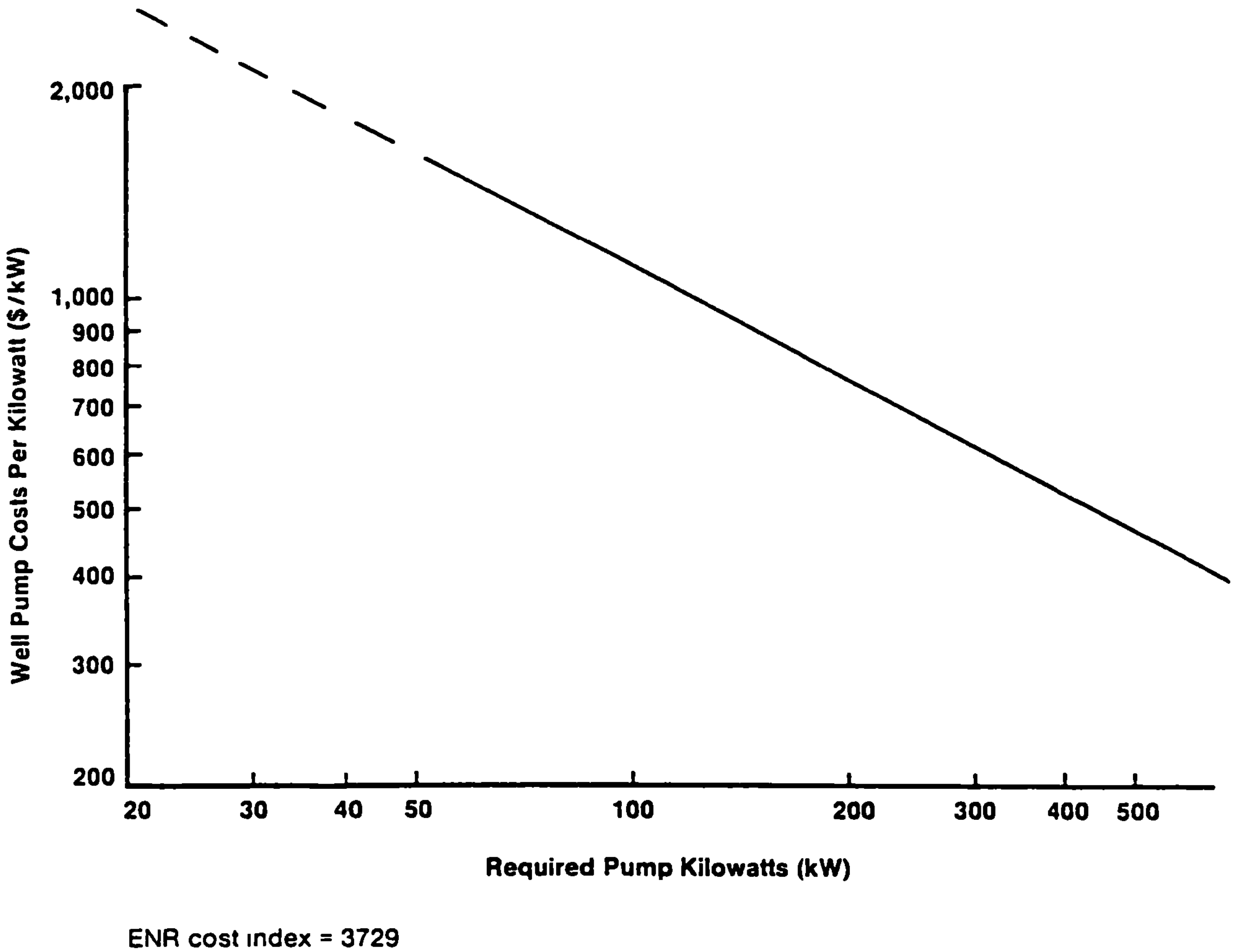


Figure 13. Total installed capital cost for geothermal wellhead pump.(43)

FACT SHEET FS-5--WIND POWER SYSTEMS

Description - Wind energy conversion systems (WECS) harness the power of the wind converting it to electricity. The system converts wind power to mechanical energy through a rotor. The mechanical power is transferred to a generator or alternator via a drive shaft. A power conditioning system (inverter) is also employed to convert the power to ac or dc and to ensure a steady output. (See Figure 14).

Technical Status - Units of 10 to over 100,000 kW are available commercially. However, the larger units are special orders that are constructed on a contractual turnkey basis with the manufacturer. Several wind energy conversion system demonstration projects are in operation, but the very large units (over 100 kW) are not considered to be proven technology.

Applications - WECS can supply electricity to the POTW.

Technical Data -

Primary source of energy	-	Wind.
Nature of output	-	Zero to maximum rated capacity depending on wind speed and duration
Comments	-	Connection to auxiliary system required, i.e., batteries, central utility, standby generator.

Design Considerations - Power requirements (load), siting requirements, local wind data, energy storage requirements, and wind turbine/system efficiencies.

Performance - The performance (output) of a wind power system is significantly affected by wind speed and direction. The electrical output of the WECS is zero until the wind speed reaches the minimum cut-in velocity. Above the cut-in velocity the power output increases with the cube of the increasing wind velocity until the maximum design velocity is achieved. At velocities greater than the maximum design velocity the power output remains constant. The WECS efficiencies range between 38 and 56 percent when interconnected to a public utility without storage. If storage is provided, the efficiencies would range from 28 to 40 percent because of the inefficiency (input/output) of the storage system.

Reliability - The lower power (under 100 kW) units with a long history of operation have proven very reliable. However, the earlier, large experimental WECS (multimegawatt units) developed design failures including structural failures and vibrational problems. Corrections of these design failures have been incorporated into later models.

Limitations -

- Geographical - High wind areas (in general, wind speed over 2 m/s) are the optimum locations for wind power systems with New England, Pacific mountain areas, and central plains states the most suitable regions for wind power applications. However, each site must be considered on a case-by-case basis.

- Productions/distribution - Current production and system costs do not reflect the large-scale manufacturing of these units. Most of the capital cost data currently available are for the experimental units. An increase in the demand for wind power systems and subsequent mass production would ultimately reduce the capital costs of these units.

- Environmental effects - Physical dimensions, such as blade diameter and tower height, may result in a significant negative (aesthetic) visual impact. Additionally, the placement of a large-scale WECS may interfere with television reception due to the motion of the rotor blade.

- Legal, social, and institutional barriers - Availability and acquisition of land and wind rights may limit the use of wind energy.

References - 6, 48 through 62.

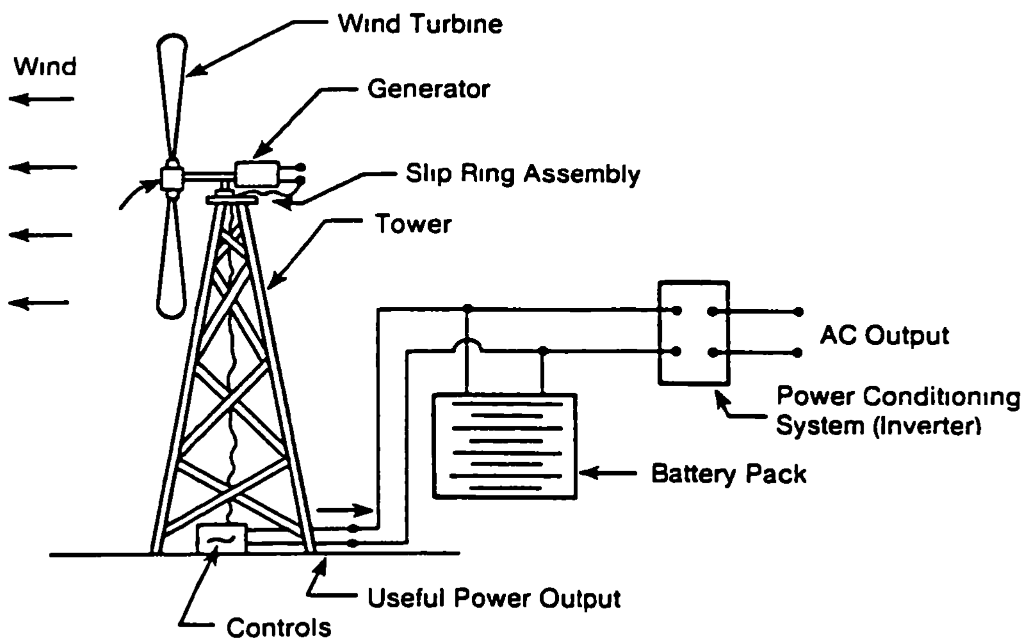


Figure 14. Small WECS with storage.(48)

DATA SHEET DS-5--WIND POWER SYSTEMS

Step 1. Load or Fraction of Load Requirements - Electrical loads can be estimated for the information presented in references 2 and 3.

Yearly load requirements __________ kWh/yr

Step 2. Wind Data (Wind Flux) -

Figure 15 can be used to estimate regional wind power availability. A detailed wind power survey is imperative in cases where wind power appears to be cost effective. Local wind power availability may significantly differ from regional data. Site features such as terrain, structures, etc., may significantly affect the amount of available wind power. Suitable site characteristics may be summarized as follows:

- o Minimum annual average wind speed greater than 2 m/sec.
- o No obstructions (buildings or trees) upwind or downwind for a distance depending on the diameter of the rotor (i.e., 5 diameters).

Step 3. Rotor Size and Area -

$$\text{Rotor area } (m^2) = \frac{\text{Load}}{\text{Efficiency x Wind flux}}$$ __________ m^2

Where:
- Load = Step 1, in kWh/jr.
- Wind flux = Step 2, in Kwh/m^2-yr.
- Efficiency = Usually 0.38-0.56, assuming no storage.

Step 4. Peak Power Output of Wind System (kW) -

P peak (kW) = Density air x rotor area x (rated velocity)^3 x K __________ kW

Where;
- P peak = Peak power output in kW.
- Density air = 1.2 kg/m^2.
- Rotor area = Step 3, in m^2
- Rate velocity = Typically 15 m/sec.
- K = Constant, 0.000153.

Step 5. Economic Considerations -

Total installed capital costs (Figure 16) $__________

Total installed capital costs are given as a function of peak power output in Figure 16. Step 4 provides the calculation for the peak power output of the wind power system.

Annual operating and maintenance costs
(usually 0.02-0.04 percent of installed capital costs) __________/yr

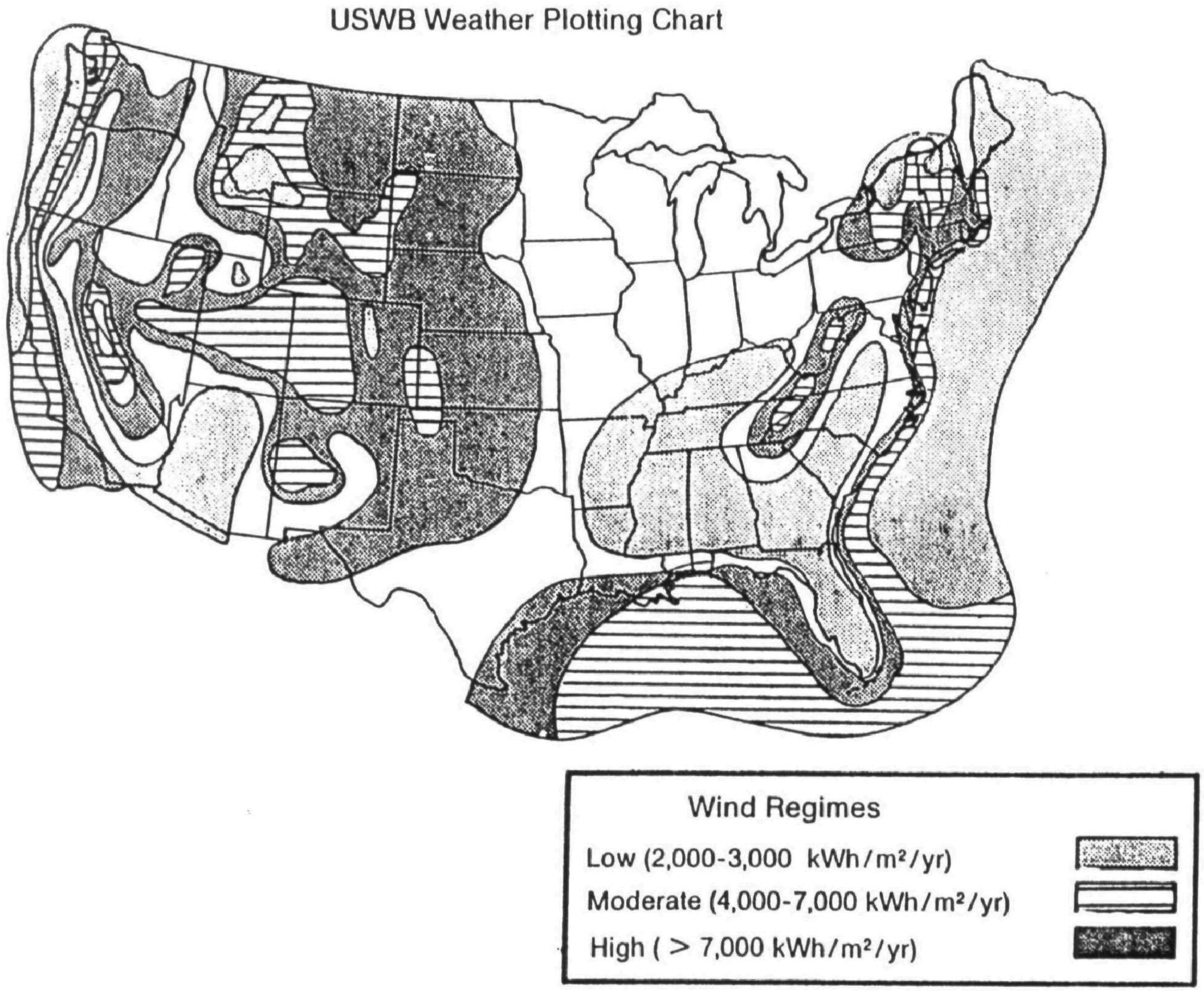


Figure 15. Distribution of favorable wind regimes over the contiguous 48 states and offshore areas. (48)

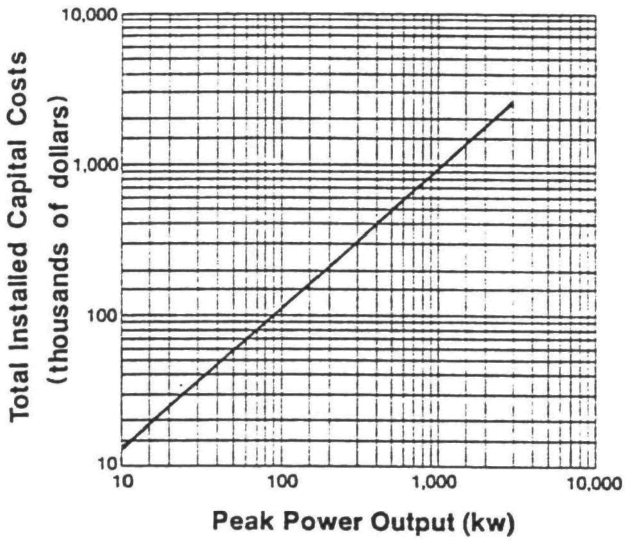


Figure 16. **Total installed capital cost of wind power systems as a function of peak power output.**

FACT SHEET FS-6
WITHIN PLANT LOW-HEAD HYDRO SYSTEMS

Description - Hydroelectric power is generated by converting kinetic energy and potential energy to electrical energy via a mechanical impeller coupled with an electrical generator. This system consists of an intake penstock which directs a water stream at a turbine runner that is directly coupled with a synchronous electric generator. (See Figure 17)

Technology Status - Low-head hydroelectric systems have been in use in the United States and Europe for over a hundred years. The technology is fully proven and demonstrated. Engineered and prepackaged systems are available through several commercial distributors. Significant technology improvements that would improve the efficiency or applicability of the technology are not expected in the foreseeable future. Low-head hydroelectric systems have been installed in POTW's.

Applications - Feasible points of application in a POTW are the influent or the outfall of a treatment plant. The point of application is dependent on the available head.

Technical Data -

Primary energy source	- Available head and flow rate of treatment plant wastewater.
Nature of output	- Seasonal and daily variation dependent on wastewater flow variations.
Comments	- Interface with conventional electrical power is required.

Design Considerations - Power requirements, siting requirements, available head, available flow, variability of watewater flow.

Performance - Low-head hydropower systems require relatively low maintenance and are easy to operate. The conversion efficiency between hydraulic energy and electrical energy is between 85 and 90 percent.

Reliability - Low-head hydro systems are considered extremely reliable. These systems generally require infrequent maintenance and essentially no operator attention. System output varies in direct proportion to wastewater forward flow. If influent flow powers the system, precautions should be taken to minimize clogging of the intake penstock and in-line turbine mechanisms. If effluent flow powers the system, the materials of construction must be of sufficient quality to prevent corrosion due to the chlorine residual in the effluent.

Limitations -

- Geographical - Available head should be approximately 3 m or greater to make the application feasible.

- Production/distribution -- None.
- Environmental impacts - None.
- Legal, social, and institutional barriers - None.

References - 63 through 72.

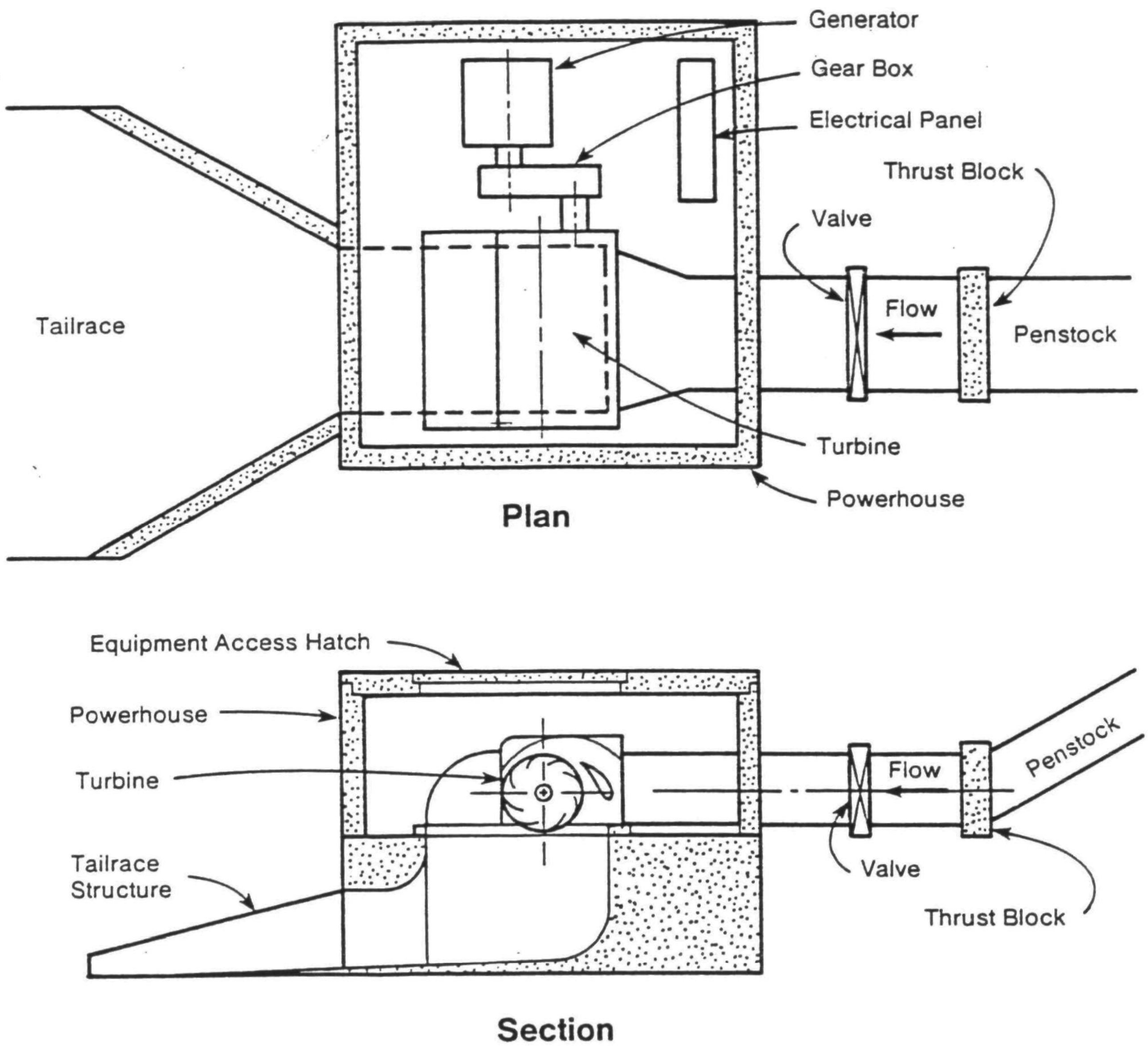


Figure 17. Low-head hydroelectric system.

DATA SHEETS DS-6
LOW-HEAD HYDROPOWER DESIGN DATA SHEET

Step 1. Load or Fraction of Load Requirements - An estimate of the electrical load can be obtained from references 2 and 3. __________ kW

Step 2. POTW Flow Data -

Design or projected average daily flow (Q) __________ m^3/d

Step 3. Available Head -

By accurate methods determine the available head (water elevation difference at site, usually plant effluent). Typically, this is accomplished through a qualified surveyor.

Available head (m) = (H) __________ m

Step 4. Installed Capacity of System -

System capacity (kW) = Q x H x 9.65 x 10^{-5} __________ kW

Where: System capacity = Power output in kW.
Q = Daily flow in m^3/d (Step 2).
H = Available head in m (Step 3).

Percent of load satisfied = $\frac{\text{System capacity}}{\text{Load requirements (Step 1)}}$ x 100 __________ %

Step 5. Economic Considerations -

Total installed capital costs
$/kW (from Figure 18) x kW (Step 4) $__________

Operating and maintenance costs (typically 0.02-0.04 percent of total installed capital cost) $__________/yr

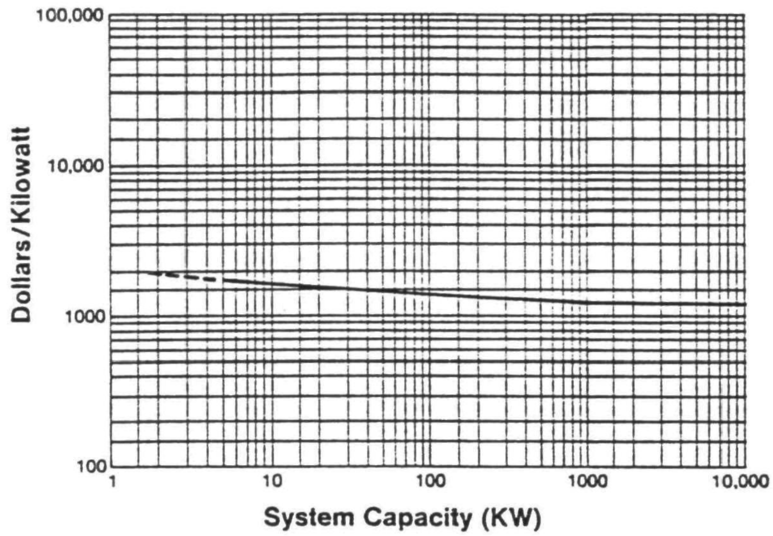


Figure 18. Total installed capital cost of low-head hydro power.

FACT SHEET FS-7 -- PASSIVE SOLAR SYSTEMS

Description - In a passive solar system, elements of the building are used to collect, store, and distribute energy. In general, passive systems are integral parts of a building's overall architectural design and construction. The solar system is classified as passive if all significant energy exchanges linking the system involve purely natural flow (conduction, convection, radiation, evaporation) rather than forced flow (fans, pumps, compressors). There are three general passive collection concepts:

- Incidental heat traps, e.g., windows, skylights, and glass structures.
- Thermosiphoning (convective loop).
- Thermal storage pond and roof concept.

(See Figures 19, 20, 21, 22, and 23.)

Technical Status - Architects commonly use passive heating and cooling in contemporary building designs. The design procedures are well documented in the literature. Current research regarding passive solar hardware involve attempts to increase system performance (e.g. transparent insulation, an "optical shutter," thermocrete, phase change insulation, and a thermic diode). Passive systems have been incorporated into recent POTW building designs.

Applications - Passive heating and cooling systems can be used to complement conventional heating and cooling systems. In general, as much as 70 percent of building heating can be met using passive solar systems. Additionally, natural (solar) lighting can complement the building's interior illumination systems.

Technical Data -

Primary source of energy	-	Sunlight.
Alternate fuel	-	None.
Nature of output	-	Seasonal and daily sunlight cycle, and cloud cover variation.
Comments	-	Auxiliary heating and cooling systems required

Design Considerations - Heating and cooling requirements, building layout, design and orientation, and material of construction.

Note: Due to the significant variations in possible passive solar applications, resulting from the variations in building architecture, no generalized data sheet has been prepared. For guidance on system design, see references 74 and 75.

Performance - For a properly insulated structure the efficiency of a passive solar system is generally independent of the geographical location. The primary factor affecting performance is the local weather conditions, e.g., cloud variations.

Reliability - A passive solar system is considered very reliabile. The system has no moving parts and is typically constructed of low maintenance materials.

Limitations -

- Geographical - None. Passive solar systems are applicable throughout the United States.
- Production/distribution - Traditional passive solar equipment is readily available; however, the new/innovative passive hardware is difficult to fabricate and is generally expensive.
- Environmental impacts - There are few environmental problems associated with passive systems other than limited concern for potential degradation of interior air quality (as measured by temperature, humidity, and air circulation) and increased hazard from glass breakage associated with large expanses of glass.
- Legal, social, and institutional barriers - The inability of the process to be easily adapted to existing structures; i.e., retrofitting is a major limitation. Sunrights and large-scale glare must also be considered.

References - 3, 7, 10, 12, 16, 17, 73 through 75.

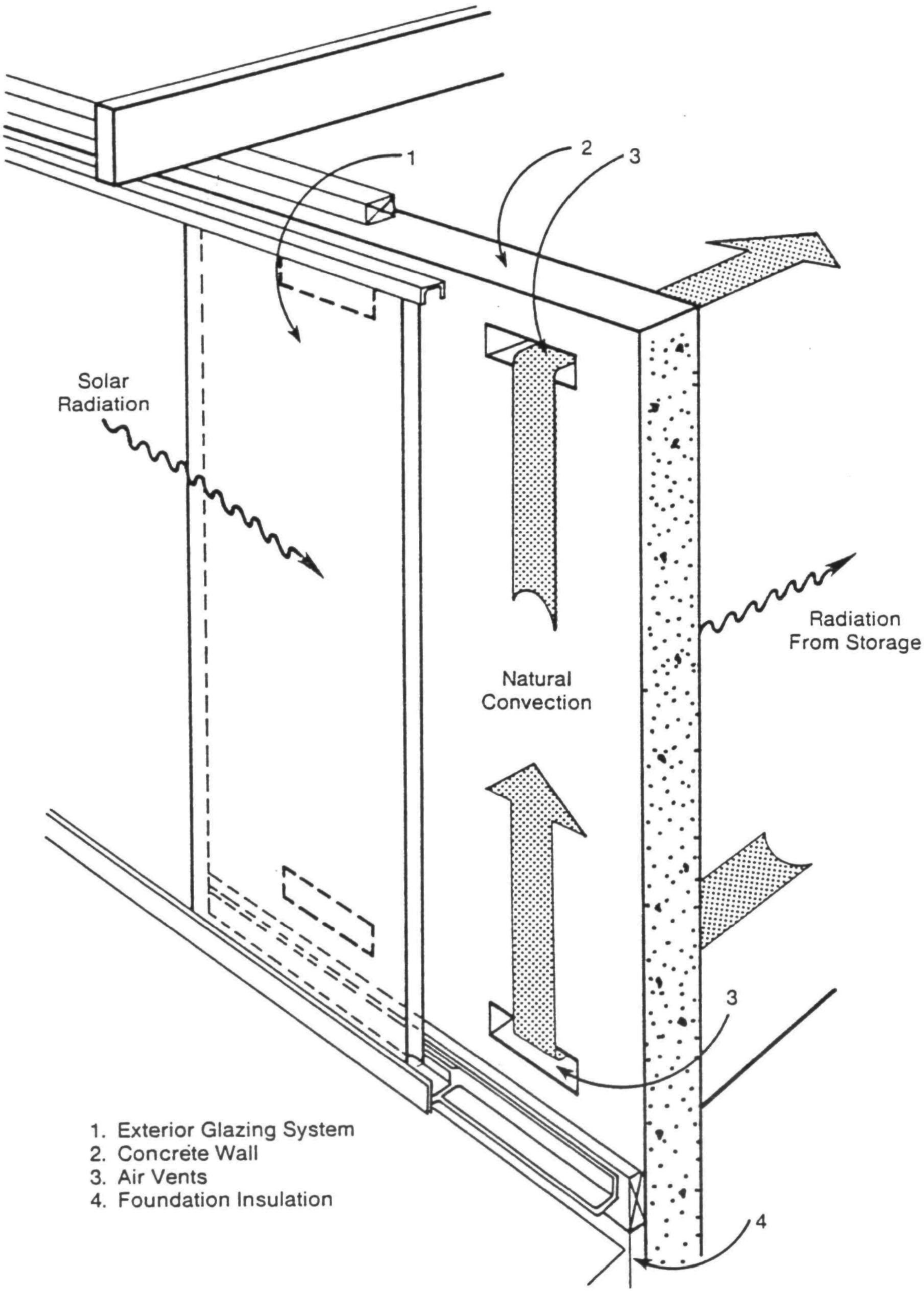


Figure 19. Typical Trombe wall design.(16)

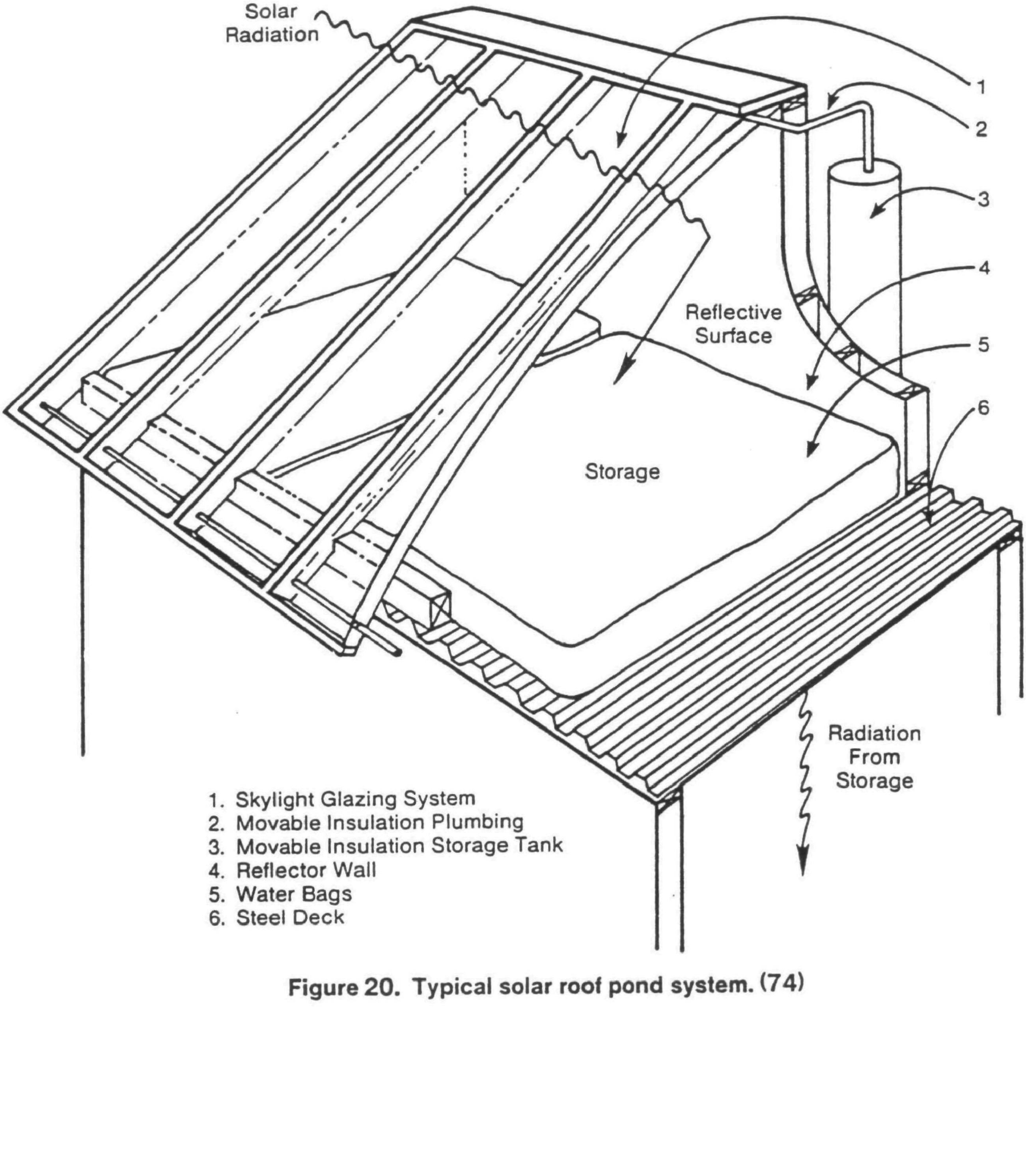


Figure 20. Typical solar roof pond system. (74)

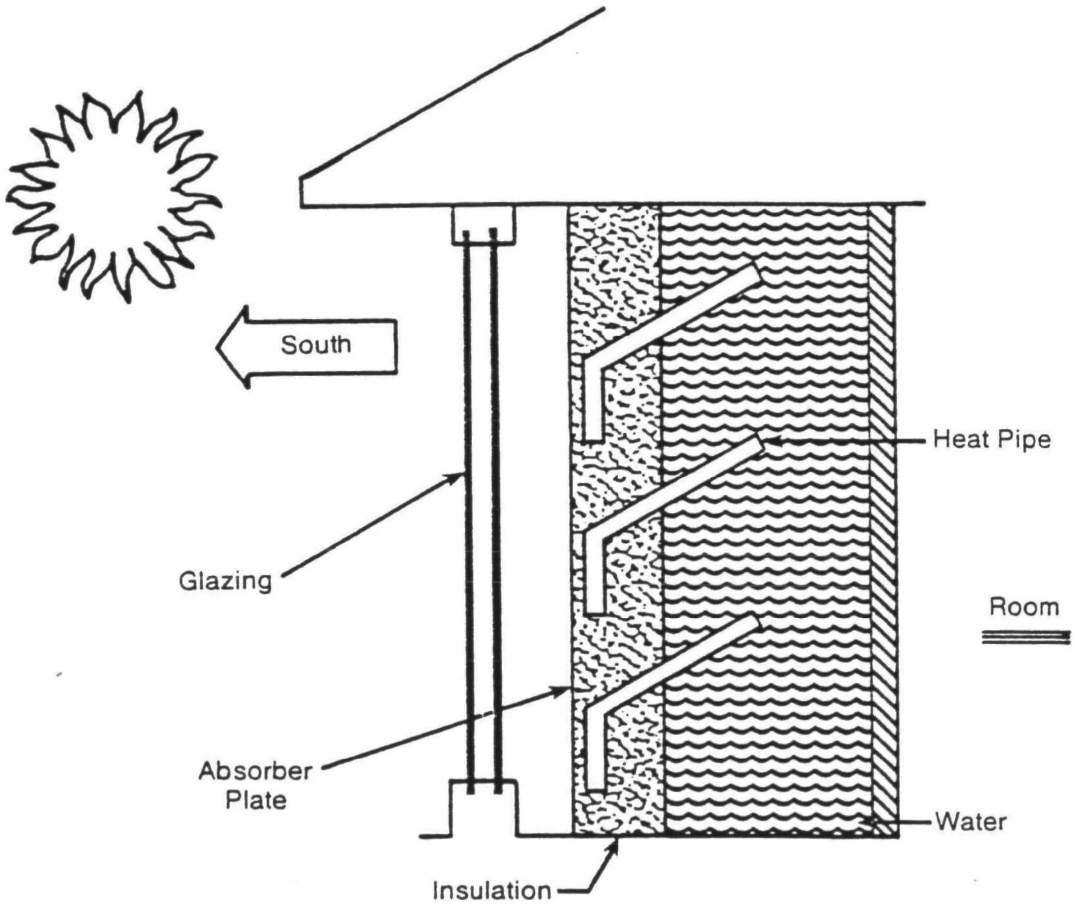


Figure 21. Heat pipe augmented water wall concept.(74)

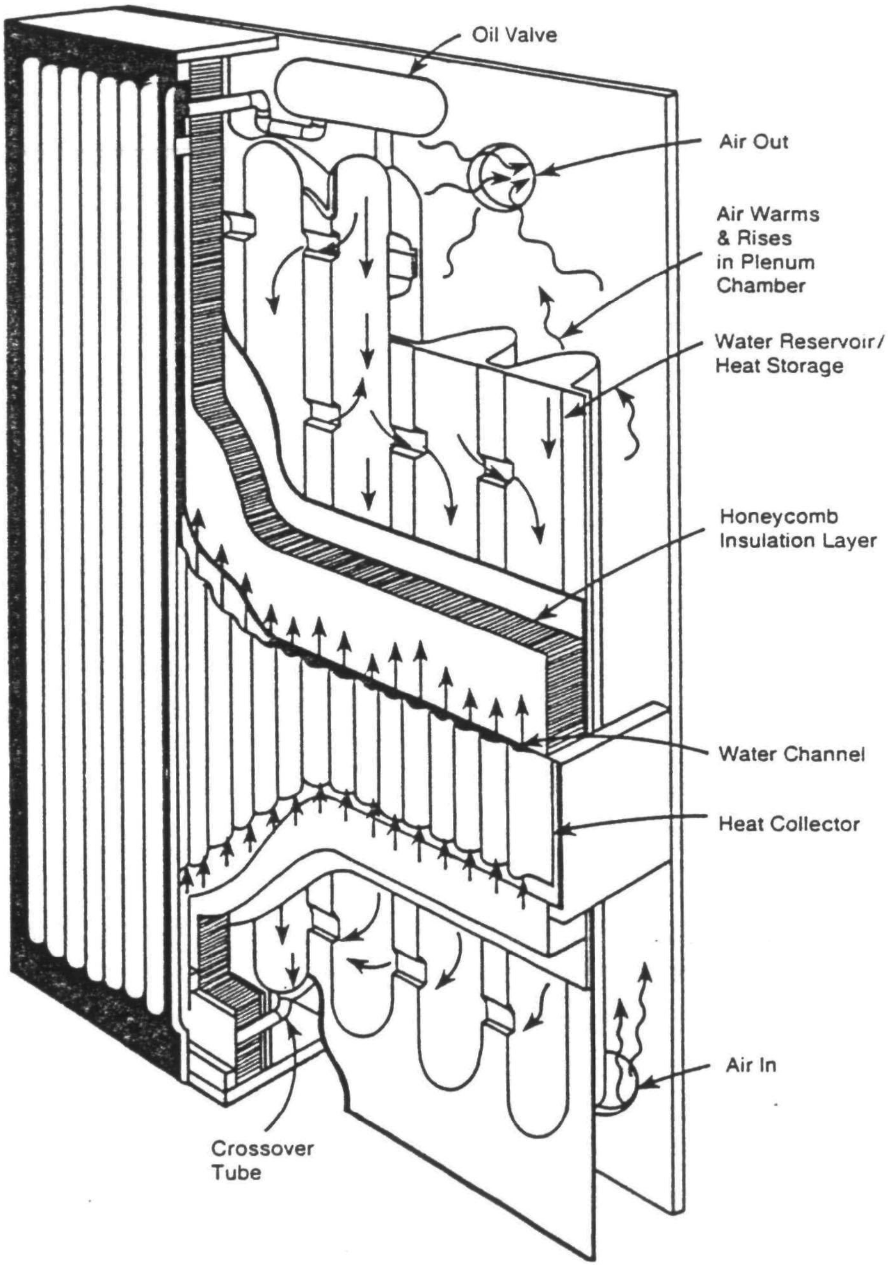


Figure 22. Thermic diode solar panel.(74)

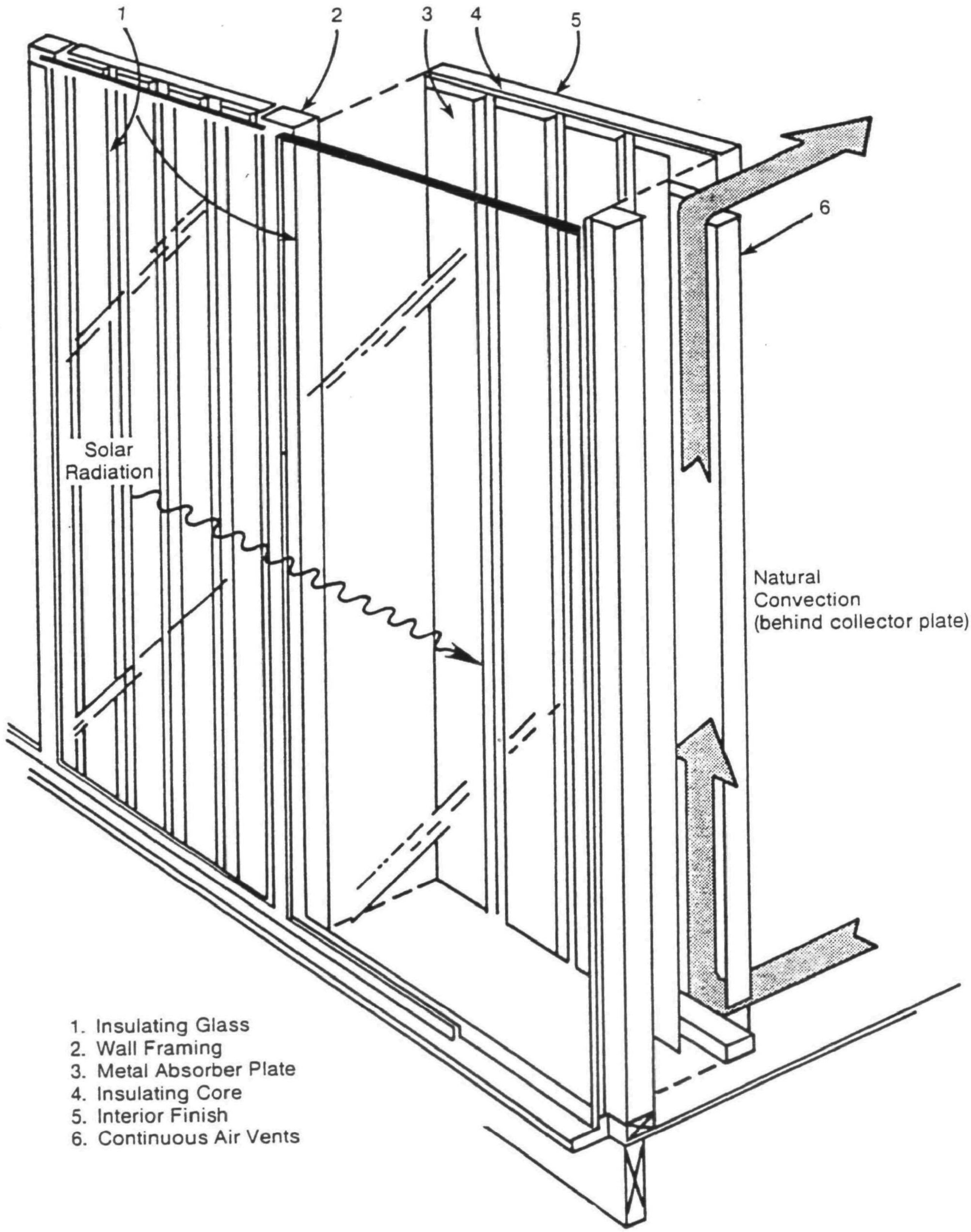


Figure 23. Typical thermosiphon air panel collector. (2)

FACT SHEET FS-8 -- GEOTHERMAL - POWER SYSTEMS

Description - Geothermal systems can provide heat for the generation of electricity. In geothermal power systems, very high temperature geothermal fluids are passed through a heat exchanger. A secondary working fluid is then heated in the heat exchanger and expanded through a Rankine cycle power turbine. This turbine then turns a synchronous generator thus creating electrical power. (See Figure 24).

Technical Status - Geothermal power systems have been used in Geysers, California since 1960.

Applications - Geothermal power systems produce electrical power and therefore could supply the entire energy requirements of a treatment plant.

Technical Data -

Primary source of energy	- Geothermal energy.
Alternate fuel	- None.
Nature of output	- Electrical energy.
	- Energy storage not required due to continuous supply of source.

Design Considerations - Power requirements, local geothermal temperature gradient, available local geothermal data, geothermal fluid quality and quantity data, and geothermal test well data.

Note: - Due to the limited applicability of these systems (see geographical limitations, below) no generalized data sheet has been prepared.

Performance - Geothermal sources have been known to produce constant and continuous output from 20 to 50 years.

Reliability - Geothermal power systems must be periodically shut down for heat exchanger maintenance. This maintenance consists of scale prevention and gasket replacement. Geothermal power systems are subject to the same maintenance schedules as conventional power systems.

Limitations -

- o Geographical - For successful application, the site must be located very near a suitable geothermal resource. This resource must be verified by both available data and actual well testing. The existence of suitable geothermal resources, i.e., thermal gradients greater than 60°C/km (see Figure 10), severely restricts the potential application of geothermal power systems in POTW's.

- Production/distribution - The smallest on-line geothermal electric plant in the United States is 10 MW, which suggests that geothermal power generation is applicable to treatment plants in excess of 378,500 m^3/d (100 mgd).

- Environmental impacts - A major concern is the proper disposal of spent geothermal fluids to avoid upsetting the local aquatic environment. Spent geothermal fluids are typically disposed of by reinjection.

- Legal, social, and institutional barriers - None.

References - 32-34, 36, 42, 44, 47, 76, and 77.

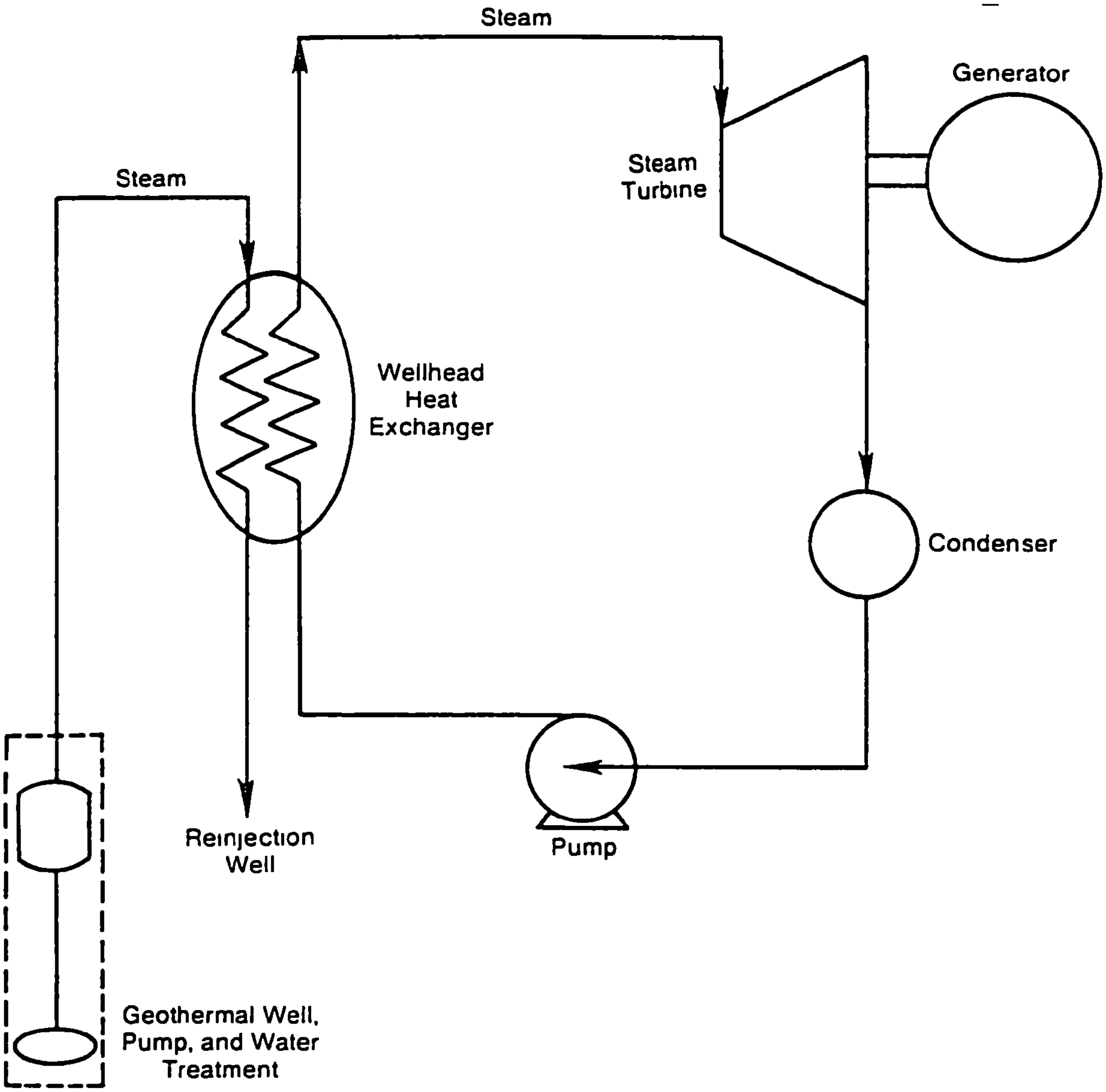


Figure 24. Typical geothermal steam power generating system. (45)

FACT SHEET FS-9 -- FUEL CELLS

Description - A fuel cell is an electrochemical device that converts the chemical energy of a fuel directly into dc electricity. The dc electricity is converted into ac electricity by means of a power conditioner. In addition to the fuel cell and power conditioner, a fuel processing or converting system (generation of hydrogen gas) is required. A waste heat recovery system is also used sometimes. Types of fuel cells currently in development include a phosphoric acid electrolyte, molten-carbonate electrolyte, and solid-oxide electrolyte. (See Figure 25).

Technical Status - Several small fuel cell power plants (12-40 kW) were demonstrated by 1975. Approximately 45 demonstration units of 40 kW are expected to be installed at various locations in the United States by 1982. In New York state a much larger unit, approximately 4500 kW, is expected to provide electricity by the mid-to-late 1980's. Although fuel cell technology has been demonstrated, it has not reached commercial readiness.

Applications - Theoretically, fuel cells are applicable to any size wastewater treatment plant. Due to their self-contained and modular nature, fuel cells may be installed anywhere in the United States. Additionally, fuel cells may be designed to supply the entire energy requirements of a treatment plant and can supply electricity proportional to the instantaneous load requirements.

Technical Data -

Primary source of energy	- Low sulfur oil or naphtha.
Alternate source of energy	- Most clean hydrocarbon sources that can be used to generate hydrogen, e.g., anaerobic digester gas (methane), propane, methanol, and hydrazine.
Nature of output	- Extremely constant ac electricity. Energy storage is not required due to the ability of the fuel cells to closely follow load power demands.

Design Considerations - Power requirements and available fuels.

Note - Due to the newly developing status of this technology, no generalized data sheet has been prepared.

Performance - Although relatively few performance data are available, fuel cells are expected to provide a continuous and constant energy output. The efficiency of the fuel cell is in excess of 90 percent; however, when the conversion of the primary fuel to hydrogen is included with the fuel cell efficiency, the overall energy conversion to electricity is only 30-40 percent. (A conventional fossil fuel power plant conversion efficiency is typically 33 percent.) It is anticipated that the overall system efficiency of 47 percent can be obtained by the late 1980's.

Reliability - As with any newly developed technology, fuel cells may be expected to be relatively unreliable, and require very specialized personnel for O&M during the first few years of commercial availability. However, the reliability of fuel cells is expected to increase thereafter once the mechanical and system deficiencies are worked out.

Limitations -

- Geographical - The application of fuel cells is technically feasible throughout the United States.

- Production/distribution - The fuel cells are not expected to be commercially available until approximately the year 2000. Additionally, the current life expectancy of the fuel cell is only 10,000 hours. The ongoing research and development programs are anticipated to significantly improve the life expectancy of the cell.

- Environmental effects - The primary fuel processor will have the same air pollution and solid waste problems of a conventional fossil fuel power plant.

- Legal, social, and institutional barriers - Public acceptance of any newly developing technology.

References - 6, 78 through 87.

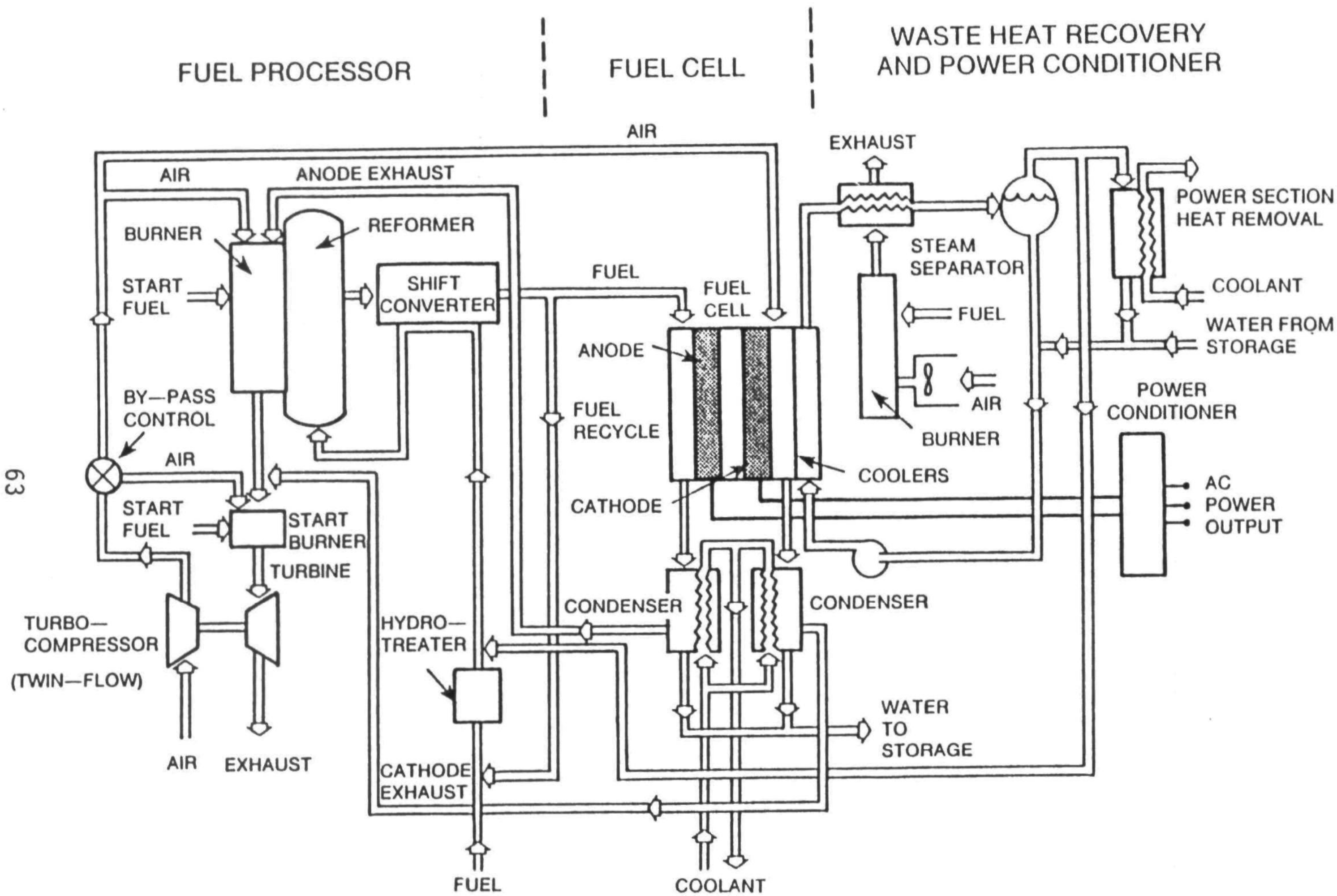


Figure 25. Schematic diagram of a fuel cell system (82)

FACT SHEET FS-10
ACTIVE SOLAR SYSTEMS FOR POWER GENERATION

Description - Heat from the solar collector is used to operate a heat engine whose output can be utilized for electrical power generation. Systems can be classified as to their levels of solar energy concentration/intensity (low, medium, high) and configuration (centralized or decentralized). Storage is provided as heat (molten salts, or heated oil, water, or rocks) or electricity (batteries). See Figures 26-29)

Technical Status - These systems are not expected to be available commercially until the mid-1990's. Only industrial process heat (steam) systems are available commercially today. Several demonstration and prototype systems are in operation, but none have been applied to POTW's.

Applications - Theoretically, solar thermal power systems can supply both electricity and process heat to a POTW.

Technical Data -	Primary source of energy	- Sunlight
	Alternate fuel	- None.
	Nature of output	- Output varies with seasonal and daily flucuations in solar insolation and local weather conditions.
	Comments	Sufficient storage would buffer the system from short heat interruptions and/or permit system operation when solar energy is not available. An auxiliary power system is required, i.e., thermal storage system, central utility, or standby generator. Additionally, most systems can utilize only direct sunlight.

Design Considerations - Power requirements, siting requirements, storage requirements, type of system (centralized or decentralized), level of solar insolation, and system efficiency.

Note: Due to the newly developing status of this technology, no generalized data sheet has been prepared.

Performance - The performance of a solar thermal system is primarily dependent on geographical location, local weather conditions, and storage capacity. System efficiencies are a function of solar energy concentrator intensity and heat engine operating temperatures. Typical efficiencies are as follows:

Low-level solar concentrator (flat plate/vacuum tubes)	5-7 percent
Medium-level solar concentrator (parabolic trough)	10-13 percent
High-level solar concentrator (point focus systems)	17-22 percent

Reliability - Solar thermal power systems are still in the developmental stage and may be somewhat unreliable and require very specialized personnel for O & M during these early years of process development. However, the system reliability is anticipated to increase once the mechanical and system deficiencies are corrected.

Limitations -

- Geographical - Solar thermal power systems are limited to areas with suitable insolation characteristics, with the southwest region of the United States the area most suitable for application of solar thermal power units.

- Production/distribution - Large-scale systems are not expected to be commercially available and economically attractive until the mid-1990's.

- Environmental effects - Environmental impacts associated with the thermal engine and storage system are primarily safety related (working fluid leaks, noise, etc.). Environmental effects are also attributable to heat rejection equipment (cooling tower plume). Misdirected solar radiation is of great concern causing possible eye injury, fires, and potential disruption of nearby air and ground traffic (glare).

- Legal, social, and institutional barriers - Aspects of concern include insolation rights, land availability and acquisition, and installation expertise.

References - 6, 88 through 100.

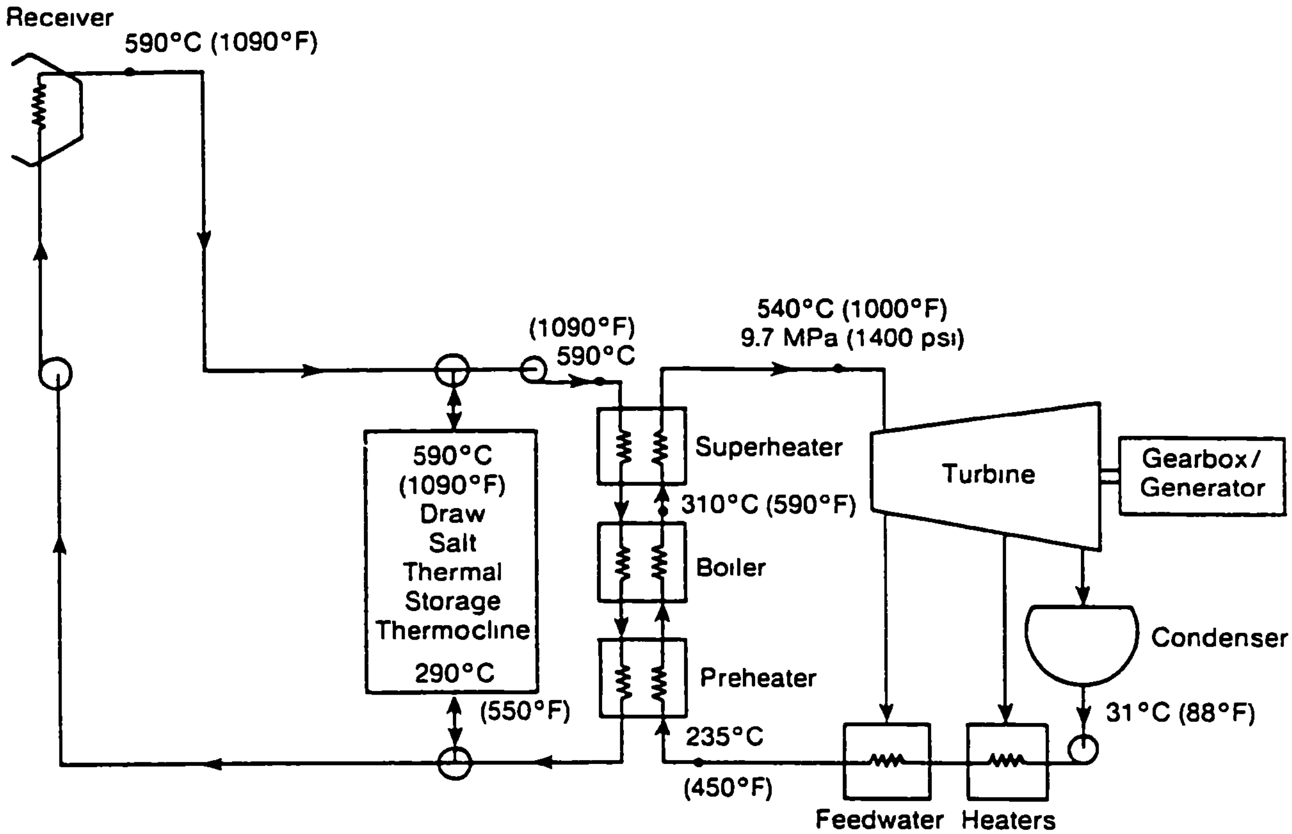


Figure 26. Point-focus central receiver/Rankine (PFCR/R) system flow schematic drawing. (88)

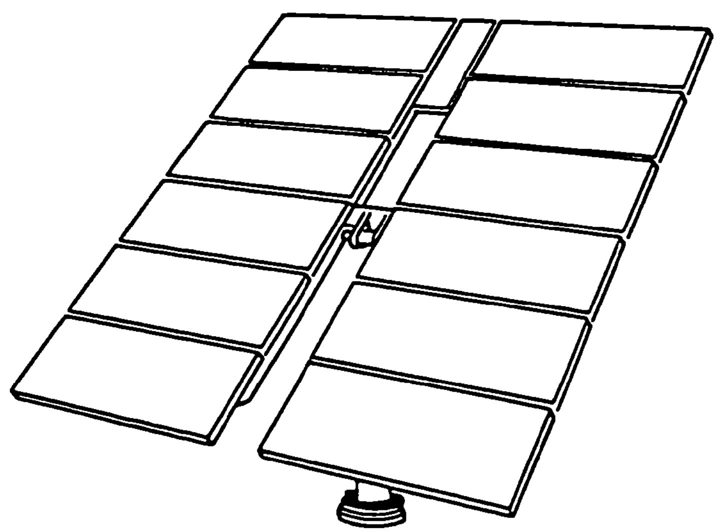


Figure 27. Two-axis tracking heliostat (PFCR). (88)

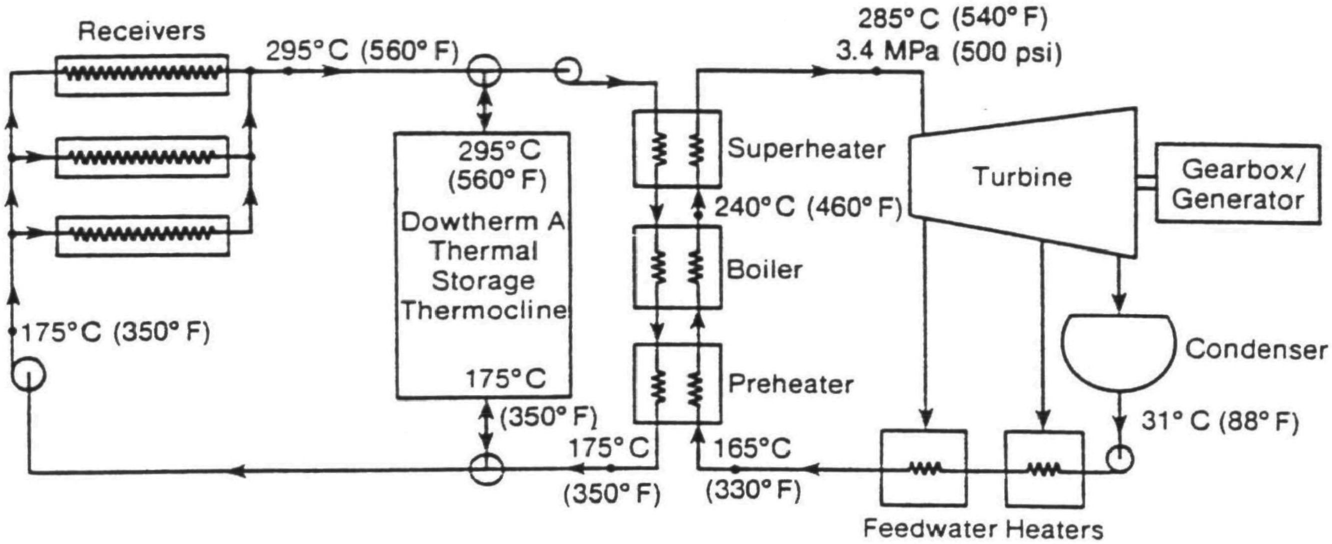


Figure 28. Low concentration nontracking (LCNT)system flow schematic drawing.(88)

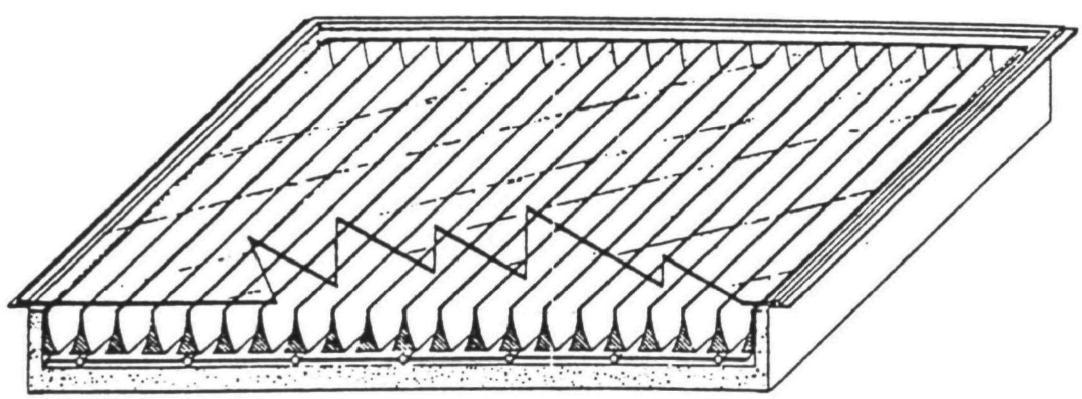


Figure 29. Low concentration nontracking (LCNT) collector module.(88)

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SECTION 5

CASE HISTORIES

GENERAL

Section 5 presents case histories of alternative energy technologies at POTW's across the United States. The case histories presented in this section include examples of the following technologies:

1. Low-head hydroelectric generation (Bonney Lake, Washington).

2. Active solar system for process heating (Newport, Vermont and Wilton, Maine).

3. Passive solar system (Hillsborough, New Hampshire and Wilton, Maine).

4. Wind power (Livingston, Montana and Southtown, New York.

5. Heat pumps (Wilton, Maine).

6. Photovoltaic system (Waynesburg-Magnolia, Ohio).

The preliminary information included in Section 5 was gathered from EPA's Innovative/Alternative Technology Staff at WERL in Cincinnati, Ohio, and from the literature. The status of each case history project was verified by the regional and/or state innovative/alternative coordinator. Additional technical information (e.g., design criteria, performance, etc.) was provided by the consulting engineer, as required.

All of the case histories included here were at least in the design phase at the time the report was written (1982). At the time of writing, only one POTW (Wilton, Maine) had been on-line long enough for meaningful operating data to have been collected. (Wilton has been operational since September 1978).

WILTON, MAINE -- ACTIVE SOLAR FOR PROCESS HEAT, PASSIVE SOLAR, HEAT PUMPS

Background

The Wilton, Maine wastewater treatment system was designed by Wright-Pierce Architects and Engineers, Topsham, Maine. Although the Wilton plant was constructed before the innovative/alternative program, EPA grant funds were used for construction. A full report describing the Wilton facility is available (1).

The 1,700 m^3/d (0.45 mgd) wastewater treatment system at Wilton was one of the first POTW's in the country to use alternative energy technology. The energy sources are interdependent and include the following:

1. Active solar system for anaerobic digester heating.
2. Digester gas (methane) utilization in a gas boiler for heating and electricity generation.
3. Effluent heat recovery by heat pumps.
4. Passive solar system for building heat.
5. Exhaust air and cooling jacket heat recovery by air-to-air heat recovery (energy wheels).

Wastewater is lifted into the plant by screw pumps that automatically provide variable flow, thus preventing overloading the treatment processes. The wastewater flow is by gravity throughout the rest of the plant. Pretreatment is provided by comminution and grit removal. Gross solids are removed by rotary screens.

Secondary biological treatment is accomplished via the rotating biological contactor (RBC) process, followed by secondary clarifiers. Solids from the secondary clarifiers are combined with the primary screenings and pumped to anaerobic digesters for stabilization before being dewatered and disposed. Effluent is disinfected with sodium hypochlorite (which is generated onsite electrochemically from salt and water) prior to discharge to the receiving stream.

Due to Wilton's cold climate, the entire plant is enclosed in two structures. To save energy, unit processes have been brought close together, while still leaving room for future expansion. The building is well insulated and zoned to enable different rooms to be heated to different temperatures. It is constructed of concrete block and brick with insulation in-between to provide a large mass that holds the heat at night. The roof is also designed to hold snow to provide good natural insulation. The surrounding juniper groundcover will also hold the snow for insulation. The building is built into a hillside, with little exposure to the north, to minimize the exterior surface. This results in lower demands for heating, lighting, and system loads.

The treatment process and energy systems are coupled to produce more alternative sources of energy. The maximum amount of excess heat energy, including excess heat from exhausted air, generator coolant, and effluent water, is recovered within the building for reuse. The recovery of 60 percent of the heat from exhaust air in the ventilation system is used to preheat cold air drawn into the plant. The effluent from the plant normally is discharged at 7.2°C to 10°C (45°F to 50°F), even in winter, which represents a potential usable source of heat. By using an electric heat pump, the Wilton plant recovers much of this wasted heat, producing three units of heat energy for every equivalent unit of electrical energy used. Not only does this help heat the building, but the resultant lowering of the effluent temperature prevents thermal shock on the stream.

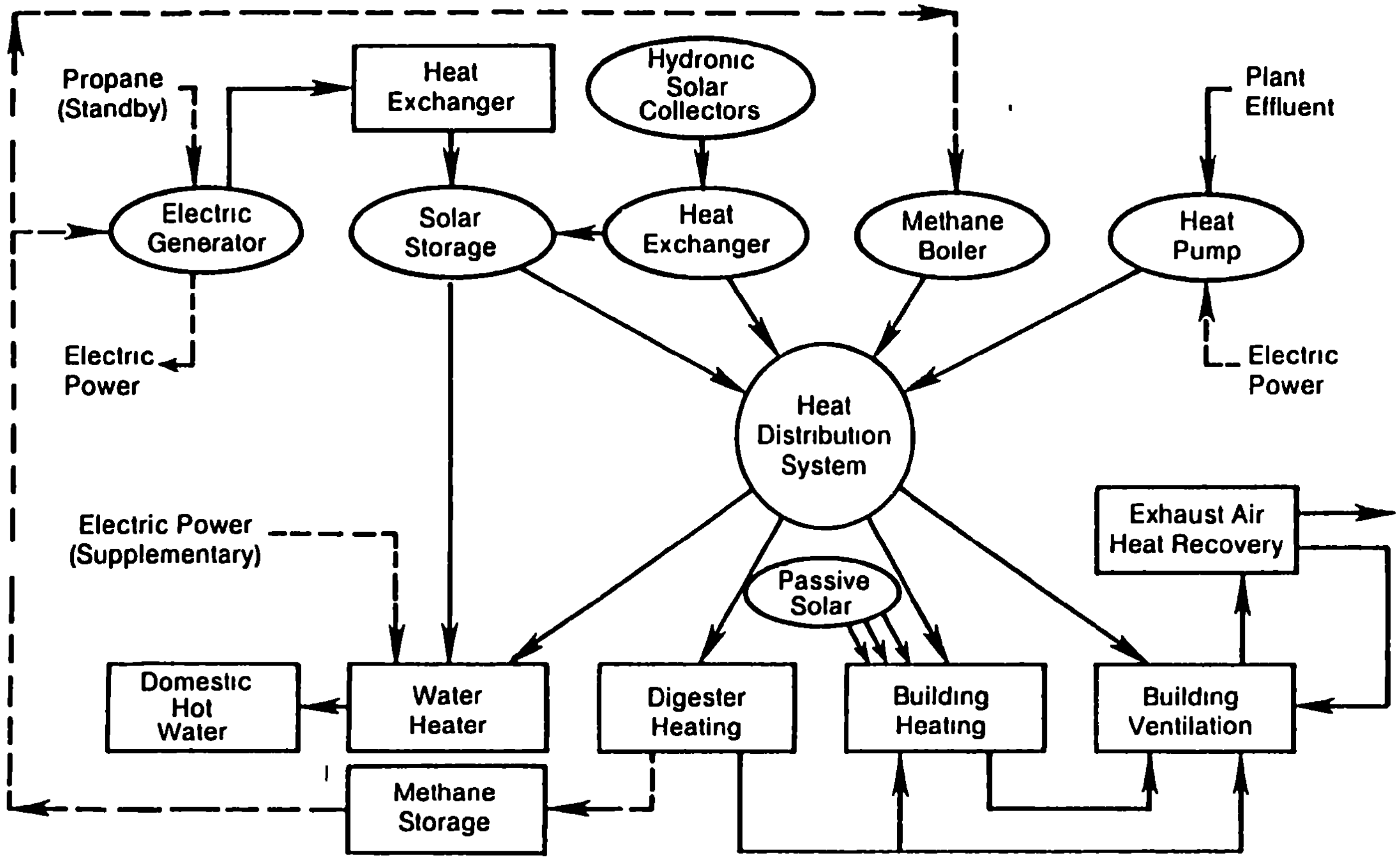
The conceptual energy flow diagram (Figure 30) shows the interaction of the various energy sources and the heating requirements of the treatment plant. It is this interdependency of energy sources and the sophisticated control of them which make the energy system unique. The design is an integrated energy source and utilization system. The sources of energy can work individually, or in combination, in conjunction with the three basic heat utilization systems. The general philosophy is that the plant will use solar energy as the primary source, gas produced in the digesters as the secondary source, and the heat recovered from the process effluent by the heat pump as the back-up and final supplementary energy source. The generator will heat the plant as a primary source only in the event of a power failure, but it will provide power for general building use when excess methane is available.

The digester/methane subsystem is not especially unique in its function and design; however, the integration with the total system and its role in the energy-conserving nature of the facility is unusual. The gas released becomes an important part of the total operation since it is used for the boiler in normal operation, and for the emergency electrical generator when excess gas is available.

Treatment Plant Design Criteria

The design criteria for the wastewater treatment plant, including the energy system, are as follows:

Quantity of sewage	1,700 m^3/d
Influent BOD_5	200 mg/L
Influent suspended solids	200 mg/L
Effluent BOD_5	20 mg/L -- 90 percent removal
Effluent suspended solids	20 mg/L -- 90 percent removal
Sludge quantity to digesters	9.46 m^3/d at 3.5 percent solids
Methane yield	110 to 125 m^3/d
Methane heat value	2.235×10^4 kJ/m^3 or 2.4×10^6 to 2.7×10^6 kJ/d



Source Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project

Figure 30. Conceptual energy flow diagram for Wilton,Maine

Active Solar System for Process Heating

The most significant innovation that reduces the requirements for offsite energy is the application of solar energy, which has been used for the first time in a sophisticated manner as an integral part of the wastewater treatment process. The enclosing structures are oriented southward to achieve the maximum value from the sun's direct energy through both passive and hydronic solar energy collection devices. Passive solar collection is achieved through the use of fiberglass pannels that let solar heat into the process rooms of the plant to heat the air directly without letting the heat out. Black metal solar collector panels, set at a 60° slope, form the south roof of the treatment plant. An anti-freeze solution is pumped through these panels and heated to between 48.9°C and 60°C (120°F to 140°F) by the sun.

Although this solar energy is used to heat the building and the hot water supply, its primary purpose is to provide heat for the anaerobic digesters. Using solar energy to heat the digesters frees the digester gas for heating the building, running the electric generator, and long-term storage. This overcomes one of the main problems of solar energy, that of storage. Digester gas is a much more economical material to store than heated water, and it is also much more flexibile to use.

System Description --

The active solar energy system is a hydronic type with flat-plate collectors, an ethylene glycol/water collection loop, a heat exchanger, and storage systems. The active solar collectors provide 232 to 274 x 10^6 kJ (220 to 260 MBtu)/yr, while the passive collectors will add another 106 to 137 x 10^6 kJ (100 to 130 MBtu)/yr. Ethylene glycol is circulated through collector plates which are heated from the sun's rays, and this energy is then exchanged to the plant's circulating water system.

The active solar array consists of 54 double-glazed panels with an effective collection area of 119.5 m^2 (1,286 ft^2) facing 2° west of south at an angle of 60° from the horizontal. The plant site is located at 45° north latitude. The specifications and installation details are described in Table 5.

TABLE 5 ACTIVE SOLAR SPECIFICATION DATA AND DESIGN CRITERIA FOR WILTON, MAINE

Item	Specification
Number of collector panels	54
Gross area	139 m^2
Aperature	119 m^2
Glazing thickness	0.476 cm (double glazed)
Transmissivity	90.5 percent/sheet
Insulation	Fiberglass R-22
Water/glycol solution	50/50
Solution temperature	48.9°C to 60°C

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

The monthly average ambient temperatures are as follows:

	°C		°C
January	-4.4	July	21.7
February	-3.9	August	21.1
March	1.7	September	16.7
April	7.2	October	12.2
May	13.3	November	5.0
June	18.3	December	-2.2

The average wind speed is 2.2 m/s.

The heating energy supplied by the active solar system was estimated by the manufacturer. Since the heating provided by the active solar system is useful only when such heating is required, the net estimated active solar contribution is shown in Table 6.

Energy System Performance Data --

The designers of the Wilton plant monitored the energy system at Wilton from June 1979 to March 1980. The actual operating results were then compared with the estimated or "design" conditions. The energy production (estimated and actual) is shown on Figure 31. The only months during which the actual total collected energy equalled or exceeded the estimated total were September and December.

Estimated/Actual Energy Production --

The overall active solar system efficiency (i.e,, the net energy collected divided by the total incident available) was 23 percent. An overall efficiency of 23 percent was signifgicantly lower than anticipated. A great deal of effort was spent in investigating the reasons, which were presumed to be one or more of the following:

1. Data/instrumentation error

2. Collector heat loss factor

   a. Inadequate thermal insulation.

   b. Possible convective losses between the absorber plate and the rigid insulation.

3. Collector heat transfer losses

   a. Air within the fluid loop.

   b. Effect of the glycol solution.

4. Control sequencing and response.

5. Collector efficiency losses due to dirt accumulated during construction.

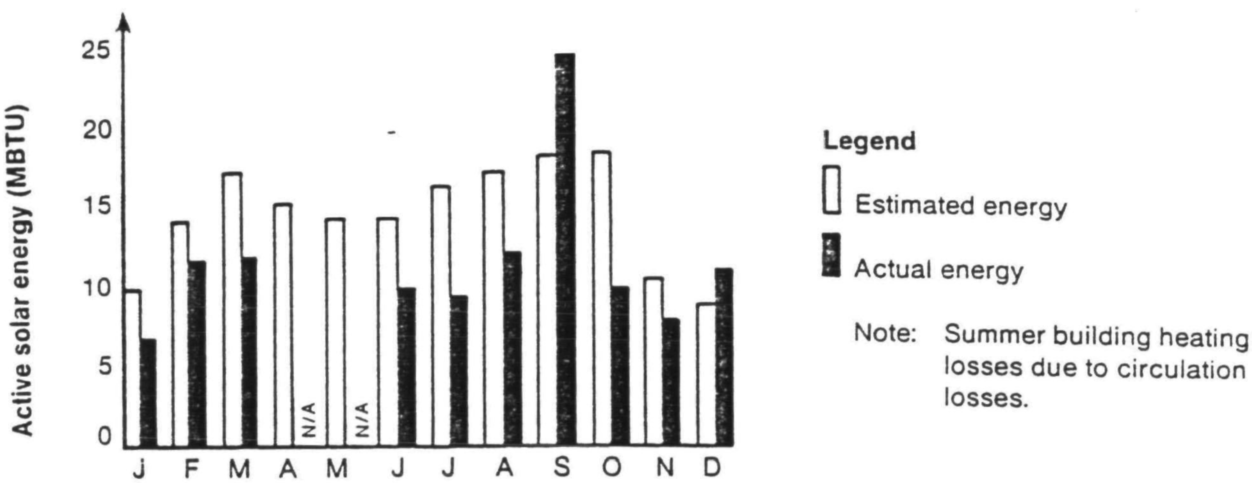
While all of these factors (excluding the first) contributed to the solar system's performance, the cause appeared to be the combination of all of them, coupled with actual weather conditions and the lack of an accurate calculation procedure to simulate this interaction.

There is obviously a significant difference between instantaneous collector efficiency and day-long, or more importantly, year-long collector efficiency. Instantaneous efficiencies are useful in comparing various types of collectors under similar steady-state conditions, but tend to create a misleading picture of the efficiency of water-heating systems operating over long periods.

TABLE 6 NET ACTIVE SOLAR CONTRIBUTION FOR WILTON, MAINE

Month	Total heating requirement remaining after passive solar contribution kJ x 10^6	Available active solar energy kJ x 10^6	Net active solar contribution kJ x 10^6
January	103.09	10.23	10.23
February	90.04	14.60	14.60
March	71.25	17.73	17.73
April	48.49	15.64	15.64
May	28.97	15.14	15.14
June	20.66	14.90	14.90
July	17.63	17.12	17.12
August	17.86	19.50	17.86
September	18.82	19.97	18.82
October	35.50	19.25	19.25
November	55.84	10.98	10.98
December	73.76	8.18	8.18

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.



Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

Figure 31. Estimated/actual energy production for Wilton, Maine -- active solar.

The energy and cost-effectiveness of the active solar system are summarized in Table 7, which shows that the active solar subsystem was a net energy producer and net cost saver. However, due to the long payback period, the system is not cost-effective.

Passive Solar System

System Description and Design Criteria --

Passive solar energy is used to heat the clarifier room at the Wilton plant. The passive solar array consists of 83.2 m^2(896 ft^2) of panels with an effective collection area of 75.4 m^2(812 ft^2) facing 2^o west of south at an angle of 60^o from the horizontal. The transmissivity is listed as 66 percent in the manufacturer's literature.

The heating energy supplied by the passive solar system is estimated by using the following factors:

1. Estimated incident solar insolation.
2. Cloud cover factor.
3. A transmissivity of 66 percent.
4. An overhead shading factor.

The net estimated contribution of the passive system is shown in Table 8.

Energy System Performance Data --

Energy production (estimated and actual) is shown on Figure 32. The only month during which the actual total collected energy equalled or exceeded the estimated total was October. The passive solar system produced 55.6 x 10^6 kJ(52.7 MBtu) during the study period. The average annual transmissivity was 32 percent. The overhang is responsible for a decrease in transmissivity during the summer up to a daily average of 14 percent.

The energy and cost-effectiveness of the passive solar system are summarized in Table 9.

Heat Pumps

Component Description and Design Criteria --

The water-to-water heat pump is used as a source of hot water heating when digester gas is not available and solar production is inadequate. The heat pump recovers heat from the plant effluent prior to discharge from the facility. The temperature sensors located at various points in the process lines indicate that the temperature of the wastewater increases as it proceeds through the plant. By recovering the energy from the effluent, the effluent temperature is lowered. The heat pump has been the major source of heating during the winter, since gas has been unavailable and solar energy has been inadequate. The heat pump provided 60 percent of the total heating requirement from June 1979 to March 1980. The specifications for the heat pump are listed in Table 10.

TABLE 7 ENERGY AND COST-EFFECTIVENESS SUMMARY -- ACTIVE SOLAR FOR PROCESS HEAT FOR WILTON, MAINE

Item	Value
Output, kJ x 10^6 -- $	153.7 -- $921
Input, kJ x 10^6 -- $	13.4 -- $168
Net gain, kJ x 10^6 -- $	140.3 -- $753
Initial investment -- $	$41,025
Energy output/input ratio[a]	$\frac{153.7}{13.4} = 11.5$
Value output/input ratio[b]	$\frac{\$921}{\$168} = 5.5$
Simple payback (yrs)[c]	$\frac{\$41,025}{\$753} = 54$

[a]Energy ratio -- Total energy produced divided by energy input required.

[b]Value ratio -- Dollar value of the energy produced divided by the input energy cost.

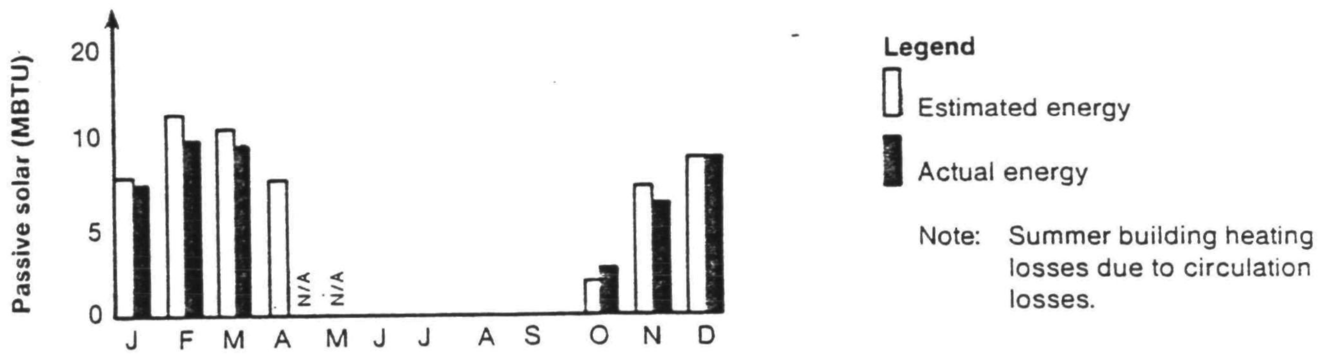
[c]Simple payback -- Installed cost divided by the net savings. No inflation factor for replaced fuels was applied.

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

Table 8 NET ESTIMATED PASSIVE SOLAR CONTRIBUTION FOR WILTON, MAINE

Month	Design heat loss monthly kJ x 10^6	Passive solar collected kJ x 10^6	Net passive solar contribution kJ x 10^6
January	19.7	12.4	12.4
February	18.0	15.6	15.6
March	13.9	18.6	13.9
April	7.0	16.5	7.0
May	0	15.5	0
June	0	15.2	0
July	0	16.2	0
August	0	18.0	0
September	0	18.5	0
October	2.2	18.1	2.2
November	8.4	11.7	8.4
December	13.3	10.0	10.0

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.



Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

Figure 32. Estimated/actual energy production Wilton, Maine -- passive solar.

TABLE 9 ENERGY AND COST-EFFECTIVENESS SUMMARY -- PASSIVE SOLAR SYSTEM FOR WILTON, MAINE

Item	Value
Output, kJ x 10^6 -- $	40.7 --- $243
Input, kJ x 10^6 -- $	0 --- $ 0
Net gain, kJ x 10^6 -- $	40.7 --- $243
Initial investment	$7,200
Energy output/input ratio[a]	N/A
Value output/input ratio[b]	N/A
Simple payback (yrs)[c]	$\frac{\$7,200}{\$243} = 30$

[a]Energy ratio -- Total energy produced divided by energy input required.

[b]Value ratio -- Dollar value of the energy produced divided by the input energy cost.

[c]Simple payback -- Installed cost divided by the net savings. No inflation factor for replaced fuels was applied.

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

TABLE 10 HEAT PUMP SPECIFICATION DATA FOR WILTON, MAINE

1. Total heat output -- 337,600 kJ/hr.
2. Condenser side --
   a. 151 lpm heating system water.
   b. Leaving water temperature -- 54.4°C.
   c. Entering water temperature -- 45.6°C.
   d. Water pressure drop -- 0.39 atm.
   e. Refrigerant staturated discharge temperature -- 60°C.
   f. Electricity input at full load -- 28.4 kW.
   g. Coefficient of performance(COP) = heat output ÷ 3.3.
3. Evaporator side --
   a. Fluid -- Sewage effluent with 10 ppm chlorine residual and minimal suspended solids.
   b. Fluid flow -- 227 lpm.
   c. Entering water temperature -- 10°C.
   d. Leaving water temperature -- As required.
   e. Maximum water pressure drop -- 0.34 atm.
4. Refrigerant -- R-22.
5. Saturated suction temperature -- 2.2°C.
6. Acceptable variation in performance from specified conditions --
   a. Total heat output -- 337,600 kJ/hr minimum.
   b. Condenser water flow -- None.
   c. Leaving condenser water temperature -- None.
   d. Coefficient of performance -- 3.1 minimum.
   e. Evaporator water flow -- 303 lpm maximum.
   f. Leaving evaporator water temperature -- 5.6°C minimum.
   g. Refrigerant -- Others will be acceptable providing they meet performance requirements.

Source: Wright-Pierce Architects and Engineers, engineers to the Wilton, Maine project.

Energy System Performance Data --

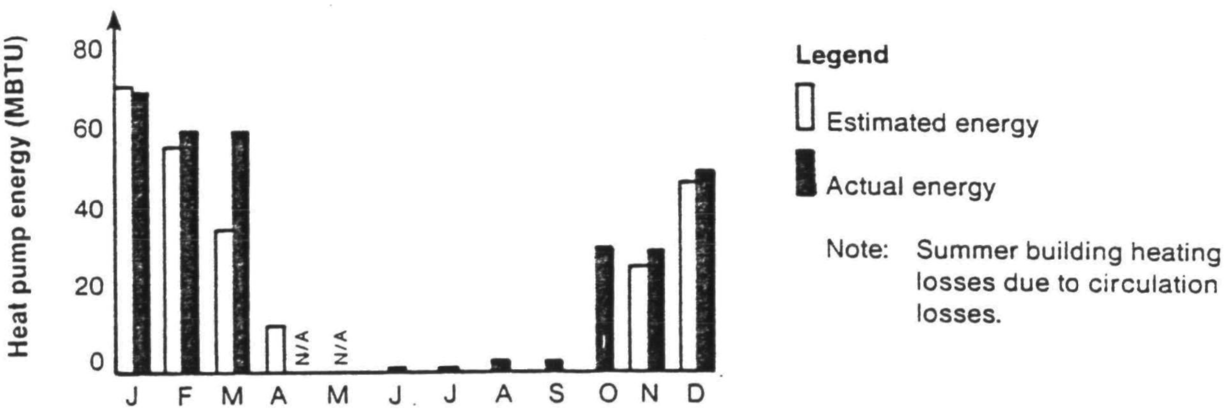
The energy production (estimated and actual) for the heat pumps is shown on Figure 33.

Table 11 summarizes the monthly heat pump energy production and coefficient of performance. The coefficient of performance (COP) of the heat pump varies with the temperature of the effluent, rising with a rise in effluent temperature and dropping as the effluent temperature falls.

The heat pump operating time was greater than anticipated from June 1979 to March 1980. The coefficient of performance was quite acceptable during the heating season. The generation of heating energy had a net cost savings, and the payback period, 18.7 years, as shown in Table 12, was reasonable. Had the heat pump operating time equaled the projected operating time, the payback period would have been closer to 25 years.

O&M Requirements --

To date, the O&M problems encountered have been relatively small. A significant amount of time, however, has been spent in cleaning the effluent strainers. Records should be kept for several years to determine realistic O&M costs for the system.



Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

Figure 33. Estimated/actual energy production for Wilton, Maine -- heat pump.

TABLE 11 HEAT PUMP SUMMARY FOR WILTON, MAINE

Month	Effluent temperature °C	Energy input (kWh) Compressor	Pump	Energy output kJ x 10^6	COP
January	7.8	6,807	204	68.80	2.73
February	6.8	6,717	202	64.15	2.58
March	6.1	6,388	192	62.64	2.64
April*	---	2,112	63	25.3	---
May*	---	2,327	70	28.4	---
June	15.7	40.5	1	0.515	3.43
July	18.3	0	0	0	---
August	20.0	241.9	7	3.540	3.95
September	19.3	224.9	7	2.750	3.29
October	16.7	2,327	70	28.39	3.29
November	13.7	2,112	63	25.32	3.23
December	10.2	4,363	131	51.07	3.16
Annual total		33,660	1,010	362.14	2.90

*Estimated.

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

TABLE 12 ENERGY AND COST-EFFECTIVENESS SUMMARY -- HEAT PUMP FOR WILTON, MAINE

Item	Value
Output, kJ x 10^6 -- $	362.14 -- $2,170
Input, kJ x 10^6 -- $	124.84 -- $1,560
Net gain, kJ x 10^6 -- $	237.30 -- $ 610
Initial investment -- $	$11,025
Energy output/input ratio[a]	$\frac{362.14}{124.84} = 11.5$
Value output/input ratio[b]	$\frac{\$2,170}{\$1,560} = 1.4$
Simple payback (yrs)[c]	$\frac{\$11,400}{\$610} = 18.7$

[a]Energy ratio -- Total energy produced divided by energy input required.

[b]Value ratio -- Dollar value of the energy produced divided by the input energy cost.

[c]Simple payback -- Installed cost divided by the savings. No inflation factor for replaced fuels was applied. Maintenance costs have not been included.

Source: Wright-Pierce Architects and Engineers, engineers for the Wilton, Maine project.

LAKE TAPPS SEWERAGE PROJECT (BONNEY LAKE, WASHINGTON) -- LOW-HEAD HYDRO (2, 3, 4)

Background

Under the EPA innovative/alternative technology program, a hydraulic turbine will be used for the first time in the United States to produce electrical energy from an elevation drop in a sewage interceptor. Power produced by the turbine will be placed on the grid of the local electric utility, and will more than offset all power used by 13 lift stations in the Lake Tapps Sewerage Project (located in northern Pierce County near Tacoma, Washington). This project has been declared innovative by EPA. Philip M. Botch and Associates, Inc., of Bellevue, Washington designed the 8,330 m^3/d (2.2 mgd) system.

System Description

Wastewater is collected from residences and businesses around Lake Tapps near the City of Bonney Lake, Washington. Lake Tapps is a storage reservoir for the White River Hydroelectric Plant. After wastewater is collected from the area, it is to be lifted over a ridge and then dropped approximately 122 m (400 ft) vertical distance over approximately 1,097 m (3,600 ft) horizontal distance to the Puyallup River flood plain after which it will flow by gravity to an existing sewage treatment plant at Sumner, Washington.

Initially, the Lake Tapps sewerage facility plan proposed a gravity sewer interceptor to a treatment plant site on the floor of the Puyallup Valley at Alderton. Although this was the most cost-effective alternative for the participants, it was not environmentally-acceptable to the residents of the region, who preferred routing the sewage to the City of Sumner Wastewater Treatment Plant. The Sumner option is much more energy-intensive and requires a large lift station to pump sewage over a hill and into the valley. The energy necessary for pumping provided a strong incentive to seek a way of recovering energy costs. In fact, the consumption of power to operate lift stations was the primary environmental effect noted in the statement of nonsignificant environmental impact.

The sewage collection area lies near a glacially-formed escarpment rising from the Puyallup River flood plain. The interceptor traverses the escarpment en route to the Sumner Regional Treatment Plant. Various methods were considered for dissipating energy across the escarpment. Deep-drop manholes presented difficult construction and maintenance problems. A pressure sewer with energy destruction presented erosion, cavitation, and foaming problems. Reclaiming energy with a turbine generator offered a more cost-effective solution with energy revenues offsetting the lift station energy costs. This system will provide a shelter against ever-increasing lift station energy costs.

Component Description and Design Criteria

The proposed alternative technology includes the use of 1,095 m (3,592 ft) of 45.7-cm (18-in.) ductile iron (DI) penstock (hydrostatically-pressurized force main) and a hydroelectric generating station that will tie directly into the utility power grid. The generating station will include a two-jet impulse turbine and induction generator. The nozzles will be fixed open without needles. A schematic of the system is shown on Figure 34. Characteristics and performance information follows:

Penstock diameter	45.7	cm
Penstock length	1,095	m
Vertical drop	112.8	m
Turbine/generator rating	125	kW
Average flow -- 1982	2,575	m^3/d
Average flow -- 2002	8,325	m^3/d
Yearly power production -- 1982	217,800	kWh
Yearly power production -- 2002	697,600	kWh
Value of power production at 1982 levels (i.e., 217,800 kWh at $0.04/kWh)	$8,712	
Value of power in 2002 with a 9 1/3 percent annual compounded escalation rate (i.e., 697,600 kWh at $0.238/kWh)	$166,029	
Turbine type	Pelton-impulse	
Number of nozzles	One	
Governor	None	
Generator type 1	Induction	
Method of operation	Automatic, unattended	
Type of plant	"Run of river"	

A preliminary treatment station, consisting of a comminutor, grit collector, and screen, will be located in the interceptor ahead of the penstock. The turbine will have an automatic jet deflector to prevent overspeed. A surge-relief valve will protect against inadvertent surges. In the event the surge relief valve malfunctions, a blowout-rupture disc is provided. If the turbine is down for repair, V-ball by-pass throttling valves will maintain the water level automatically in the forebay.

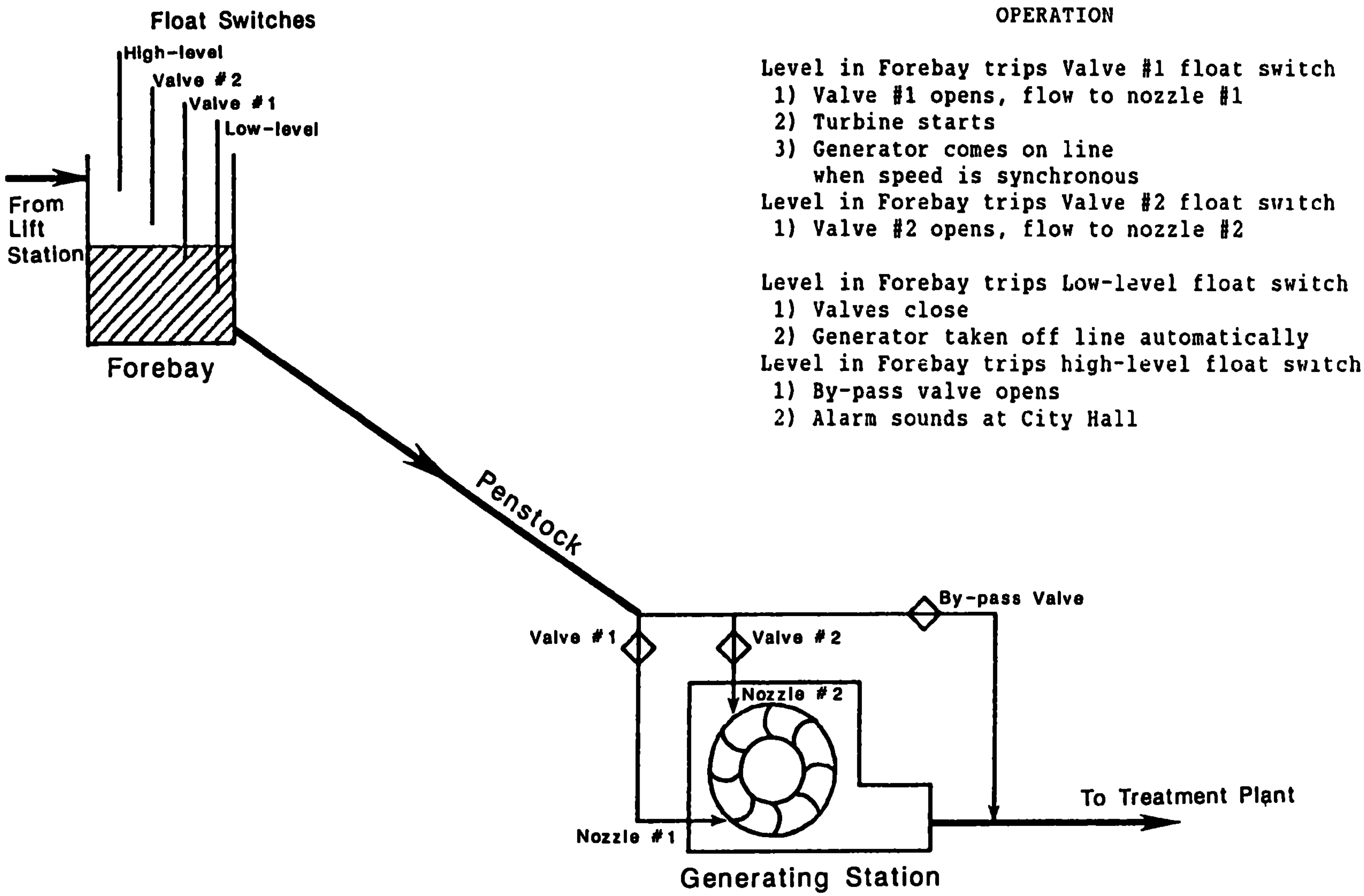


Figure 34. Schematic diagram of Lake Tapps sewerage project (Bonney Lake, WA).
(Source: P.M. Botch and Assoc.,Inc., engineers for the Lake Tapps project.)

A special variable opening nozzle employing a modified V-port valve will be used to substitute for the nozzle in a common Pelton turbine. The nozzle commonly used in a Pelton turbine uses a controlled needle opening. The smaller annular space around the needle at low loads, along with the vane straighteners supporting the needle steady bearing, appeared to present an additional risk factor for clogging. The special nozzle will be tested in a hydraulic laboratory before incorporating it in the turbine.

Energy System Performance Data

The energy analysis indicates that the five lift stations will require 137,984 kWh/yr at startup (2,575 m^3/d or 0.68 mgd) and 461,925 kWh/yr in the year 2000 (8,325 m^3/d or 2.19 mgd). Similarly, the generating station will produce 217,800 kWh/yr and 697,600 kWh/yr. Therefore, the net energy production of the proposed innovative alternative is 79,816 kWh/yr at 2,575 m^3/d (0.68 mgd) and 235,675 kWh/yr at 8,325 m^3/d (2.19 mgd).

NEWPORT, VERMONT -- ACTIVE SOLAR FOR PROCESS HEAT (5)

Background

The wastewater treatment facility designed for the City of Newport, Vermont incorporates innovative technology in its energy conservation methods. The treatment processes include the following:

1. Bar screening.
2. Grit separation.
3. Primary clarification.
4. Aeration with fine-bubble diffusers.
5. Secondary clarification.
6. Chlorination.
7. Sludge thickening.
8. Two-stage high-rate anaerobic digestion.

The methane generated from anaerobic digestion is used to generate some of the process heat for the digester. The innovative technology for energy conservation includes an active solar system which is the primary heat source for the digester.

The Newport wastewater treatment system was constructed under a grant from EPA. Webster-Martin, Inc., of South Burlington, Vermont, designed the 4,540 m^3/d (1.2 mgd) plant. Most of the information contained in this subsection was obtained from the consultant.

System Description

The solar system has been designed for 232 m^2 (2,500 ft^2) of solar-collection field area, based on optimizing the auxiliary fuel purchase against the cost of the system. With the solar energy being the prime heat source for the digester, the methane gas produced in the digester could be considered as a fuel for an engine-powered generator that could continuously produce 15 kW of electric power. Through further consideration of this operation, it was determined that the system could efficiently recover both the heat from the engine jacket water and the exhaust stack. A reservoir for short-term storage of heated water for the solar collection system could be easily provided in the lower level of the control building.

The Newport system utilizes a two-stage high-rate anaerobic digestion process. The first stage is mixed by compressed gas (methane) generated by the process and injected near the bottom of the tank. The contents are maintained at 35°C (95°F) by a methane-fired boiler system and a fuel-oil-fired boiler system. The second stage (not mixed) is heated to a maximum temperature of 60°C (140°F). This second stage provides additional passive stabilization, gravity concentration through supernatant withdrawal, and residual gas accumulation and storage.

An additional innovative design incorporated in the Newport treatment facility is the capability to utilize the contents of the secondary digester for long-term storage of solar-collected heat energy. This feature will allow recovery of not only the excess solar energy collected during warm weather, but also recovery of the heat energy resulting from the 35°C (95°F) sludge being transferred daily from the primary digester to the secondary digester.

The treatment facility will also conserve heat energy by the following means:

1. Use of activated carbon filtration to reduce the level of outdoor ventilation air required by certain areas of the treatment facility that need frequent complete air changes, such as pump galleries.

2. Use of rejected heat from the large horsepower aeration blowers to heat the polymer feed room and janitorial area.

3. Use of radiant heat rejected by the engine-generator to heat the plant control room, workshop, and toilet room.

In summary, the heating system designed for the Newport treatment facility consists of several interconnected subsystems, as follows:

1. Solar collection system.

2. Heat recovery system from the methane-powered electric generator.

3. Short-term hot-water storage.

4. Long-term heat storage in the secondary digester.

The operation of these subsystems as one large heating system appears possible in theory. While there is historical operational data from other installations on subsystems 1, 2, and 3 there are no operational data on subsystem 4, nor on the overall heating system. Control of the overall heating system will take regular monitoring and fine tuning. The complete heating system will reduce energy costs, and, if operated properly, should result in increased reliability.

Component Description and Design Criteria

The control system flow diagram for the total heating system at the Newport facility is shown on Figure 35. Table 13 summarizes the design criteria for the active solar system at Newport.

Estimated Costs

Table 14 shows the estimated capital and installation costs for the facility. The estimated annual electrical energy requirements (in kWh/yr) are shown in Table 15. The estimated annual costs for electrical energy are listed in Table 16. Table 17 shows estimated first-year O&M costs, including chemicals, electrical energy, fuel, sludge disposal, salaries, and maintenance.

HILLSBOROUGH, NEW HAMPSHIRE -- PASSIVE SOLAR (2, 6)

Background

The Town of Hillsborough, New Hampshire, has chosen to implement an alternate energy systems approach in the design of their 1,800-m^3/d (0.475 mgd) wastewater treatment plant. The features included in this system are as follows:

1. Active and passive solar comfort heating.
2. Active domestic hot water heating.
3. Active solar heating of anaerobic digesters.
4. Passive solar enclosure for heating of rotating biological contactors (RBC's)
5. Recycling of methane gas to power gas-driven electric generators.
6. Generator coolant heat recovery.
7. Ventilation system heat recovery via air-to-air heat exchangers.
8. Effluent heat recovery via heat pumps.

This project was approved as innovative technology by both EPA and the State of New Hampshire. Anderson-Nichols (Boston) designed the Hillsborough plant.

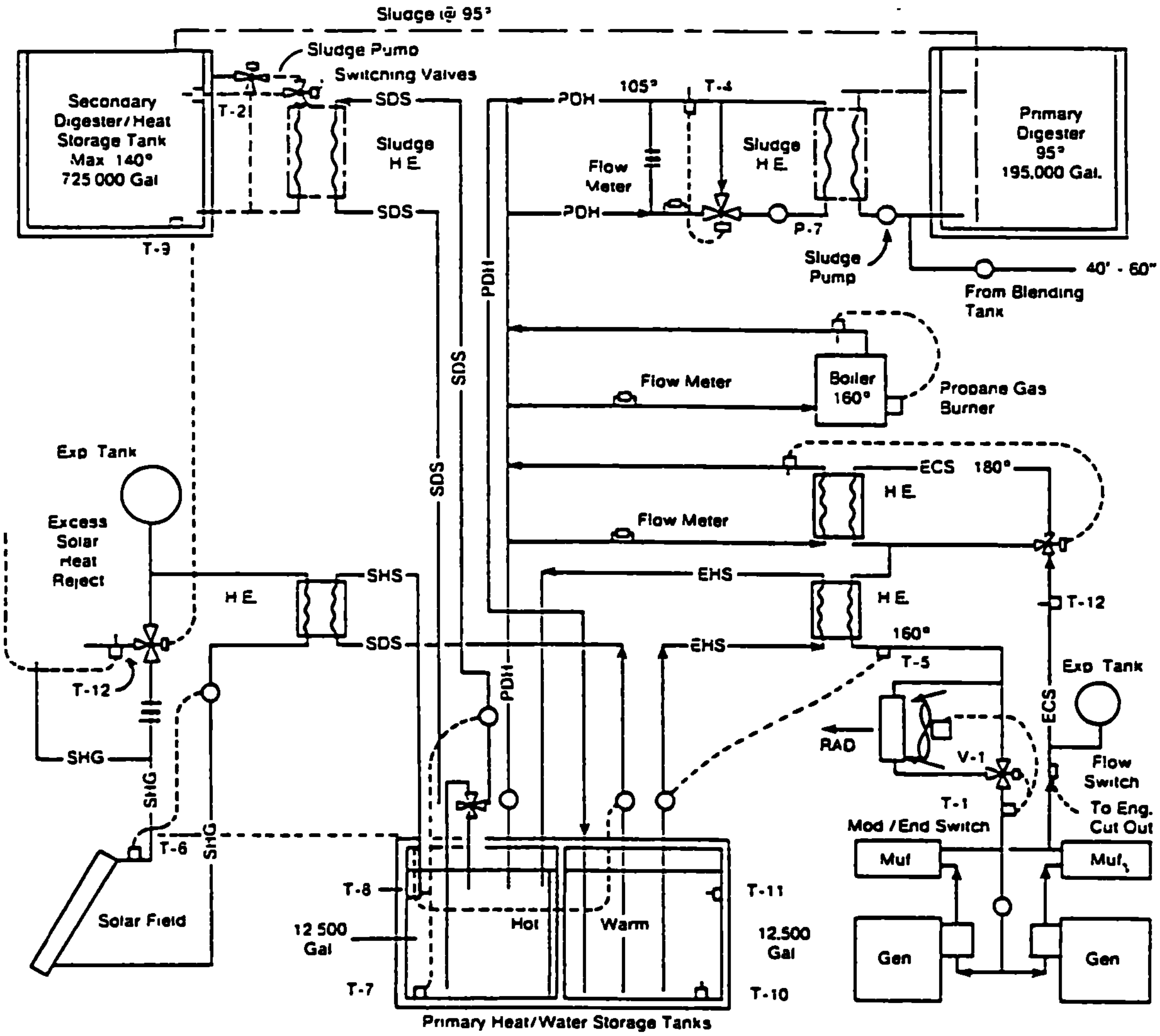
Special architectural design features that were incorporated include the following:

1. Underground construction was utilized wherever possible.

2. Northern exposure of the facility was minimized.

3. Concrete block and brick were used in conjunction with heavy insulation to retain heat at night.

4. Facility roof was designed to retain a heavy snow load for natural insulation.



Control System Flow Diagram

ECS — Engine Cooling System
EHS — Engine Heat Storage
PDH — Primary Digester Heating
SDS — Secondary Digester Storage
SHS — Solar Heating System
SHG — Solar Heating Glycol

H E. — Heat Exchanger
V — Control Valve
T — Thermostat-Controller
P — Pump
P S — Pressure Sensor

Source Webster Martin Inc. engineers for the Newport, VT project

Figure 35. Control system flow diagram for Newport, VT

TABLE 13 SELECTED DESIGN CRITERIA FOR ACTIVE SOLAR SYSTEM FOR DIGESTER HEATING AT NEWPORT, VERMONT

Parameter	Value
Collector	
Collector area	232 m^2
Collector area flow rate x specific heat/area	195.5 kJ/(hr x m^2 x ^oC)
Collector slope	55^o
Ground reflectance	0.5
Latitude (Burlington, VT)	44.3^oN
Storage unit	
Tank capacity/collector area	7,929 kJ/(^oC x m^2)
Storage unit height: diameter ratio	0.78
Heat loss coefficient	2.03 kJ/(hr x m^2 x ^oC)
Delivery device	
Minimum temperature for heat exchanger operation	12.8^oC
Load	
Daily operation time	24 hr/day
Load return temperature	10^oC
Auxiliary device	
Auxiliary fuel type	Gas
Auxiliary device efficiency	0.8

Source: Webster-Martin, Inc., engineers for the Newport, Vermont, project.

TABLE 14 PRELIMINARY COST ESTIMATES FOR NEWPORT, VERMONT

Item	Cost ($)
Existing building - preliminary treatment, pumping, laboratory, etc.	345,300
Primary clarification, including flow split	235,600
Aeration tanks with diffusers	372,000
Secondary clarification with flow split	503,500
Gravity thickener and sludge blend	105,000
Chlorine contact chamber	81,600
Basic building with basic equipment without heat	1,169,600
Primary digester	184,200
Refurbish existing digester	134,500
Heating system	269,500
Methane-fueled generator	30,000
Site work	470,000
Sludge storage (liquid)	60,000
Total	$3,960,800

Source: Webster-Martin, Inc., engineers for the Newport, Vermont, project.

TABLE 15. ESTIMATED ANNUAL ELECTRICAL ENERGY REQUIREMENTS FOR NEWPORT, VERMONT.

Unit	Electrical Energy (kWh/yr)
Continuous Operation	
Influent pump	360,900
Comminutor and grit separator	12,300
Primary clarifier	8,800
Aeration -- blowers	431,000
Secondary clarifiers	8,800
RAS pumps	149,000
Gas mixing	57,800
Sludge blend and gravity thickening	124,400
Plant water system	50,800
Chlorine rapid mix	15,700
Total continuous kWh	1,219,500
Intermittent Operation	
Primary clarifier sludge pumps	6,200
Activated sludge wasting pumps	6,500
Grit-air scour and removal pump	16,000
Sludge pumping -- heating and transfer	11,800
Miscellaneous and lighting	37,000
Total intermittent kWh	77,500
Total annual kWh	1,297,000

Source: Webster-Martin, Inc., engineers for the Newport, Vermont, project.

TABLE 16 ESTIMATED ANNUAL COSTS OF ELECTRICAL ENERGY FOR NEWPORT, VERMONT.

Design/cost	Total
Annual use	1,297,000 kWh
Monthly average	108,100 kWh
Energy cost	
First 25,000 kWh at $0.025/kWh	$ 625
83,100 kWh at $0.01918/kWh	$ 1,594
135 kW demand at $1.55/kW	$ 209
	$ 2,428 per month
	$ 29,136 per year
Generated electrical energy	15 kW
Credit	
15 kW demand x $1.55 x 12	$ 280
15 x 24 x 365 x $0.01918	$ 2,520
	- $ 2,800
Total annual electrical energy cost	$26,336

Source: Webster-Martin, Inc., engineers for the Newport, Vermont project

TABLE 17 ESTIMATED FIRST YEAR O&M COSTS FOR NEWPORT, VERMONT

Item	Cost
Chemical purchases	$ 12,000
Electrical energy	26,350
Fuel -- heat	1,000*
Sludge disposal	16,600
Salaries and administration	56,500
General equipment maintenance and replacement	11,000
	$123,450
Present worth - 20 years at 7-3/8%	$ 1,270,550
Construction cost (estimated)	3,960,800
	$ 5,231,350

* Annual heat energy cost as per computer run based on design year conditions was $864.57. The first year projected cost of purchased fuel for heat was estimated at $1,000.

Source: Webster-Martin, Inc., engineers for the Newport, Vermont project.

Covered rotating biological contactors were selected to treat the wastewater because the large surface area of the contactor is alternately exposed to warmer air (which is passively heated by the sun), and to the cooler wastewater. This procedure maintains the wastewater temperature, thereby improving both RBC performance and effluent heat recovery via the heat pumps.

System Description and Design Criteria

The wastewater treatment system consists of coarse screening and grit removal prior to influent pumping to the primary clarifiers, covered RBC's, secondary clarification, chlorination, and discharge. Primary and waste secondary sludge is transferred to a solar-heated anaerobic digester. A second unheated digester is provided to store and thicken the digested sludge. Heat can be recovered from this unit.

Energy System Performance (Design) Data

Based on a unit-by-unit breakdown of power usage of individual pieces of equipment, the basic energy requirement of the treatment system has been estimated at 1,536 MkJ/yr (1,456 MBtu/yr). However, when energy credits are applied for solar space heating, solar digester heating, and methane utilization with heat recovery (by means of heat pumps), the total net energy is as shown in Table 18.

TABLE 18. TOTAL NET ENERGY FOR PASSIVE SOLAR SYSTEM -- HILLSBOROUGH, NEW HAMPSHIRE

Energy parameters	Net energy requirements MkJ/yr
Basic requirements	1,536
Space heating credit from solar space heating	(198)
Digester heating credit from solar digester heating	(407)
Credit from methane utilization	(276)
Credit from heat recovery	(368)
Total net energy	287

Source: Anderson-Nichols & Co., Inc., engineers for the Hillsborough, New Hampshire project.

By implementing alternative energy sources, an estimated 80 percent of the energy requirements of the wastewater treatment system can be met independently of outside sources.

Estimated Costs

The present worth of the estimated treatment plant construction, plus project costs, is $2,428,000. The annual operation and maintenance cost estimates for the wastewater treatment system are as follows:

Labor	$	31,000
Electrical power		9,715
Chemicals		3,155
Heating		1,025
Administrative and equipment allowance		7,500
Subtotal	$	52,395
Credit for methane and heat recovery		-5,560
Total	$	46,835

The labor estimate is based on three full-time workers. The electrical power cost estimate was developed from a breakdown of the various electrical equipment requirements and estimates of approximate average running horsepower requirements. Chemical costs were based on chlorine requirements, and on expected chemical usage for sludge dewatering and miscellaneous laboratory analyses. Heating requirements were based on the control building space requirements. A portion of the heat requirement for the digesters was included to account for periods during which the solar-heating equipment might not be adequate to meet that requirement (approximately 25 percent of the time).

LIVINGSTON, MONTANA -- WIND POWER (2, 7, 8)

Background

The City of Livingston, Montana, has upgraded its wastewater treatment plant to increase the treatment level from primary to secondary. The plant utilizes rotating biological contactors to achieve secondary treatment. Basic design criteria for the plant are as follows:

Design population	10,500 persons
Average daily flow	7,570 m^3/d
Peak flow	18,925 m^3/d
BOD_5	1,064 kg/d
TSS	1,077 kg/d

Livingston is located in southwestern Montana 85.3 km (53 mi), north of Yellowstone Park along the Yellowstone River, and is an area of high wind potential. Accordingly, the City of Livingston, in conjunction with the Montana Energy and Research and Development Institute (MERDI), has received funding from the State of Montana to construct a wind energy conversion system (WECS) to generate electricity to power the wastewater treatment plant. Because of the limited availability of funding, the WECS is to be constructed in phases. The original design specified a wind farm consisting of eight windmills. However, under available funding, only four windmills have been installed thus far. The remaining four will be added as funds become available. The wind farm as originally designed (i.e., with eight windmills) is expected to supply a significant portion of the electricity for the wastewater treatment plant.

The wastewater treatment plant expansion was funded by EPA. The windmills were added later and have been funded by the State of Montana and through private sources. The treatment plant was designed by Christian, Spring, Seilbach and Associates (CSSA) of Billings, Montana. CSSA worked with Montana Power Company, MERDI, and City of Livingston officials to determine the best approach for incorporating WECS into the design.

System Description

The WECS is tied into the utility company grid system prior to reaching the treatment plant. The necessary transformers, relays, and switches have been designed into the system. The WECS output is metered prior to hookup with the utility grid. At the point of hookup, a relayed oil circuit breaker is used to combine the WECS output with the utility grid so that sufficient power may be supplied to the treatment plant.

The oil circuit breaker senses the energy being delivered by the WECS and supplies the difference in load from the utility grid. The total energy being delivered to the treatment plant is then metered downstream from the circuit breaker. In this design, the treatment plant is assured of sufficient power to operate when the wind is not blowing. However, if the utility grid or the line supplying the treatment plant goes down, a switch automatically shuts down the WECS, and simultaneously, a transfer switch activates the standby generator. The standby generator will supply energy to the primary loop until the utility line comes back into service and the WECS is turned back on.

Component Description and Design Criteria

The total connected electrical energy load for the treatment plant is 177 kW (237 hp), and the probable operating horsepower is 113 kW (152 hp). The wind farm has been designed to supply energy to meet these requirements.

Component Capital, Installation, and O&M Costs

The total installed capital cost for the eight-windmill wind farm is estimated to be $355,000 (1980 dollars). The annual O&M costs are expected to be $2,000.

SOUTHTOWN SEWAGE TREATMENT CENTER (WOODLAWN, NEW YORK) -- WIND POWER (2, 9, 10)

Background

The new wastewater treatment facilities at the Southtown Sewage Treatment Center in Woodlawn, New York, will be powered by wind turbine generators (WTG). The Southtown facility is located on the shore of Lake Erie, near Buffalo, New York, which is an area of strong and persistent winds. Initial construction of the treatment facility began at Southtown in the fall of 1977, and all construction, including the wind turbine generator system, is expected to be finished in February 1983. Design flow for the Southtown Sewage Treatment Center is 60,560 m^3/d (16 mgd). Major unit operations include pure oxygen activated sludge, chemical addition for phosphorus removal, sand filtration, and chlorination. Sludge will be disposed of by incineration; however, this portion of the project has not yet been built. The effluent will be discharged to Lake Erie.

WTG Energy Systems, Inc., Buffalo, New York, designed the wind power system for the treatment plant.

When the treatment plant reaches full operation, it is estimated that the peak demand at the facility will be 1,750 kW. Using an estimated load factor of 82 percent, the annual kWh demand is projected to be 1,320,000 kWh. A system of three 200-kW wind turbine generators will provide over 11 percent of the annual demand, displacing the equivalent of 477 m^3 (3,000 bbl) of oil per year. Based on a cost-effectiveness analysis, it is estimated that the net annual savings from the wind turbine generator system will be in excess of $21,000, as shown in Table 19.

TABLE 19 COST-EFFECTIVE ANALYSIS FOR SOUTHTOWN SEWAGE TREATMENT CENTER[a,b]

Period of analysis -- 20 years		
Life of equipment -- 30 years		
Discount rate -- 7-1/8 percent		
New York State Power Pool fuel oil rate -- ($/kWh)		
Average statewide: summer (June-Sept.) -- $0.0704/kWh		
Average statewide: winter (Oct.-May) -- $0.0618/kWh		
Average statewide: annual rate		
4/12 (0.0704) + 8/12 (0.0618) = $0.0689/kWh		
First cost (installed unit)	$1,010,688	
Salvage value (1980 $)	336,896	
Present worth of wind generators	$ 673,792	
Annual principal and interest payments		
$673,792 x 0.093119 capital recovery factor		$62,743
Annual operating costs		
Lubricants and spare parts	$ 4,500	
Labor (234 hrs @ $10/hr)	$ 2,340	
Total operating costs		$ 6,840
Total annual costs		$69,583
Annual savings		
1,320,000 kWh at $0.0689/kWh		$90,948
Net annual savings		$21,365

[a]July 1980.
[b]Multiple-unit (3) installation.

Source: "Proposal for the Installation of a Wind Turbine Generator (Model MP-200) at the Southtown Sewage Treatment Center," by WTG Energy Systems, Inc.

System Description

Three 200-kW wind turbine generators (model MP-200, supplied by WTG Energy Systems, Inc.) will provide the power. A typical wind turbine system has been previously presented in Section 2.

The model MP-200 consists of a 24.4 m (80 ft) diameter, three-blade upwind rotor driving a 200 kW, 480-V, 60-cycle AC generator through a 1 to 40 ratio speed-increaser fully-enclosed gear-drive assembly. The rotor, gear drive assembly, generator, and hydraulic system are mounted on a rotating base and are enclosed within the machine cabin. This assembly is mounted atop a 24.4 m (80 ft) pinned truss steel tower, and is yawed by a hydraulically-controlled bull-gear unit that provides 360° positioning to ensure maximum upwind efficiency of the rotor.

The rotor blades are a fixed pitch GA(w)-1 airfoil design incorporating blade-tip drag flaps that are automatically activated to stop the rotor under conditions of excessive wind speed, vibration, or any system malfunction. This "fail-safe" system permits unattended operation of the wind turbine, and prevents any aggravated system failures.

Electrical generation begins in wind speeds of 3.58 m/s (8 mph). The rated generator output of 200 kW is achieved at 13.4 m/s (30 mph), and the maximum generator output of 313 kW is reached at a 15.6 m/s (35 mph) wind velocity. Shutdown occurs at 26.8 m/s (60 mph). The survival wind speed is 67.1 m/s (150 mph). Throughout its operating range, the rotor of the MP-200 system will maintain a constant 30 rpm for the production of constant frequency 60-Hz power.

The control unit of the MP-200 system is a solid-state microprocessor located in the control house at the base of the tower. This preprogrammed computer continually monitors and controls all generating and operational functions of the wind turbine. The microprocessor ensures that, within the range of productive wind speed, the maximum power output is introduced into the utility grid system at precision-controlled voltage and frequency. Even if the MP-200 system is the only generator on the transmission line system, precise voltage and frequency will still be maintained.

Component Capital and Installation Costs

The estimated capital and installation costs for the wind turbine generator system, consisting of three 200-kW units, are as follows:

Three 200-kW wind turgine generators	$	787,300
Foundation	$	79,800
Erection	$	73,500
480-V distribution (305 m)	$	60,000
Testing	$	10,100
Total installed cost	$	1,010,700

Manpower Requirements

The estimated manpower requirements are based on operating experience from other WTG, Inc., installations with MP-200 systems. The system is designed for unattended operation; however, the system will require an annual allocation of approximately 78 man-hours for scheduled maintenance on each of three wind turbine generators.

The estimated annual maintenance requirement for the MP-200 system has been calculated based on data obtained from a wind analysis program conducted at the Southtown facility, as follows:

Annual machine availability	90 percent (minimum)
Annual estimated machine operating time	5,804 hr (66 percent per year)

O&M Requirements and Costs

The estimated O&M requirements and costs are as follows:

Lubricants and spare parts (3 wind turbine generators at $1,500)	$4,500
Labor (3 wind turbine generators at 78 hr, $10/hr)	$2,340
Total annual operating costs	$6,840

WAYNESBURG-MAGNOLIA, OHIO -- PHOTOVOLTAIC (6-11)

Background

The design of the Waynesburg-Magnolia, Ohio, wastewater treatment system incorporates both innovative treatment processes and energy-supply methods. The treatment sequence includes the following unit processes:

1. In-line flow equalization.
2. Fabric belt primary filtration units.
3. Random-cage biological oxidation units.
4. Final clarification.
5. Disinfection (ultraviolet or sodium hypochlorite).
6. Sludge treatment by composting.

It is proposed that the entire plant be powered by solar (photovoltaic) energy generated at the treatment plant. It is anticipated that purchased electricity will not exceed 25 percent of the total demand on a year-round basis. The Waynesburg-Magnolia project was granted design and construction funding from EPA in the summer of 1981. Hammontree and Associates, Ltd. (North Canton, Ohio) designed the 1,500 m^3/d (0.4 mgd) plant.

System Description

All of the process units will be powered by the output from a photovoltaic cell array located on the site. The primary heat source within the structure will be latent heat from sewage in the treatment processes, augmented by a thermosolar heating system. Thermosolar panels will be located on the roof of the structure.

As a backup source of a electrical power for the 20 to 25 percent of the year when photovoltaic electrical generation may fall short of immediate needs, a standby diesel-powered generator will be included in the equipment design to ensure continuity of electrical supply. The photovoltaic and standby systems could make the plant completely independent, and not require any outside commercial power. By this arrangement, plant operation could be 100 percent self-sufficient for electrical energy.

Component Description and Design Criteria

Construction of the Waynesburg-Magnolia Plant was expected to begin in late 1982. The photovoltaic (PV) system has been provided by Solarex Corporation (Rockville, Maryland). Since their photovoltaic process has been improved substantially, the size of the solar collector system has been reduced to one-third the size originally estimated in the facilities plan.

The energy demand of the wastewater treatment system is estimated to be 25 kW (33.5 hp). Solarex has estimated that to provide only the photovoltaic grid system would cost $354,000, while installing both the photovoltaic grid system and a battery storage system to provide a 20-day backup would cost approximately $3,000,000. This would eliminate the necessity of providing a hookup with the local utility. However, the decision has been made to not provide the battery storage system at this time.

The electrical system for the wastewater treatment plant will have controls to determine the percentage of power provided by the photovoltaic system vs. the percentage required from the local utility. This photovoltaic project was the first to receive innovative/alternative (I/A) funding in Region V. It will serve as a pilot system, and data will be gathered on collector efficiency, operation, O&M problems, etc.

Component Capital and Installation Costs

Component capital, installation, and annual operating cost estimates for the innovative design are shown in Table 20.

TABLE 20 WASTEWATER TREATMENT PLANT COSTS* FOR WAYNESBURG-MAGNOLIA, OHIO# -- INNOVATIVE DESIGN

Item	Cost ($)
Bar screen and communitor pad	3,000
In-line flow equalization	74,000
Paper filtration	70,000
Bio-drum secondary treatment	84,000
Final clarifiers	99,000
Upgrade laboratory and building	35,000
Disinfection	40,000
Cascade aeration	23,000
Composting equipment	38,000
Rehabilitate spiralgester	20,000
Building and concrete floor	170,000
Fencing	25,000
Solar power system (photovoltaic grid system)	354,000
Total plant construction costs	$1,035,000
Engineering	
- Solar energy system	55,000
- Plant design	140,000
Interest during construction	65,000
Resident engineer and construction supervision	92,000
Fiscal, administrative, and land acquisition	26,000
Contingency costs (5 percent)	52,000
Total plant capital costs	$1,465,000
Annual O&M costs	
Manpower costs	18,000
Power costs	1,400
Supplies, including fabric cost	12,000
Maintenance of equipment	9,000
Total annual O&M costs	$ 40,400

Present worth of 20-year O&M

20 years at 7 percent (10.594) x 40,400 = $428,000

Total plant construction costs present net worth including 20-year O&M = $1,893,000

*March 1980.
#Plant capacity = 1,514 m^3/d

Source: Hammontree and Associates, Ltd., engineers for the Waynesburg-Magnolia, Ohio project.

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