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Project Summary

Monitoring Integrated Energy Systems at a Wastewater Treatment Plant in Maine

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Performance was monitored for several alternative energy systems installed in the municipal wastewater treatment plant in Wilton, Maine. These systems include active and passive solar, effluent heat recovery, digester gas generation, air-to-air heat recovery, and electricity generation using digester gas.

To accomplish the monitoring, an instrumentation system was installed and data were collected from May 1979 to March 1981. This instrumentation system includes solar pyranometers, hydronic BTU computers, electrical and gas meters, a weather station, and numerous temperature transmitters. Data for the solar and digester system are available in both digital and analog forms.

The data analysis results and subsequent engineering evaluation of the design concepts led to the conclusions that (1) effluent heat recovery through the use of a heat pump and ventilation air heat recovery are cost effective; (2) the standard procedure for designing active solar systems based on instantaneous efficiencies can lead to significant overestimates of projected system performance; and (3) the use of solar thermal energy collection to supplement anaerobic digester heating is not cost effective.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The municipal wastewater treatment plant at Wilton, Maine, was designed to incorporate energy conservation and alternative energy features such as active and passive solar space and process heating, effluent-heat recovery, digester gas generation and use, ventilation air heat recovery, and electricity generation using digester gas. Designed in 1975, the plant became operational in September 1978. A grant from the U.S. Environmental Protection Agency (EPA) funded the monitoring of the plant's energy systems.

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The primary objectives of the project were:

1. To determine the effects of weather performance of the systems.
2. To establish the amount of energy used and produced by each system and its contribution to the various process and building requirements.
3. To determine the cost effectiveness for each system.
4. To review possible design and operational problems for improved performance.

Description of Treatment Plant

The Wilton Wastewater Treatment Plant was designed to provide secondary treatment of the wastewater generated by the town's population of 4,200, with the added requirement that there be zero discharge to the receiving stream at stream flows less than 0.12 m^3/day, the 7-day, 10-year drought flow (7/Q/10).

Wastewater is lifted into the plant by screw pumps. Preliminary treatment consists of grit removal, comminution, flow measuring, sampling, and screening. Secondary biological treatment consists of rotating biological contactors (RBC). Final clarification takes place in two peripheral feed clarifiers. The effluent is then disinfected and discharged. To meet the 7/Q/10 steamflow limitations, a 4.5-ha spray irrigation plot is used directly north of the treatment facility. This system is designed for 10 continuous days of operation during drought conditions. Sludge consisting of screenings from the preliminary screens and sludge from the final clarifiers is combined and mixed in a raw-sludge holding tank; then it is pumped to anaerobic sludge digesters for stabilization. High-rate, two-stage mesophilic digestion is used. Following digestion, the sludge is pumped to the dewatering area, dewatered, conveyed to the disposal vehicle, and trucked to a local farm for spreading on fields.

Architecture is a key element in any project where energy conservation and the use of alternative energy sources are prime objectives. Because of Wilton's cold climate, the entire plant is enclosed in two structures with all the processes placed close together to keep the structures as small as possible and to reduce hydraulic runs while providing for future expansion. Gravity is used to avoid unnecessary pumping. The building is shaped to hold snow on the roof and collect drifts of snow against walls for increased natural insulation during the colder months. Projections past the wall lines adjacent to glazed surfaces reduce surface wind velocity and cut heat loss, as do recessed windows and doors. Basic concrete materials were chosen for walls and roofs because of heat retention potential and low maintenance factors. Insulated glass is used in all windows. The building's interior spaces are partitioned into separate areas requiring different temperatures and different air changes for maximum control of heat loss. Partitions and doors between spaces with a temperature differential of more than 6°C are insulated. Wherever possible, translucent fiber glass partitions are used so that lighting from adjacent spaces can be shared. Natural ventilation and air flow are controlled by louvers and windows. To minimize the exterior surface, the building is built into a hillside with little exposure to the north. Shrubs and trees provide wind breaks. Reflection from snow in front of the building and from an earth mound to the west supplement solar energy collection. The enclosing structures face south to achieve maximum value from the sun's direct energy through both passive and hydronic solar energy collection devices. Insulated translucent fiber glass panels face south at a 60° tilt for passive collection of solar energy. The panels cover 89 m^2 and have a light transmission factor of 45% and a U factor of 0.29.

Flat-plate hydronic solar collector panels covering 130 m^2 are set at a 60° slope from the south roof of the treatment plant. The collector consists of an extruded aluminum plate and frame, copper tubing to transport the collector fluid, and two panes of low-iron-content tempered glass. The backs of the collectors are insulated with 114 mm of rigid polyisocyanurate foam board insulation. An ethylene glycol solution is pumped through these panels and heated to 50° to 60°C by the sun.

Although solar energy is used at Wilton for space heating and domestic hot water, its primary purpose is to provide heat for the anaerobic digesters. The methane gas produced in the digestion process can be stored and used not only in the methane boiler for heating purposes, but to run the plant's emergency generator. This application of solar energy attempts to overcome two of the main constraints on its widespread acceptability—namely, its traditional seasonal use and the difficulty of storing solar energy. By using solar energy to heat the digesters, the solar equipment is used year-round, significantly decreasing the payback period. By producing methane as part of the anaerobic sludge digestion process, solar energy is effectively stored in the form of a compressible, combustible gas, which is a much more efficient storage medium than the usual hot air or water.

A sophisticated heating and ventilating design had to be achieved to accomplish the energy goals. Because the main design component is solar energy gathered by flat-plate collectors in a cold climate, a basic constraint on the heating system design was the use of relatively low-temperature hot water (50°C) instead of the conventional 90°C water. Energy conservation practices become extremely important when dealing with such low temperatures. The thermal zoning of rooms to allow for individual room temperature control is very important. The office, locker room, and laboratory, which are clustered at the northeast end of the building, can be maintained at 20°C for the operator's comfort. The rest of the areas in the plant will experience seasonal and diurnal temperature fluctuations, dropping as low as 7°C in winter and perhaps approaching 30°C on warm, sunny days in the summer. The operators are normally not in these areas for any extended period of time. Most of these areas contain processes that are not normally housed. The operator is very important to the success of the energy conservation effort since he must see to it that temperature controls are properly set, the doors are kept closed, and temperatures are set back at night.

The heating system is designed for cascading the heating loads. The digesters can be heated with 49°C water, building space heating can be accomplished with 38°C water, and ventilation units use 32°C water. The water that heats the digesters can in turn be used to supply heat to the building's heating system and ventilation units without requiring supplemental heat between steps. The system maintains the flexibility of supplying heat directly to one specific load as required.

Ventilation is a major problem in energy-efficient heating design for wastewater treatment plants, since many of the process areas require many air changes. To avoid throwing heat away, the plant makeup is warmed by heat exchange with the exhaust air before the exhaust air is vented.

Solar energy is the prime source of heat, both for the sludge digestion process and the building. A secondary source of heat is the methane gas produced in the anaerobic digesters, and its availability intimately depends on the success of solar heating. Another source of heat is an electric heat pump that uses the heat energy available in the plant's effluent. This heat pump is approximately three times as efficient as electric resistance heat, and its use in wastewater treatment facilities can be very cost effective.

The interrelationships among the heating sources and heating loads are depicted in Figure 1. Heat from the solar collectors can either be transmitted directly to the heat distribution system, or it can be sent to the solar energy storage tank, which is a 7.5-m^3 water tank. Which route it takes depends on the relative temperatures of the solar collector loop and the solar storage tank, and on the needs of the system for heat.

Fueled by digester gas produced in the anaerobic digesters, the methane boiler comes on only when there is a call for heat that cannot be satisfied either by direct input of solar energy or by hot water stored in the solar storage tank. The heat pump operates only when solar energy is unavailable (either directly or indirectly) and when methane is unavailable.

Backing up the three primary heat sources are some secondary sources that can be significant. Methane is used as the prime fuel for the plant's 55-kW electric generator in addition to being used to fuel the methane boiler. Propane is stored onsite in case of prolonged power outages when the supply of methane is exhausted, but it is not normally used as a fuel for the generator. When the generator is operating, it gives off a great deal of heat and is cooled by water from the solar storage tank, thus becoming a usable source of heat.

The solar storage tank can be considered a heat source, since it is used for short-term storage of excess energy that is not directly usable. By using the storage capacity, the operator does not waste potentially usable energy from the solar collectors or the electric generator. Heat from the solar storage tank can either be put into the heat distribution system or go directly to heating domestic hot water. The hot water heater can be heated electrically, but such a measure is unlikely to be required often.

Passive solar energy is provided by translucent fiber glass panels for direct heating and lighting. Finally, building ventilation air is conditioned by exhaust air through the use of a heat exchanger.

To accomplish the objectives of the digester gas system, two levels of storage are used. Short-duration storage is accomplished by compressing the gas to 0.138 MPa (absolute pressure), a conditioning storage mode used to ensure steady flow of methane for digester mixing and to prevent too rapid cycling of the high-pressure methane storage compressor. Longer-duration storage is accomplished through the high-pressure methane storage system, in which methane is compressed to 1.38 MPa (absolute pressure). The boiler and generator are supplied from the high-pressure gas storage tank.

Energy Monitoring Objective and Description

The objectives of the energy systems monitoring program were to predict, verify, and summarize the performance of the building thermal systems on a totally integrated basis that is not available through predictive analysis of individual components. These objectives are tied very closely to the basic energy-conserving design of the plant. No subsystem has a unique design by itself, but the integrated subsystems pose complex problems in the interaction of process variables. Such problems are especially prevalent in the interaction among energy sources (i.e., solar input, methane boiler, and heat pump) and energy users (i.e., digesters, building heating, and ventilation).

The integration of these subsystems is unique, and the design was partly based on data provided by manufacturers of solar equipment, emergency generators, boilers, and digesters. These manufacturers have detailed knowledge of their equipment but limited knowledge of the total system. Monitoring of these subsystems was conducted to determine how the components interface.

Results

The monitoring system was designed and installed based on anticipated results. Generally, the equipment had sufficient sensitivity and range to provide valid results. With the available data, each major component of the heating system was analyzed and evaluated for its energy and cost effectiveness.

Active Solar System

The active solar system data collected between June 1979 and April 1980 are summarized as follows:

1. Recorded clear-day insolation levels were consistently above American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) estimates with an average difference of 13.8%.
2. The recorded percent of possible sunshine was 60% versus the 52% average predicted. This figure is consistent with the unusually low precipitation levels experienced.
3. The average incident solar radiation was 37.3% above that estimated.
4. The total solar energy collected was 122 gigajoules (GJ), which was 64% of that estimated.
5. The overall solar system efficiency (the net energy collected divided by the total incident available) was 23%.

An overall efficiency of 23% is significantly lower than that 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 or instrumentation error
2. Collector heat loss factor:
   a. Inadequate thermal insolation
   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 response sensitivity
6. Collector efficiency losses because of dirt accumulated during construction.

Though all of these factors but the first certainly contribute to the solar system performance, the overriding cause appears to be the combination of all of them coupled with the lack of an accurate calculation procedure to simulate this interaction.

Obviously, significant differences exist among instantaneous collector efficiencies. The latter are useful in comparing various types of collectors under similar steady-state conditions, but they tend to create a misleading picture of the efficiency of water heating systems operating over long periods.

In the month of March, for example, approximately one-third of the incident radiation was of too low an intensity to collect. In many cases, the collector plate temperature never reached a usable or threshold level, though considerable insolation was available. An illustration of these losses in long-term efficiency appears in Figure 2 for a clear day. The corresponding losses for a cloudy day are obviously greater, particularly if the solar radiation intensity equals the critical or threshold intensity.

The dominant factor in establishing the threshold intensity level is the temperature difference between the absorber plate and the ambient air. If this difference is minimized by either a warmer climate or a cooler collector fluid (as in the case of a heat-pump assisted system) or both, then this threshold level would be reduced and the long-term system efficiency would be improved. For example, in the case of a heat pump and solar system with an average collector fluid temperature of 10°C and an ambient temperature of 24°C, the threshold intensity level would actually be negative, enabling the system to collect heat within solar radiation.

As indicated, the causes for the lower overall efficiency were investigated based on the assumption that the estimating procedures were accurate. Numerous alternative procedures were studied with similar inflated results. In the course of the investigation, several publications were discovered that included test data for actual solar systems monitored for a 1-year period. The results of these studies are similar to the findings at the Wilton plant.

Passive Solar Systems

The passive solar array is built into the wall at two levels. Solar radiation passes through the array, providing both heating and lighting in the clarifier room. Each bank of panels has an overhang that tends to shade them during the summer months when heating is not required. Operable windows cool the space when the temperatures become excessive. The energy collected during these times is lost and thus is not considered useful.

Increasing the transmissivity and/or decreasing the U factor would increase the net quantity of collected solar radiation. More would be provided as useful during the winter, but more would have to be dumped during the summer. For the panels, varying the ratio of transmissivity to U factor and estimating the net energy collected would provide an indication of what a change in that ratio would do to the system. Other factors such as overhangs, the blocking effect of the internal panel spacers, and variations in transmissivity with incident angle also need to be considered.

For this installation, the variation in overall performance appears adequate with transmissivity increasing during the winter and decreasing during the summer. The overhang is responsible for a daily average decrease in transmissivity of up to 14%.

Heat Pump

The heat pump operating time was greater than anticipated during this period. The coefficient of performance (COP) was a quite acceptable 2.9 during the heating season. The generation of the heating energy gave a net cost savings, and the payback period was reasonable (11.4 years). Had the heat pump operating time equaled the projected operating time, the payback period would have been closer to 25 years, which is still reasonable.

The actual and projected hours of operation are based on present operating conditions. As the plant flow increases and digester gas production increases, the heat pump may be used less, with an increasing payback period as a result of less operating time.

To date, the operation and maintenance problems encountered have been relatively small, but considerable time has been spent in cleaning the effluent strainers. Records should be kept for several years to determine realistic operating and maintenance costs for the system.

Generator Heat Recovery

The generator heat recovery loop operated approximately one half-hour per week during the generator exercise period. During part of that time, the recovery loop was not used because the storage tank temperature was warmer than allowed by the maximum generator-cooling heat exchanger. Town water was then used to cool the generator. This condition arises regularly during the summer, when there is a limited heating demand and the active solar system is able to provide most of the heating required. The generator could be exercised for longer periods of time during the heating season, when digester gas is available.

The generator heat recovery loop has the highest energy output to input ratio, but the payback period is the worst. The reason is the low periods of use being experienced. Increased usage would increase cost effectiveness.

Digester Gas Generation

The digester gas generation system is not cost effective with regard to recovery. But process requirements must also be considered when evaluating this system.

Reflected Solar Radiation

The attempt to measure the magnitude of the ground-reflected solar radiation component met with limited success. The reflected component for peak nonclear days was within the experimental accuracy of the equipment being used. The average daily reflected component consists of both reflected and some diffuse solar insolation. Thus no meaningful data on the magnitude of the reflected component were gathered. Part of the reason was the minimal snow cover experienced during the winter of 1979-80.

Electrical Usage

Even with the heat pump operating more and the generator operating less than anticipated, the total electrical usage has been 12.5% less than projected.

Conclusions

The analysis of the monitoring data and the engineering evaluation of the energy systems at the Wilton, Maine, wastewater treatment plant have led to the following conclusions:

1. Heat recovery from wastewater treatment plant effluent through the use of a water-to-water heat pump is cost effective under relatively severe temperature conditions. Operational problems can be minimized by properly designing the effluent sump from which the heat pump draws to provide sufficient capacity at minimum plant effluent flows.
2. Heat recovery from ventilation air is cost effective.
3. Heat recovery from the generator cooling loop may be cost effective if increased use of the generator is warranted.
4. Passive solar heating is not cost effective as analyzed for the Wilton plant, but it can be made cost effective with design modifications. Passive solar heating of treatment plant structures can be cost effective in occupied areas such as the office and laboratory if good energy conservation principles are followed in the design of such areas. Passive solar heating is less cost effective when applied to process areas exposed to water surfaces. In the latter case, room thermostats must be set at 5°C, a temperature that can largely be maintained by the water passing through these areas. Combined with task heating (if necessary) and proper energy conservation design, passive solar heating and lighting can be cost effective in process areas.
5. When solar system instantaneous efficiencies are applied to clear-day insolation levels and the mean expected percent of sunshine, the result may be an overly optimistic evaluation of the actual long-term performance. These losses are related to the system threshold insolation intensity and the random

weather patterns. Thus accurate estimate of long-term efficiences would require computer simulation using site-specific, averaged, hourly weather data and system performance criteria. Moreover, since the threshold intensity level is predominantly affected by the difference in the average collector fluid and ambient temperatures, the long-term efficiency may be significantly reduced in northern climates.

6. *Collecting solar thermal energy to* produce supplemental heat for anaerobic sludge digesters is probably not cost effective under currently accepted economic projections, regardless of the size or location of the facility.
7. Instrumentation and controls should be simplified as much as possible. The theoretical advantages of integrated energy systems can be offset by complicated, trouble-prone instrumentation.

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The complete report, entitled "Monitoring Integrated Energy Systems at a Wastewater Treatment Plant in Maine," (Order No. PB 84-197 292; Cost: $14.50, subject to change) will be available only from:
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