

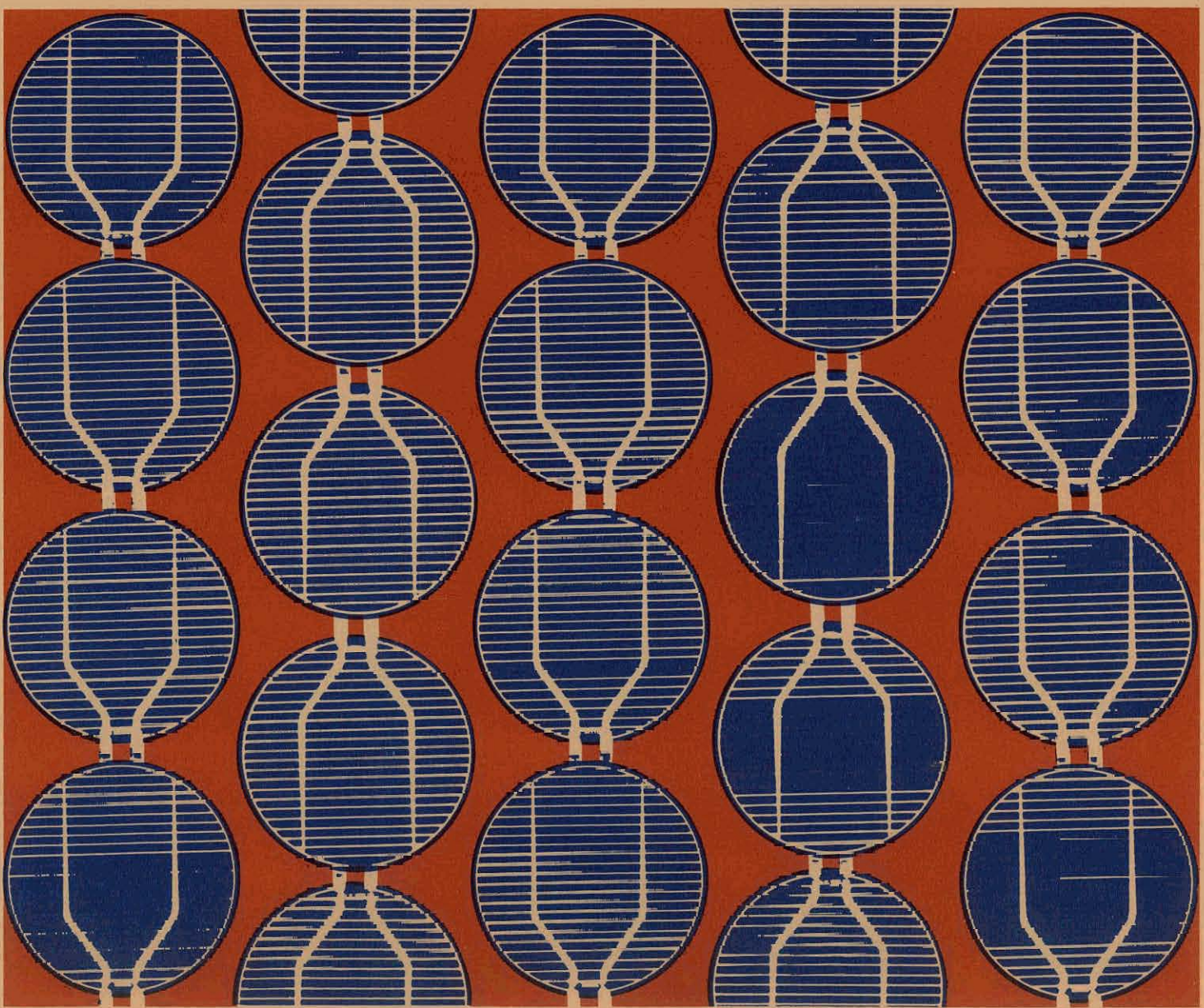
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# Energy Conservation Program of the Division of Substation & Control Engineering

## An Interim Report

U.S. Department of Energy  
Bonneville Power Administration  
Prepared by Division of Substation  
and Control Engineering

**MASTER**



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**THE ENERGY CONSERVATION PROGRAM OF THE  
DIVISION OF SUBSTATION AND CONTROL ENGINEERING**

An Interim Report

April 1981

**DEPARTMENT OF ENERGY  
BONNEVILLE POWER ADMINISTRATION  
Division of Substation and Control Engineering**

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Cover photo: Photovoltaic array

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THE ENERGY CONSERVATION PROGRAM OF  
THE DIVISION OF SUBSTATION AND CONTROL ENGINEERING

An Interim Report

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## SUMMARY

In the past the Pacific Northwest enjoyed an abundant supply of electricity, but in recent years an ever-growing demand for power has strained the region's hydroelectric resources. Further large-scale hydroelectric development does not appear feasible, and while coal and nuclear thermal projects have been scheduled to augment the power supply, these have incurred repeated delays. As a result, current projections indicate possible energy deficits in the 1980's, unless alternative sources of power can be found.

Energy conservation is generally acknowledged to be the most readily available source of addition low-cost power. Recognizing this fact, the Bonneville Power Administration (BPA) has long carried on a program of research and development to increase the technical efficiency of its transmission system. But during the 1970's BPA sought to broaden the scope of its conservation efforts by creating a Branch of Energy Conservation and by implementing throughout the Agency projects aimed at reducing the energy requirement of the ultimate consumer of electricity. The Division of Substation and Control Engineering has been involved in much of this work, initiating a number of projects ranging from the development of prototype equipment to the field testing of energy saving measures that could benefit residential and commercial users.

This document describes the projects undertaken by the Division of Substation and Control Engineering, reports on their progress, and indicates directions that they will take in the future. The first projects presented are those being done at BPA's Midway Residential Community: studies on air infiltration and weatherization, and evaluation of such energy conservation measures as heat pump and solar water heaters. The next section of the report involves an energy audit and retrofit program undertaken in response to Executive Order #12003 to reduce energy consumption in BPA's own buildings. The third section, also concerned with BPA's efforts to reduce internal energy consumption, presents the application of passive solar techniques to the design of new BPA buildings. The fourth section reports on a system developed to utilize waste thermal energy from transformers and solar energy for space heating and cooling. The fifth section also involves the development of a prototype system, one to monitor energy usage of industrial equipment. The final sections report on projects involving solar and wind energy, the Photovoltaic Applications Program and the Mod-2 Wind Generator project at Goodnoe Hills.

THE ENERGY CONSERVATION PROGRAM OF THE  
DIVISION OF SUBSTATION AND CONTROL ENGINEERING:  
An Interim Report

INTRODUCTION

The Pacific Northwest long enjoyed an abundant supply of electricity, inexpensive and rich in potential for development. Federal multi-purpose dams harnessing the energy of the Columbia River and its tributaries created a vast hydro system that for many years was more than adequate to meet the region's demands for power. But this source of low-cost electricity attracted energy-intensive industries to the Pacific Northwest, and at the same time the growth of the region accelerated. Currently the demand for electricity exceeds the capacity of the system, and it now appears that the potential for further large-scale, economically feasible hydroelectric development has been exhausted. Some thermal projects, both coal and nuclear, have been built to meet an ever-growing demand for power, but other projects scheduled to augment the hydroelectric base have met with repeated delays. As a result, the energy situation in the Pacific Northwest is rapidly becoming critical, and indeed projections now indicate that should the region experience years of reduced streamflows in any year of the 1980's - as it did in 1973, 1977 and 1979 - severe power shortages might occur.

In recent years it has been generally acknowledged that conservation is essential to the management of our dwindling energy resources. Nationally, diminishing fossil fuel reserves, with attendant increases in their cost and demand, focused attention on energy conservation, culminating in passage of legislation such as the National Energy Conservation Policy Act of 1979, which implemented a variety of measures intended to encourage energy saving in both the private and public sectors. In the Pacific Northwest, a growing awareness of conservation was intensified by the effects of the Arab oil embargo in 1973 and by a drought in the same year that reduced hydroelectric resources to a critical level.

In its role as the primary transmitter and wholesale distributor of power in the Pacific Northwest, the Bonneville Power Administration (BPA) has long been aware of the value of energy conservation. Recognizing that reducing the amount of energy consumed postpones the need for new, expensive generating facilities, BPA since its establishment in 1937 has conducted ongoing research and development to improve the technical efficiency of the region's electric power system. But during the 1970's it became clear that if the Pacific Northwest's energy requirements were to be met, BPA's research and development program should include conservation projects of a much wider scope. Thus, although limited in the amount it could spend on conservation programs without direct Congressional approval, BPA initiated a number of small but significant projects that were aimed at reducing the electricity required by the end user. This early interest has grown into a separate program of study, research, development of equipment, and field testing of various practical measures consumers might take to conserve energy with cost savings for themselves. In serving the Northwest and national interest, BPA felt that its experience in the transmission and distribution of electrical power, and its considerable technical staff, could best be utilized by confronting practical problems faced by homeowners, businesses, industries, and local and state governments.

While much of the task of implementing energy conservation is done by the Division of Energy Conservation, whose pilot projects on residential weatherization, solar water heating, and irrigation pump testing are well underway, this work is supplemented by engineers and technicians working in other branches and divisions of the agency. The Division of Substation and Control Engineering has been involved in a great deal of the day-to-day work of conducting studies, overseeing projects and evaluating equipment, and the current status of its efforts is described in this interim report. This report augments other publications which give an overall, general view of energy conservation in BPA, focusing instead on engineering and research at the working level. Its purpose is to acquaint those involved in decisions effecting energy conservation - not necessarily engineers or technicians - with the work being done at BPA.

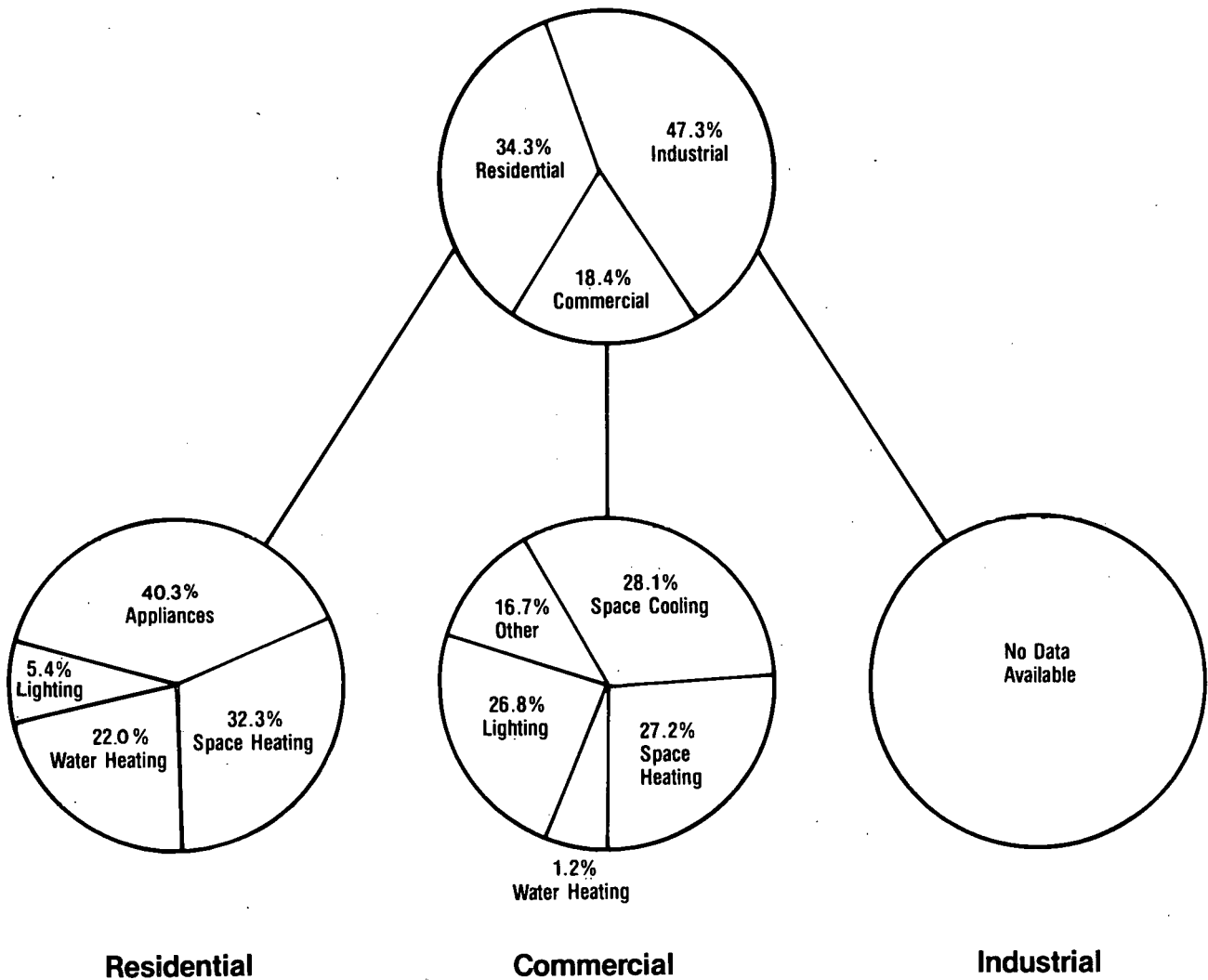
Additional copies of this report, as well as copies of individual technical reports referred to herein, may be obtained through the Division of Energy Conservation, Bonneville Power Administration.

#### BACKGROUND

The early efforts of Bonneville Power Administration in the field of energy conservation received considerable impetus from President Carter's Executive Order #12003 of 1977, requiring energy savings in the Government's own buildings, the National Energy Conservation Policies Act of 1979, and the Department of Energy's strong advocacy of energy saving as a national goal. Since much of BPA's energy conservation work would entail alteration of and additions to buildings, a large part of the energy conservation research and development program was assigned to the Division of Substation and Control Engineering, that part of the Agency most involved with building design.

Preliminary work on energy conservation research and development involved the selection of particular projects, design of testing procedures, and preparation for gathering data from testing sites. Selection of projects was by two main criteria: substantial benefit in practical energy saving, and feasibility of the project itself. While long range research in new technology was not ignored, projects were selected first of all for their potential for being translated into practical energy conservation measures within a short period of time. The first step was to identify end uses in order to determine the areas where the greatest energy savings could be achieved. Surveys conducted by the Power Requirements Section of BPA supplied data on end uses for the West Group Area -- Oregon, Washington, Idaho, and parts of Montana. A current forecast of end-use demand is shown graphically on the following page:

## Percentage of Total Electricity Use by Sector



### End Use Within Sectors

SOURCE: "Preliminary Estimates of End-use Electricity Use"  
BPA Requirements Branch, July 1980

Figure 1. Forecast of Electrical Energy Use 1980 For Oregon, Washington, Idaho and Western Montana

As Figure 1 indicates, the greatest requirement for electricity - 47.3% of the total demand - comes from the industrial sector. Currently, however, there is insufficient data to permit accurate assessment of the types of industrial energy end use; as a result, there is a serious need, both on a national and regional level, for a means of acquiring this kind of information. In response to this need, the Systems Control Branch of the Division of Substation and Control Engineering undertook a project in cooperation with the Department of Energy to design a microcomputer system for monitoring the energy usage by types of industrial equipment. The system, now being used at the Hanford Reservation to monitor industrial processes, is expected to yield data on energy usage and in addition will provide information about the feasibility of load management.

Although much remains to be learned about how energy is used in the industrial sector, there is considerable data available on residential and commercial end use and a wide range of technology on which to draw for resolving energy conservation problems in these sectors. The two largest items of residential and commercial use - space and water heating - suggested that a savings in these could bring about far reaching reductions in Northwest electrical energy consumption.

The requirement for space heating breaks down as follows:

Table 1. Requirement for Space Heating

Use	% of End Use for Space Heating	Share of Total Use	% of Total Use (% of End Use x Share)
Residential	32.3	34.3	11.1
Commercial	27.2	18.4	5.0
		Total % of Use	16.1

Because of its larger requirement for space heating - accounting for 11.1% of projected total electrical use - attention was first drawn to the residential sector. Here there were a number of conservation measures aimed at reducing the energy requirement for space heating, but in many cases much remained to be learned about their efficacy and cost-effectiveness. Hence, among our projects were studies of solar space heating, air infiltration, weatherization, and the like. Furthermore, many of the techniques and energy conservation measures tested in residences would apply to Bonneville Power's own reduction of energy waste in its buildings - a conservation measure mandated by Executive Order #12003 - and to commercial users.

The commercial requirement for space heating - 5.0% of total regional use - is considerably less than the residential - 11.1% - , primarily because the heat generated by lighting and equipment reduces a building's heating requirements. However, during the summer these same sources of heat increase the space cooling requirement for the commercial sector, accounting for 5.13% of the total regional electrical use. To address this energy problem we initiated a project to develop and test a prototype solar-assisted absorption air conditioner sized for commercial applications. This application of solar

energy, unique in the Pacific Northwest and one of the first of its kind in the nation, is currently being evaluated by BPA in three different locations.

Wherever possible, then, and where a project was determined to be feasible, effort was directed at resolving a conservation problem of considerable magnitude. Another target problem was reducing the electrical energy requirement for heating water, shown below:

Table 2. Requirement for Water Heating

Use	<u>% of End Use to Heat Water</u>	<u>Share of Total Use</u>	<u>% of Total Use (% of End Use x Share)</u>
Residential	22.0	34.3	7.5
Commercial	1.4	18.4	0.2
Industrial (approx.)	2.0	47.3	0.9
		Total % of Use:	<u>8.6</u>

According to present BPA research data, replacement of conventional resistance element water heaters by heat pump or solar water heaters could bring about an estimated reduction of nearly one-half of electrical consumption now devoted to this use. The 4.3 percent of total electrical consumption in the West Group area which could be saved by this hypothetical changeover from resistance heating is equal to 57,620 megawatthours, or the equivalent of the yearly electricity needs of approximately 340,000 homes. The magnitude of the potential benefit, along with the feasibility of the project, was decisive in testing a prototype heat pump water heater in BPA's Midway Residential Community.

Interest in energy conservation measures which displace electricity - such as solar space heating and solar water heating - led to the exploration of applications of alternative sources of energy that produce electricity. Two such sources, solar cells and wind power, have been the focus of projects involving the Division of Substation and Control Engineering. In cooperation with the Department of Energy, BPA has implemented a photovoltaic program to explore the potential of solar cells and a project to build and test three large Mod-2 wind generators.

The selection process completed, a number of projects were initiated. These made up six major groups. First was field testing of energy saving installations and equipment at BPA's Midway Substation residential community. Second was implementation of energy conservation measures in BPA's own buildings. Third was research in passive solar energy applications. Fourth was the development and testing of a prototype energy retrieval and active solar heating and cooling system. Fifth was the development of pilot project to monitor energy usage. Sixth was research in photovoltaic cell applications. Finally, there was field testing of wind generators. The most extensive of these sub-programs has been that involving the Midway Substation community. The BPA-owned residences of the substation, located some 35 miles northwest of Richland, Washington, provided an excellent site for a number of test projects. BPA's Ross Control House Substation facilities were to provide

means of testing a prototype energy retrieval and active solar system of interest to industry. BPA's buildings were another source of study: our goals were to exceed the requirements of Executive Order #12003, both in retrofitting existing buildings and in the design of new ones, such as the Ross Complex Construction Services Building, now in the preliminary design stage. In some cases, Bonneville invested in new facilities—for instance, wind generation units are being built and tested in the Goodnoe Hills near Goldendale, Washington.

Actual groundwork on the various projects selected began with installing equipment and instruments—in the case of Midway community a miniature weather station—and means of relaying data to BPA's Portland, Oregon offices, e.g., through microwave transmission. Computer programs were designed to handle incoming data. In some cases, following installation of data gathering equipment, machinery had to be modified or designed, and, since some of these machines were prototypes, closely monitored for mechanical problems. BPA personnel had to be instructed in use of instruments and care of equipment. Consultants and contractors had to be selected.

By mid-1978 most projects were well underway, and were to proceed at an uneven pace. As might be expected from the variety of its activities, ranging from straightforward testing of equipment to study of complex phenomena, energy conservation research and development had to be flexible and open-ended. Overall, energy conservation research and development has become a slowly evolving, constantly changing endeavor alert to new technology on the one hand, and on the other constrained by its dedication to finding practical, economical measures that prevent energy waste.

Under current consideration are a variety of additional projects, many involving waste in residential energy use, such as the "House Doctor" program (diagnosis of sources of energy losses by trained technicians), home energy management systems, energy storage heating units, the heating-only heat pump, and the impact of attached greenhouses on energy use and daily conditions of living. Others under consideration have wider application—automatic reduction of interior lighting, peak-load management, control of electric motors by the Nola Power Factor Controller—or approach basic research, as in photovoltaic applications. In all cases, selection of a project will have as an overriding determinant potential kilowatt and dollar savings. However, bulk potential benefits will be weighed with other, equally important factors: the feasibility of a project, the soundness of its methods, reliability of data, and long range significance of its results. Thus, a project attacking waste in only a small part of overall regional energy consumption may be selected because of high prospects of success and because its results can be widely applied. For example, in the Northwest nuclear and coal-fired plants produce only a small part of electrical generation, but their energy waste is high:

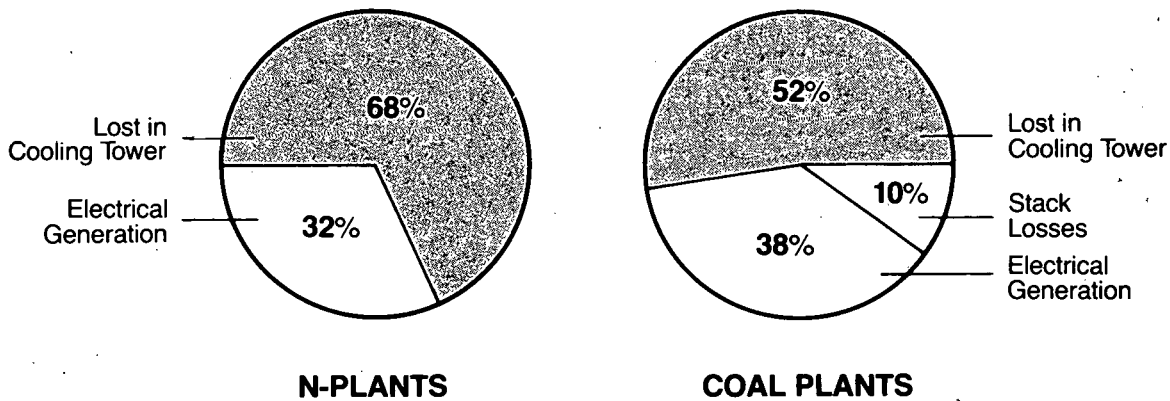


Figure 2. Energy Loss in Electrical Generation

If it does not lower generation efficiency, retrieval of a portion of the energy now lost in cooling towers can be a substantial saving. The technology exists whereby waste heat can be utilized. Furthermore, energy retrieval techniques developed in this kind of project might well be applicable to other industrial situations. Here in this example, as elsewhere in our choice of projects, immediate goals of reduced electrical use are balanced off with long range benefits and practical considerations of cost-effectiveness of money and effort expended on a project. Thus, BPA's Division of Substation and Control Engineering is actively weighing a number of possibilities; their variety and scope attest to the dynamic character of its research and development program.

It is because of this multiplicity of projects, their unique character, and their different stages of completion that this interim report is divided into six major sections and describes progress under the following headings:

- . Tests of conservation measures at Midway community.
- . BPA's internal energy audit and conservation measures fulfilling Executive Order #12003.
- . Research into passive solar energy applications.

- . Development and testing of energy retrieval and active solar-assisted heating and cooling.
- . Development and testing of a system for monitoring industrial energy usage.
- . Research into photovoltaic applications.
- . Development and testing of wind generation units.

Each section of this report, then, can be considered a separate description of the status of a particular sub-program. Where noted, there are individual technical reports on specific projects completed, or are forthcoming on projects soon to be completed. These technical reports are available by request.

## MIDWAY COMMUNITY ENERGY CONSERVATION PROGRAM



Figure 3. Midway Community

### OVERVIEW

Research and development at BPA's Midway Substation residential community comprises a number of test projects having to do with space conditioning (heating and cooling) and water heating. Conservation measures have been taken to save energy in both areas, and tests have been run, or are being run, on their effectiveness. Those projects having to do with space conditioning involve weatherization (insulation, ventilation, storm windows and doors), air infiltration, and solar heating. Those projects concerned with water heating involve three kinds of equipment: heat pump, solar, and point-of-use water heaters.

Of the seven projects originally planned, three are substantially completed. Testing of the energy saving and reliability of a prototype heat pump water heater has shown that when in trouble-free operation, the unit offers a 48 percent saving of energy compared to that used by conventional resistance heaters. Results of the weatherization study suggest that installing storm doors and windows is a more effective energy conservation measure than supplementing existing insulation. A study of air infiltration is completed, and a report is currently being prepared.

Projects under consideration for the future include testing a cost-effective means of reducing air infiltration, study of the causes and remedies of high or low relative humidity in homes, development of economical solar heat storage, and evaluation of passive solar energy collection by greenhouses attached to homes.

## INTRODUCTION AND BACKGROUND

Bonneville Power Administration's Midway Substation Residential Community has been the setting for a variety of energy conservation projects, primarily because it is a site offering unusual advantages for testing and an excellent situation in which to do a statistical home energy study. A good many studies of residential energy use lack statistically valid results either because there are too few houses under study or the houses are geographically separated, with different environmental influences acting upon them. Neither is the case with Midway. Furthermore, Midway has cooperative, knowledgeable BPA personnel who have actively participated in experimentation and the monitoring it entails. Early in 1978 preliminary plans were made for selective alteration of 13 of the community's 18 houses, five being left as a "control" group in their original state.

The design of investigation for the Midway program was provided by the staff of the Research Division, College of Engineering, Washington State University, Pullman, Washington, and has been implemented in the projects underway. The design of investigation is intended to avoid potential problems of variances and statistical validity that could impair results, and to provide a firm basis for the program as a whole with consistency of method for the projects composing it. The underlying goals of research design were twofold: to assess the effectiveness of established treatments to the houses (insulation, storm windows, and the like); and to investigate treatments of a more experimental nature (solar water heating, heat pump water heating, etc.), the results of which may or may not be cost-effective, but which can provide energy savings.

Once the design of research was established, and appropriate projects chosen, instrumentation was installed and a data acquisition system implemented. In order to measure specific climatic conditions which would affect much incoming data, a miniature pole-mounted weather station was installed:

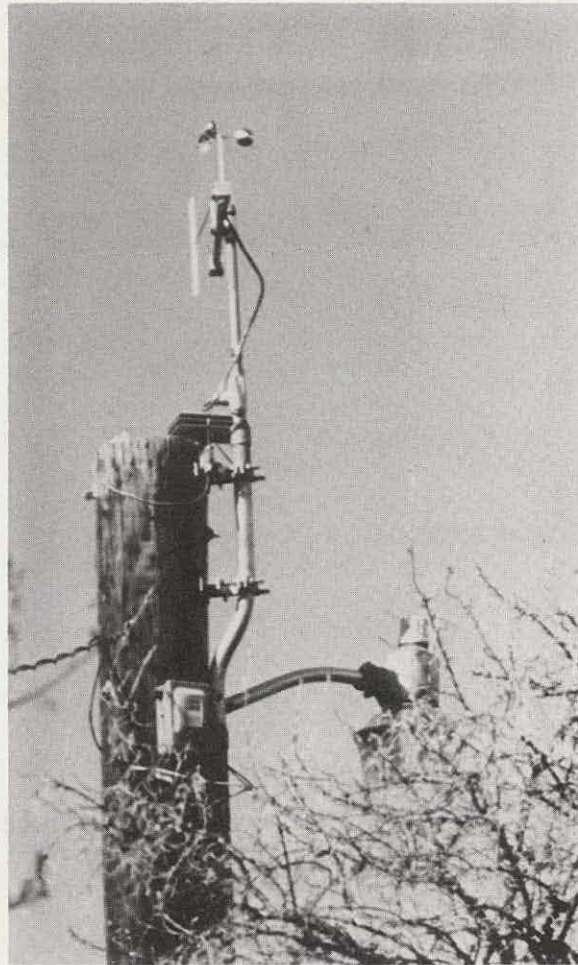


Figure 4. Pole-Mounted Weather Station at Midway

Kilowatt-hour meters were installed, along with humidity sensors, timing devices, temperature sensors, and a number of flow meters, but because of heavy workloads on Midway personnel, complicated by the effects of ash fallout from the eruption of Mount St. Helens, only the kilowatt-hour meters and, later, the humidity sensors were wired.

The complete data acquisition system consists of 216 channels (12 per house) hard wired to a computer terminal at Midway which transmits the 15-minute interval data to a central BPA computer in Portland. The data are then forwarded to Washington State University in the form of 9-track data tapes for analysis. Of the available 216 channels, however, only 76 were wired and available to relay data during the collection period which began in January 1979. Additional sensors were wired in October 1980 and there are now 133 channels available, providing data for much more detailed analysis. Analysis of the data collected thus far and what results could be determined at the

time were reported to BPA by Washington State University in July 1980. On the whole, this report is the basis for the descriptions of the status of projects to follow.

#### Data Acquisition System/Instrumentation

Because of cost considerations, a data acquisition system was not designed specifically for the Midway program; rather, an existing system was used, suitably modified for this particular application. Partly because of the limitations of the system, and partly because of the difficulties that could be expected in maintaining and repairing equipment in such a remote location as Midway, there were hours and sometimes whole days when data were not available. Due to the specialized nature of equipment—machinery itself, such as the prototype heat pump water heaters, as well as instruments—expeditious repair or adjustment could not be done by local contractors, nor by BPA personnel busy with their own tasks in operating the substation. On occasion, the result was failure of a mechanical component, with consequent loss or skewing of data. Still, the system operated reliably over 90 percent of the time, and, considering the number of other variables that entered into final calculations of results, its performance was more than adequate. In retrospect, it appears doubtful that the considerable expense of a custom-designed system would have been justified by slightly more precise results: breakdown of prototype machines no doubt would have still occurred, and the remoteness of the community would have still been a factor. Instrumentation was to be in two phases, the first in operation by July 1978, the second by October 1980. Among the first installations was a weather station recording ambient temperature, wind speed, wind direction, and solar insolation. Seventy-two kWh meters, four per house, were installed to record measurements of space heating, space cooling, water heating, and total use. Later, four humidity sensors were installed. The second phase of instrumentation concentrated on measuring use of energy for heating water, and included temperature sensors, kWh meters, and a number of flow meters (e.g., cold water inlet to hot water tank, shower lines, point-of-use water heaters). With calibration channels, this instrumentation now provides 133 channels of incoming data.

#### Space Conditioning Projects

Under the current research design by the College of Engineering, Washington State University, projects making up the Midway Program fall into two groups, those having to do with space conditioning and those having to do with water heating. Of the space conditioning group, weatherization and air infiltration tests are completed in their field work and analysis. Technical reports are being written on each.

Weatherization: Using the five "control" houses left in their original state as a basis for comparison, the testing of weatherization measures taken on 13 residences provided data for estimating the energy savings and cost-effectiveness of various treatments for the homeowner.

Two groups of test homes were modified: the first group had existing insulation supplemented only. Fibrous insulation was blown into attics to a depth of about seven inches, bringing them to a rating of R30; ventilation ports were installed in the roofs. Crawl space perimeter insulation was fiberglass batting with an R19 rating; a vapor barrier of sheet plastic was laid down on the floor of houses having a crawl space rather than a full basement. Caulking was done where the floor joists joined the concrete foundation. The second group of houses received this same treatment, and, in addition, was fitted with storm windows and doors.



Figure 5. Storm Window Installation

Data were collected for 12 months on the entire group of 18 houses before treatment to provide a basis for comparison. After the 13 houses were retrofitted, data were collected between December 15, 1979, and April 15, 1980. Treated houses were studied as a group and individually, since the living pattern of occupants could vary markedly from house to house, with one family preferring a higher inside temperature than another or using outside doors more frequently than another. Furthermore, structural differences in the homes, which were not all built at the same time, and other variables had to be taken into account.

Data were analyzed by two methods: measuring the rate at which an individual house uses energy before and after retrofitting, and comparing the mean energy use of a group of similarly modified houses. The two methods yielded somewhat divergent results, probably due to the differences arising from the residents' living habits. When the results of the two analyses were averaged, they showed that added insulation alone produced a 13.4% energy savings over prior consumption, while added insulation plus storm windows and doors produced a 29% energy savings over electricity used before the houses were modified.

An important goal of the weatherization work at Midway community is to determine the cost-effectiveness of the various weatherization treatments. The basic data for a Net Present Value analysis - installed cost and annual savings in kilowatt hours - are shown below in Table 3, which also provides dollar savings on the basis of 3¢ per kWh, currently typical in the Pacific Northwest. The figures represent the average investment and saving per house.

Table 3. Investment in Weatherization Measures at Midway

<u>Energy Saving Measure</u>	<u>Installed Cost</u>	<u>Annual Savings in kWh</u>	<u>Value of Energy Saved, at 3¢ per kWh</u>
Added Insulation plus Storm Windows and Doors	\$4,023	6630	\$198.90
Added Insulation Only	\$1,860	3059	\$ 91.77
Storm Windows and Doors Only	\$2,163	3517	\$107.13

The installed costs of the modifications - cost of materials + equipment + installation - ran uncommonly high, primarily because of the remote location of Midway (37 miles from the nearest sizeable town). Estimates for similar modifications, had they been done in Pullman, Washington, ran 40% less than the costs incurred at Midway. In practice, however, many homeowners weatherize their own homes, or do a substantial part of it, themselves. Were a homeowner to weatherize his home himself, his investment might run as low as 25% of the installed costs at Midway.

Preliminary analysis indicates that the energy saving measures of Table 3 are cost-effective, but it should be pointed out that such a determination cannot properly be made by the simplistic procedure of dividing installed cost by first-year savings. Rather, it is necessary to make reasonable assumptions for such items as electrical energy cost, escalation rate of electrical energy cost, general inflation rate, interest rate (discount rate), lifetimes, salvage values, maintenance costs, and then perform a Net Present Value analysis to find the rate of return on investment. A detailed analysis of the cost-effectiveness of weatherization measures is to be included in the Technical Report on weatherization studies at Midway, to be available June 1981.

Another goal of the Midway weatherization project is to determine the effects of house tightening on the environment within a residence. Increase in humidity, for example, may create discomfort for the occupants of a home. But even more important is the question of how weatherization measures affect the quality of the air inside a house. To answer this question, the Mechanical Section, in cooperation with Lawrence Berkeley Laboratory, will monitor the indoor quality of the Midway houses during 1981.

Air Infiltration: Another test project of the space conditioning, or heating and cooling, group of energy conservation studies at Midway community concerned air infiltration, or the passage of cold air into a house through cracks, holes for plumbing or wiring, and the like. Since air infiltration is a phenomenon which has only recently attracted the attention of researchers, and since structures vary widely in their methods of construction, quality of workmanship, and materials, this project was considered to be closer to primary research than to practical application. While it has been known for a long time that air infiltration losses of heat are a significant part of the total energy loss of buildings, understanding of the factors involved is less than complete. It is only recently that satisfactory methods for measuring air infiltration losses have been developed, and as for measuring actual energy losses, little work on methods of measurement has been completed. Thus, much of this project has been concerned with these fundamental problems, as well as with questions of cost-effectiveness of "house tightening" measures.

Testing consisted mainly of measuring air infiltration before and after modifications (added insulation, caulking, storm windows and doors, etc.) which could be expected to "tighten" a house. The primary technique for measuring the effects of these modifications is to install a reversible, variable speed blower mounted in an expandable door that replaces the entry door of the house and is taped at the joints to eliminate drafts. The installation is shown on the following page:

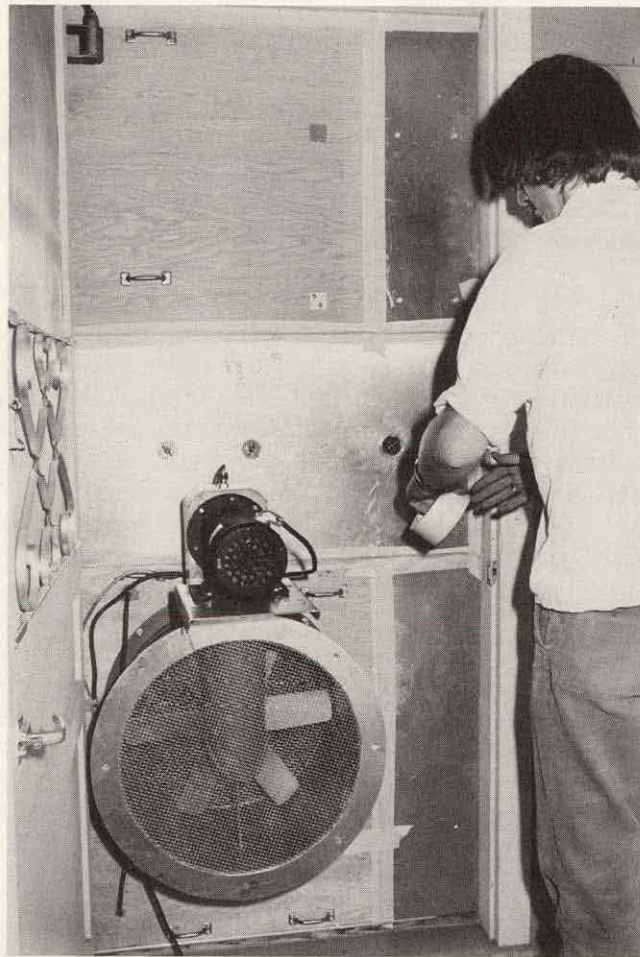


Figure 6. Blower Door Installation

An indication of "tightness" is obtained by recording the blower's speed while the house is being pressurized or depressurized, and the pressure differences between inside and outside. This test procedure was augmented by "smoke tests" and infrared scanning to pinpoint significant heat leaks or points of infiltration of cold air. The 18 test houses were thus measured before and after modifications.

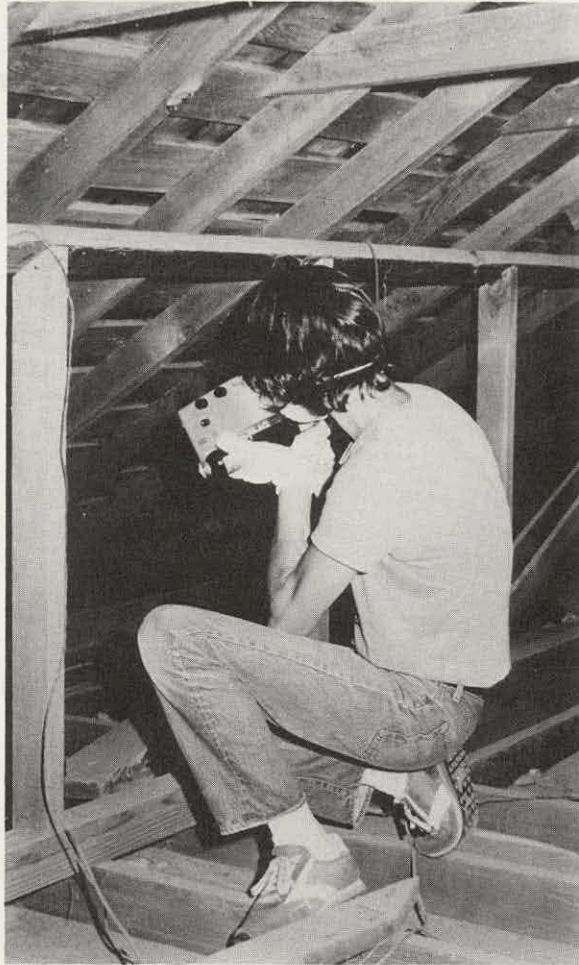


Figure 7. Infrared Scanning for Air Infiltration

Testing was done by Dr. David Grimsrud and his assistants from the Lawrence Berkeley Laboratory, Berkeley, California. Pre-modification measurements of infiltration were taken from September 4 to September 6, 1979. Results were forwarded to BPA on September 28, 1979. Measurements of air leakage in modified houses were taken from May 13 to May 15, 1980, again, by personnel of the Lawrence Berkeley Laboratory.

Results were compared with those measurements taken before retrofitting. As expected, there was no significant change in the amount of air infiltration in the five houses left untreated as a "control" group. And surprisingly, there was almost no reduction in air infiltration in those houses with added insulation only. But in the houses retrofitted with added insulation and storm windows and doors, there was an 18% reduction in air infiltration. Thus, the results of not only the Weatherization project but the Air Infiltration project as well clearly suggest that the addition of storm windows and doors can be a significant energy conservation measure for the homeowner.

But even more significantly, the techniques used in the Air Infiltration project were able to trace the sources of air infiltration in the houses at Midway. Once leaks and bypasses that admit cold air into a house have been identified, the house can be "tightened" to reduce energy losses even more. Systematic techniques, sometimes called "house doctor" procedures, need to be developed and tested, and to this end a House Tightening project is planned for Midway during FY 1981.

Solar Heating With Storage: Another test project associated with the space conditioning group of conservation studies at Midway concerns a system with an outer wall-mounted solar heating unit associated with a heat storage box. Of considerable interest is the potential of such heat storage systems for load-leveling, the reduction of the power load of a supplier during hours of peak demand. While solar systems utilizing heat storage have not had widespread application, commercially marketed units are currently available, and the project should ultimately help to determine the energy savings afforded by such a system and the problems, if any, associated with its installation. Fully monitored operation began October 1980.

Comprising six flat plate solar collectors mounted on and parallel to the outer south wall of house #19, and taking up about 8 feet x 20 feet of wall space, the solar system uses air rather than water as a medium of heat transfer. Heated air collected by the plates is supplied by a fan, with dampers and controls, to the house in various modes of utilization. Direct solar space heating is provided by forced air duct; a 10 kilowatt resistance heater is installed in the duct as partial supplement to energy supplied by the solar collectors, or, in times of no solar radiation, as the primary heat source for the house. When space heating demand has been met, solar energy is used to heat water; solar energy in excess of these demands is stored in "trays" of phase-change salt contained in a box in the basement of the house, to be released upon need for space heating. The collectors and the installed heat storage unit and fan system are shown below:

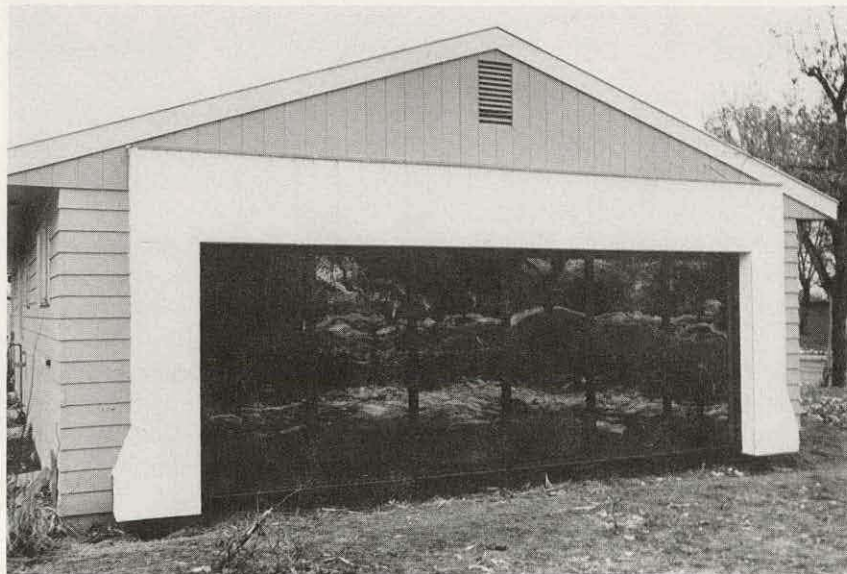


Figure 8. Wall-Mounted Solar Collector Array

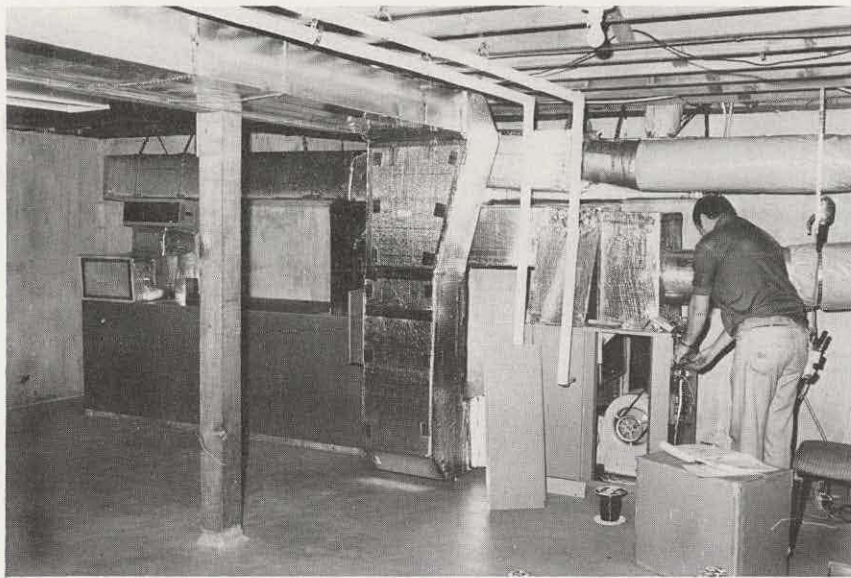


Figure 9. Solar Heating System with Storage

The major part of the system was installed in December, 1979; storage trays were installed in February, 1980. Data have been collected on the total energy use of the system. Fully monitored operation began in October 1980, with data to be collected until the end of September 1981, after which a final report will be written.

## Water Heating Projects

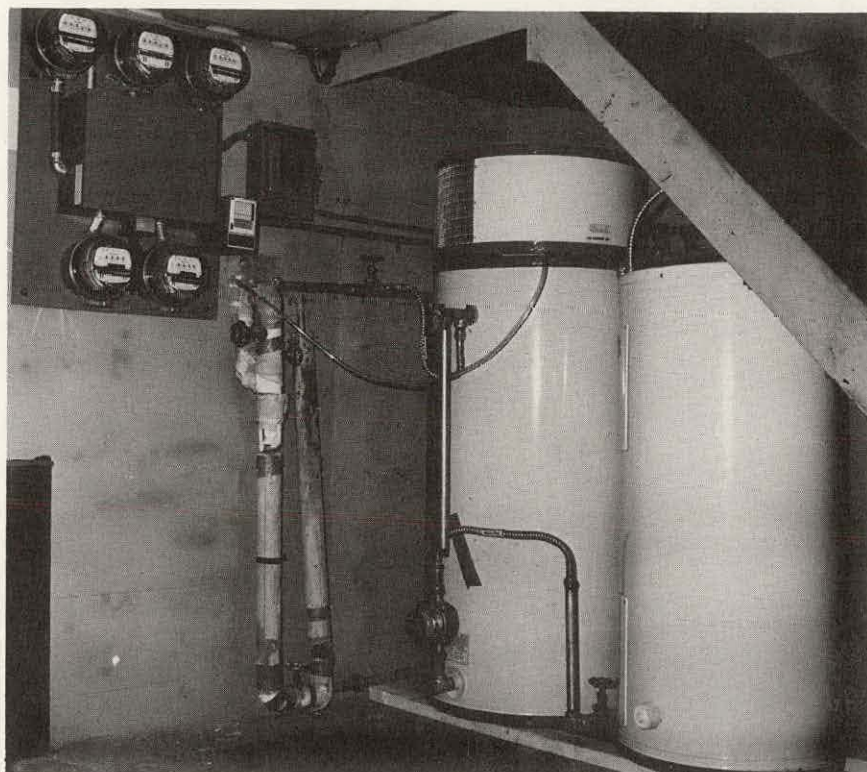


Figure 10. Heat Pump Water Heater Installed

Still largely in the data-collection stage, the Midway projects involving water heating have not progressed to the point of analysis by the primary investigators, the Research Division of the College of Engineering, Washington State University, although a BPA study of one of the projects has been completed. The three projects in this group are those testing the heat pump water heater, various kinds of solar water heaters, and point-of-use resistance heaters.

The Heat Pump Water Heater: The Mechanical Section of the Division of Substation and Control Engineering participated in the testing of five prototype heat pump water heaters, a project which served a national program conducted by the Department of Energy as well as the Midway study. Five "Temcor" heat pump heaters were purchased by Bonneville Power Administration for testing at Midway. Testing of the prototype units, manufactured by Energy Utilization Systems, Inc. of Pittsburgh, Pennsylvania, was chiefly to evaluate this mode of heating as part of the total Midway Program. However, evaluation of the reliability of the units themselves became a further goal because BPA participated in a national testing program of 100 of the units sponsored by the Department of Energy. This aspect of the heat pump water heater—evaluation of reliability and of performance of a prototype unit—has been completed, and a technical report of findings published by BPA. Further

testing and comparison with other modes of water heating are continuing as part of Washington State University's study of water heating at Midway.

In general, a heat pump water heater works much like an air conditioner, except that it pumps heat from the surrounding air into a hot water tank rather than outdoors; it can draw heat from such areas as basement, garage or utility room. In the case of the particular unit tested, components (compressor, evaporator, fan, etc.) are encased in a circular housing which is either incorporated into a unitized water tank-heat pump or fitted to the top of an existing water heater. The "Temcor" unit used in the Midway tests is of the latter variety. Its configuration is shown below:

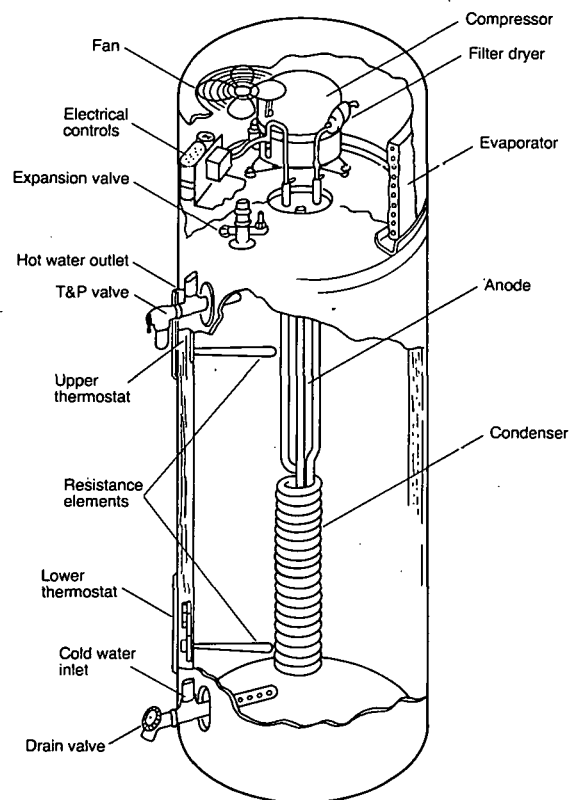


Figure 11. The "Temcor" Heat Pump Water Heater

The tests of reliability and overall performance of the prototype "Temcor" heat pump water heater showed somewhat mixed results. Both unitized and retrofitted units were tested over an eight-month period, and both kinds of prototype units showed mechanical failures or problems requiring repair,

sometimes modification. Reliability, then, was difficult to assess, the more so because the units were prototypes. Overall performance was affected by unreliable operation. Depending upon how performance was measured, the units showed promise of considerable energy saving—close to that of an Oak Ridge National Laboratory simulated model. The heat pump water heater was evaluated in terms of the coefficient of performance (COP), the ratio between output and input, or heated water coming from the tank and heat supplied to the tank. The table below summarized three measurements of COP and the percent of energy savings they represent:

Table 4. Heat Pump Water Heater Test Results

	<u>COP</u>	<u>Energy Savings</u>
Eight-month Midway Community tests (average)	1.35	23%
Normal, Trouble-Free Operation, Midway	1.9	48%
Oak Ridge National Laboratory Model	2.1	50%

When free of the mechanical problems to be expected with prototype equipment, the units achieved a high coefficient of performance and a high percent of energy saved in comparison with the conventional electrical resistance heater. Furthermore, initial cost of the heat pump water heater is about one-third the cost of a solar-powered heater. For further details see the published Technical Interim Report, Midway Home Energy Conservation Project: The Heat Pump Water Heater.

Promising as these limited results are, they do not present the total picture of heat pump water heater operation in a family environment. Interior heat of some kind is drawn by the heat pump to supply the water heater tank; where this heat source comes from and how much is drawn may have significant impact on the overall energy use of a household. Since the Department of Energy-sponsored test focused on the prototype unit in isolation from such factors, it cannot be said to represent operation of the heat pump water heater fully. For this reason, and for reasons of full comparison of various kinds of water heating, the project is being continued as part of the Washington State University study of Midway energy conservation measures.

Solar Water Heating Systems: In addition to studying various modes of heating water, the researchers of Washington State University and of Bonneville Power Administration were interested in comparative analyses of different kinds of solar systems and their performance. Rather than one solar water heating system to be compared to heat pump and point-of-use water heating, five different solar systems have been installed at Midway. Wiring of the instrumentation to the computer was completed during October 1980, and data will be gathered on the performance of the systems to determine their comparison energy savings and cost-effectiveness. The remainder of this discussion, then, will describe each of the five systems.

The first solar system has three flat plate collectors mounted on and parallel to the south side of the roof. The heat transfer medium is water. When fluid temperature drops close to freezing, an air compressor is activated to "blow down" the water from the collector panels and piping into a storage tank.

After correction of an initial difficulty with the "blowdown" operation, the system has operated satisfactorily.

The second solar water heating system is similar to the first. It has two flat plate collectors mounted on and parallel to the south side of the roof; its heat transfer medium is water also. But instead of a blowdown of water to tank to prevent its freezing, there is a "draindown" of the water from collectors and piping to a waste dump. The water is replenished automatically when there is no longer any danger of freezing. The third kind of system has three flat plate collectors mounted on and parallel to the south side of the roof. Its heat transfer medium is "antifreeze," which circulates through collectors and a heat exchange tank.

The fourth solar system has an array of two vacuum tube collectors, mounted vertically on the exterior south wall of the house. It uses "antifreeze" as a heat transfer medium.

The last solar water heating system is also wall-mounted, but uses air as a heat transfer medium, and circulates the air by fan equipped with damper and controls. The system also heats space and stores heat. It has been described earlier in this report (see Solar Heating With Storage, page 18).

The various solar water heaters have had no significant operational problems. Data currently being gathered on their performance will be analyzed to determine if, as estimated, such solar systems can bring about a reduction of fifty percent in the energy used to heat water by conventional electrical resistance units. Work on the project is scheduled to be completed in March 1982, with a technical report to follow.

Point-Of-Use Water Heaters: Another mode of water heating to be under study soon is point-of-use, or post-heating of water already heated by a conventional electrical resistance element. The point-of-use units are rated at 4,600 watts at 220 volts, and can raise water 31° F. (3/8 inch line, water at 60 pounds per square inch). Since point-of-use heating allows the main water tank temperature to be turned down to 110° F., measurement will be of total energy saving, if any, by reducing tank losses.

Units are installed under the kitchen sink in the hot water line since their main use will be in dishwashing; the electric dishwashers at Midway are of the portable type, attached to the kitchen sink hot water faucet. Instrumentation is installed, and data gathering began October 1980, with analysis and technical report scheduled for January 1982.

#### SUMMARY

The studies of energy conservation in the Midway Substation residential community are varied and rich in potential contribution to theory and application. In the table below the various projects are indicated in terms of actual installation of energy conservation measures:

Table 5. Modifications of Midway Residences

<u>Type of Modification</u>	<u>Number of Houses</u>
Increase of insulation level	6
Insulation plus storm windows and doors	7
Heat pump water heater installed	5
Solar water heater installed	5
Point-of-use water heater installed	4

Overall, studies on space heating are nearing completion or are completed; studies on water heating are still in progress, with their most important results to appear in 1981.

Meanwhile, the Midway program has generated a number of lines of potential research and development. The most promising of these are currently under consideration:

- o House Tightening Project--study of corrective measures for tightening houses against heat loss.
- o Heating-Only Heat Pump--evaluation of effectiveness of a heating-only heat pump for the Pacific Northwest.
- o Home Energy Storage--evaluation of energy storage unit in a home and measurement of its effectiveness in load management.
- o Passive Solar Energy Collection by Greenhouse--evaluation of greenhouses, atriums, or "sunspaces" as collection devices, as well as architectural enhancements.

Whether these particular or other projects are chosen will, of course, depend upon complex factors and priorities of funding. But it would appear that Midway community will continue to be a unique living laboratory contributing to the wider needs of energy conservation in the Pacific Northwest and the nation.

BONNEVILLE POWER ADMINISTRATION'S  
INTERNAL ENERGY AUDIT AND CONSERVATION MEASURES  
UNDER EXECUTIVE ORDER #12003

OVERVIEW

On July 20, 1977, President Carter signed Executive Order #12003, in which he called for conservation measures to be implemented to reduce energy usage in Federal buildings. Concerned with savings in fuel for combustion engines as well as energy consumption in structures, Executive Order #12003 used the President's powers under the Motor Vehicle Information and Cost Savings Act and the Federal Property and Administrative Services Act of 1949 to mandate an eight-year plan for energy conservation through a wide variety of measures. Those structures mentioned in the Order which applied to BPA were office buildings and storage facilities, but leeway was left to include such other structures as was deemed appropriate. Thus, Bonneville's interpretation of structures to be modified for energy efficiency could be broader than the Order's stipulation of buildings "more than 5000" gross square feet of space, and more inclusive, even, than the Department of Energy's later stipulation that buildings of over 1000 gross square feet of space be audited and modified, if needed, to conserve energy. All BPA owned buildings of over 1000 square feet of space (205 structures) underwent an energy audit, and smaller buildings (480 structures) also are being retrofitted with energy saving equipment.

Moreover, the Executive Order's conservation goals of 20% reduction in energy use from 1975 levels for existing building, and 45% reduction for new structures, were considered minimal—a starting point rather than an outer limit of our conservation efforts. While some buildings, due to their construction, could be economically retrofitted, that is, modified or their equipment altered, to achieve only a 10% energy saving compared to their energy consumption in 1975, others could be retrofitted to accomplish as much as 45% energy saving. Currently, BPA has achieved well over a 20% average with buildings over 1000 square feet space that have been retrofitted. Energy savings with its more numerous smaller structures are also estimated to be well over 20%, but have yet to be calculated precisely. Our new buildings will exceed the energy conservation requirements of the Executive Order by a substantial margin. Finally, Executive Order #12003 mandates an eight-year plan to achieve its goals; BPA will have achieved or surpassed these goals in six years for all of its existing buildings.

AUDIT OF ENERGY USE

One of the requirements of E.O. #12003 was to conduct preliminary audits of energy use in existing buildings to determine the size of the building, energy use level and major energy using systems. These audits were to be followed by a detailed survey to assess energy consumption and determine potential areas of conservation. Since BPA staff had records providing much of the information needed for audits, they were able to combine the audit and survey steps, thus reducing personnel time and costs. The survey included auditing and analysis of loads; analysis was done by computer modeling techniques since most BPA buildings do not have their energy consumption metered individually.

Staff of the Division of Substation and Control Engineering prepared survey checklists and forms, and trained personnel of Operations and Maintenance in their use. On-site inspection of BPA structures was conducted during the period March 1, 1978 to October 1, 1979. Inspection consisted of actual observation of a building, including consultation of its architectural drawings where necessary; interview of its occupants as to use and work patterns; location of problem areas of energy use; and compiling of results of inspection into a summary report.

Results of field inspection were then compiled and used to model each building by means of computer simulation. Energy use in BPA's buildings was modeled through computer programs available from Energy Management Services of Portland, Oregon. This simulation-modeling allowed for ranking buildings according to their energy efficiency and for clear indication of the most productive conservation measures that could be implemented in each case. The most energy-inefficient buildings, then, were targeted for retrofitting first.

The criteria by which specific conservation treatments were ranked are as follows:

1. Energy saving in relation to dollars invested over the life of the building.
2. Energy saving in relation to dollars invested per year.
3. Payback period, in non-discounted dollar return.
4. Payback period, in discounted dollar return.
5. Ratio of dollar savings to dollars invested.

These criteria are compatible with the Executive Order's requirement that agencies improve buildings in a manner consistent with standards established by the Director of the Office of Management and Budget, and set out in OMB Circular A-94.\* All in all, the BPA approach was to single out the least energy efficient buildings, to focus on the most cost-effective improvements that could be made to them, and to give implementation of these improvements first priority.

#### ENERGY CONSERVATION MEASURES TAKEN AND TO BE TAKEN

As a result of its preliminary energy audits, BPA initiated a retrofit program, with the first nine contracts issued in October, 1978. Since each building has unique structural features, retrofitting was to proceed unevenly. Some buildings required only added insulation to reduce heat loss; others required modification of heating and air conditioning equipment; others required only more efficient thermostats. Whatever was cost-effective and available on the market was used, as long as the measure produced quantifiable savings in energy of significant magnitude. As of now, 38 of Bonneville Power Administration's buildings over 1000 square feet have undergone various kinds

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\* BPA used discounting guidelines set down by the Water Resources Council rather than those of Circular A-94.

of retrofitting, including added insulation, replacement of heating and air conditioning equipment, weatherstripping, and installation of "spring timer" or clock-regulated setback thermostats which reduce heating energy by maintaining a cooler building, usually at times when the building is unoccupied. Although not required by Executive Order #12003, conservation measures have also been undertaken for smaller buildings as well.

Most of the measures taken on the 38 buildings that have undergone retrofitting, and on the approximately 165 buildings to be retrofitted within the next three years, are standard practices utilizing available materials, equipment, and technology. Others are innovative, and apply mainly to new building design, while still others are undergoing research and development to find more effective means of reducing wasted energy in day-to-day operations--for instance, use of solar driven absorption chillers for cooling (see next section of this report). Innovation and use of "state-of-the-art" developments in the field of energy conservation, however, have not been primary goals of this program. Rather, they have been by-products of an effort subject always to requirements of cost-effectiveness and to the greatest energy savings for each dollar expended.

In calculating savings, total dollar expenditure for a particular retrofitting is not necessarily an indication of effectiveness. Energy conservation measures planned for the Dittmer Building, Vancouver, Washington--a structure of nearly 130,000 square feet containing the computerized control and load management system of BPA--call for an investment of some \$440,000, primarily for installing a heat recovery chiller in the air conditioning system. By contrast, installation of setback thermostats in a number of small buildings has cost between \$150 and \$500 per building. While the savings predicted from the Dittmer retrofit are very large when compared with those available from a single thermostat change in a smaller building, the collective energy savings brought about by use of the thermostats has been more substantial than their low cost would suggest. Any modification of an existing building is determined by energy conservation compared to dollar amounts invested, meaning that each measure taken must produce substantial dollar savings in the form of lower energy use.

#### ENERGY CONSERVATION MEASURES PLANNED FOR NEW BUILDINGS

As with determining specific energy conservation measures in retrofitting existing buildings, new construction for Bonneville Power Administration must meet or exceed the standards set down in Executive Order #12003 and in the National Energy Conservation Policy Act, while being cost-effective. Cost-effectiveness is measured by a discounted "pay-back" period, usually a maximum of 10 years, during which time the value of the energy savings must be equal or larger than the amount invested for each particular conservation feature. Executive Order #12003 required that design of new buildings shall have as a goal "a reduction of 45 percent in the annual energy requirements per gross square foot of floor area in 1975".

Calculations of actual energy requirements are based on the consumption of energy by an "Assumed Average Building" in 1975, determined by the General Services Administration (GSA) to be 37 kWh/s.ft./yr. For purposes of

comparison, such a building is arbitrarily rated as 0 percent energy efficient. Requirements for new commercial buildings set by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in their Standard 90-70 include a reduction in energy consumption of 36 percent, or 23.6 kWh/sq. ft./yr. The General Services Administration has called for a reduction in energy use of 60 percent in its new buildings. When cost-effective criteria can be met, design goals for BPA's new buildings are to exceed this level of energy efficiency.

#### SUMMARY

Because of the considerable number of its buildings (205 are over 1000 FT<sup>2</sup> in size) and the great variety of their structural characteristics, BPA's energy conservation measures taken in response to Executive Order #12003 are difficult to summarize. The work of retrofitting is currently underway on some structures, with funds allocated for improvement of some others. Even where work has been completed there is often insufficient history of energy use after retrofitting to quantify effectiveness with reasonable certainty--performance over one heating season, for instance, may or may not be representative of energy efficiency for heating in the future. In general, however, conservation measures have significantly exceeded 20% energy savings over energy consumption of the "1975 building", in individual structures, achieving as high as 40-55% saving in buildings with 8-hour-per-day use and for structures occupied intermittently, considerably less for buildings used 24 hours per day. With only 19% of its buildings retrofitted, BPA has already achieved a level of 6.5% energy savings in its buildings overall. As accurately as it can be summarized, BPA's progress to date and future projections of its internal energy conservation are shown graphically on the following page:

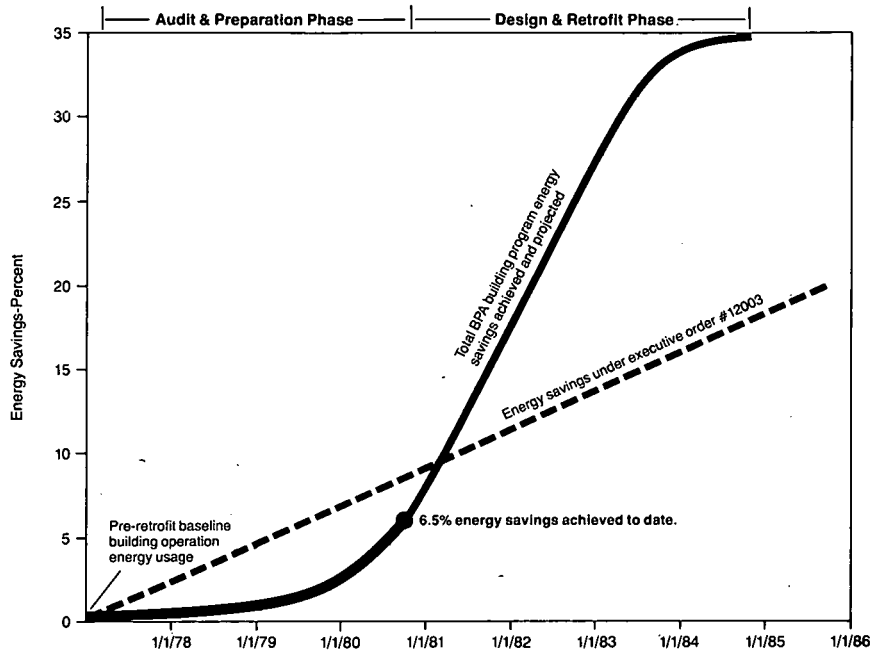


Figure 12. BPA Energy Savings Compared to Goals of Executive Order #12003

While predictions beyond 1983 cannot be made with much certainty, it can be expected that Bonneville Power Administration will continue to pursue its high goals of energy conservation, consistent with its position as a leader in the field and its responsiveness to regional and national needs.

## PASSIVE SOLAR APPLICATIONS IN ARCHITECTURE

### OVERVIEW

Closely related to Bonneville Power Administration's response to Executive Order #12003 is work in passive solar applications in architectural design. Whereas the retrofitting and energy efficient design of BPA's buildings use a variety of conservation measures, passive solar applications constitute a somewhat special category of techniques whose overall aim is the siting and construction of a building so as to take full advantage of natural, low cost sources of energy. Passive solar applications are not added to a building, but rather are parts of its essential concept as a structure and a working or living environment.

Involvement of the Division of Substation Control and Engineering in passive solar applications comes about because much of the design of BPA's own buildings is done by the Division's Architectural Section. In achieving energy efficiency the staff of the Architectural Section has studied a variety of solar applications and, wherever cost justified, has included them in design. Of these, some of the most cost effective are careful use of site, orientation of the building, and inclusion of structural features that can lead to long-range energy savings applications. The work of the Architectural Section complements that of another BPA unit, the Branch of Energy Conservation, which fosters implementation of energy conservation practices in construction generally. Passive solar applications in BPA's buildings, then, are not only demonstrations of BPA commitment to energy conservation, they are embodiments of design concepts that may have far-reaching impact on construction practices in the Pacific Northwest.

### PASSIVE SOLAR APPLICATIONS

To date the only application of passive solar principles in a BPA building has been in the Keeler Maintenance Headquarters, near Hillsboro, Oregon. The building houses power system control and system protection maintenance shops and offices, along with other substation shops and facilities. Out of the total building (4,040 square feet of floor space), an area of 1,290 square feet used for office and workshop space was selected as appropriate for passive solar applications. These include use of direct heat gain through south-facing windows and roof-mounted clerestory windows, shown on the next page:

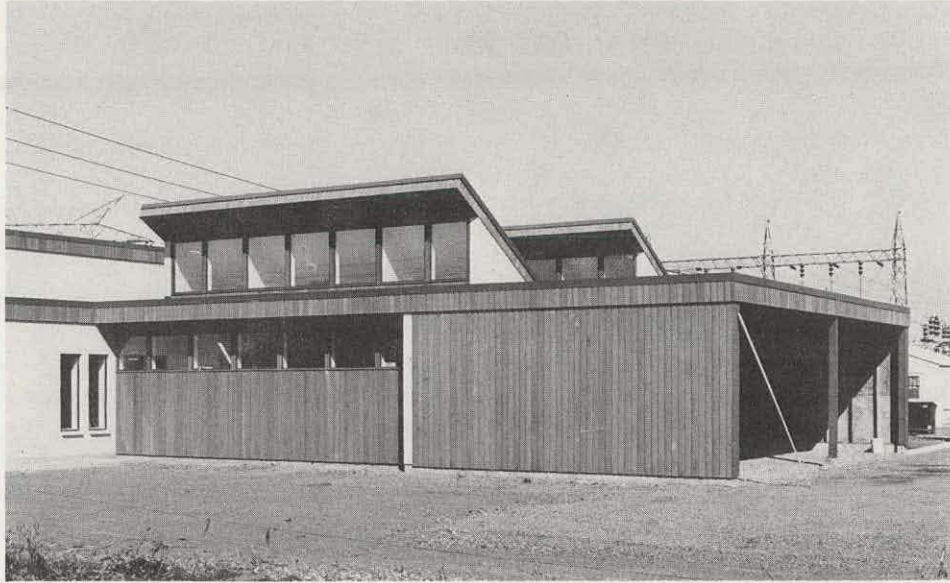


Figure 13. Keeler Maintenance Headquarters

Sunlight passing through these windows strikes two interior thermal storage walls which absorb heat during the day and release it slowly at night. Supplemental heat to the space is provided by a heat pump. The Mechanical Section of the Division of Substation and Control Engineering will monitor the energy usage of the building during the heating season to determine the effectiveness of the conservation measures.

Proposed passive solar application projects include the study of greenhouses attached to residences (Midway Community) and development of design criteria for optimal energy efficient use of site, landscaping, use of indoor space, window location, heat gain storage, and other structural features. The Architectural Section will also be participating in design aspects of BPA's planned Energy Efficient Passive Solar Home Construction Pilot Program.

#### SUMMARY

Relatively young as an area of BPA's research and development in energy conservation, study and application of passive solar techniques in building design is growing as a necessary part of the effort to achieve high energy efficiency in structures. Though much can be accomplished by retrofitting existing buildings, ideally a building should be sited and constructed so as to utilize renewable, low cost sources of energy and to take advantage of a particular physical environment. Work on passive solar applications is directed toward this goal.

## ACTIVE SOLAR AND ENERGY RETRIEVAL PROGRAM



### OVERVIEW

The Active Solar Systems and Energy Retrieval Program consists of three projects, one on waste heat retrieval augmented by solar energy-assisted space cooling, now completed, and two on active solar energy utilization for space heating and cooling. The original project focused on using waste energy from a large transformer to heat a control house and on using solar collectors to drive an absorption air conditioner, or chiller, for cooling the Control House. Out of this project--Prototype Energy Retrieval and Solar (PERS) System--grew two others which concentrated on solar-assisted absorption cooling. These are located in a manufacturing plant in Tyler, Texas, and in BPA's Big Eddy Substation; their prototype systems are currently undergoing evaluation, to be completed in January and June 1981, respectively. Funding for the PERS System was provided by BPA. The other two projects are sponsored in part by the Department of Energy.

### DEVELOPMENT OF EQUIPMENT AND TESTING

During 1975-1976, under contract to BPA, the Mechanical Engineering Department of Oregon State University investigated the recovery of waste heat energy from transformers. The final report of October 1976 proposed several alternative systems, among them waste energy retrieval by means of a heat pump with solar assisted heating and solar absorption cooling. Design and implementation of such a system was contracted to Carrier Corporation, which developed a prototype for BPA's Ross Substation Control House in Vancouver, Washington. Installation of the Prototype Energy Retrieval and Solar (PERS) System was completed in June 1978. Contracts for a one-year evaluation of the system

were let to Oregon State University and Carrier Corporation; their reports were submitted on October 13, 1979, and January 1, 1980, respectively.

Evaluation of the PERS System by OSU and Carrier Corporation indicated that the air-to-water heat pump recovering waste heat energy had better performance than a typical air-to-air heat pump; however, overall performance of the waste heat retrieval system fell short of expectations, primarily because the top oil temperature rise, the difference between the transformer oil temperature and that of the ambient air, of the transformer was not high enough for efficient waste heat recovery. However, the PERS absorption chiller performed well. The performance goal for it at the outset of testing was a Coefficient of Performance (COP) of 0.70 at an entering collector fluid temperature of 180°F. During evaluation the chiller operated with a COP ranging from 0.60 to 0.73, even at relatively low collector fluid temperatures.

Based on these findings, modifications were made in the design of the absorption chiller. Two units were subsequently installed at Tyler, Texas, and BPA's Big Eddy Substation, The Dalles, Oregon. A major feature of these two units is factory-assembled, unitized packaging, which reduces installation time and cost and improves quality control, thus encouraging future commercial development.

#### STATUS OF PROJECTS UNDERWAY

The three projects included in the Active Solar Systems Program are each at different stages of development. The first stage of the PERS project has been completed; modifications and additional testing of the system have been proposed for FY 1981. The two other projects, focusing solar energy-assisted absorption cooling, are currently underway and are scheduled for completion in January 1981 and June 1981. The PERS project is described fully in a separate Technical Report, The Prototype Energy Retrieval and Solar (PERS) System.

#### PROTOTYPE ENERGY AND SOLAR (PERS) SYSTEM

The overall purpose of the project was to demonstrate the feasibility of recovering transformer waste heat and of using solar collectors to drive an absorption chiller for heating and cooling a substation control house. Two pieces of prototype equipment were developed: a heat pump to recover thermal energy from the cooling oil of a power transformer, and an absorption machine, or chiller, powered by solar collectors to cool the building. Whether assisted by waste thermal energy or solar energy, the PERS System has essentially two modes of operation, heating and cooling. The components of the system, however, operate in different combinations for each mode.

During the winter waste heat generated by the transformer - enough energy to heat the Control House - is picked up by the cooling oil circulated through the transformer and is rejected through air-cooled radiators. An evaporator coil mounted in the heated air stream transfers heat to the refrigerant in the heat pump compressor. Heat created by the compressor is transferred to a stream of water in the condenser. This heated water is then pumped through a conventional fan coil unit for space heating.

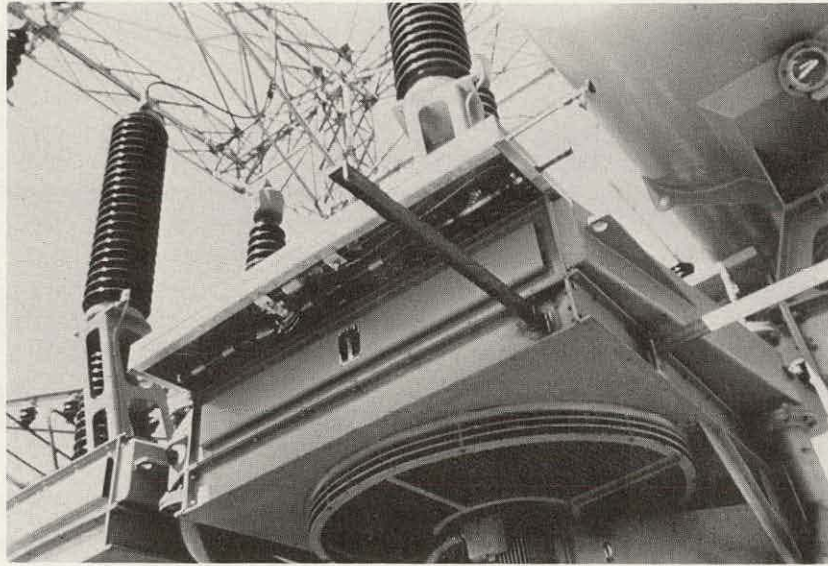


Figure 15. Transformer with Cooling Oil Coils and Evaporator Coils

Although not specified in the contract with Carrier Corporation, a solar heating mode was integrated into the system. When thermal energy from the transformer falls below a predetermined level, water from a storage tank heated by the solar collectors can be pumped directly into the fan coil unit of the system to supply heat to the control house.

During the summer, vacuum-insulated tubular solar collectors supply heated water to drive a 15-ton capacity lithium-bromide absorption air conditioner. When the solar-heated water reaches 180°F, the absorption chiller starts up, chilling water which is pumped into a storage tank. This chilled water is then pumped to a heat exchanger located in a fan coil unit, directly cooling the air distributed through ductwork to the Control House. The absorption chiller is shown on the following page:

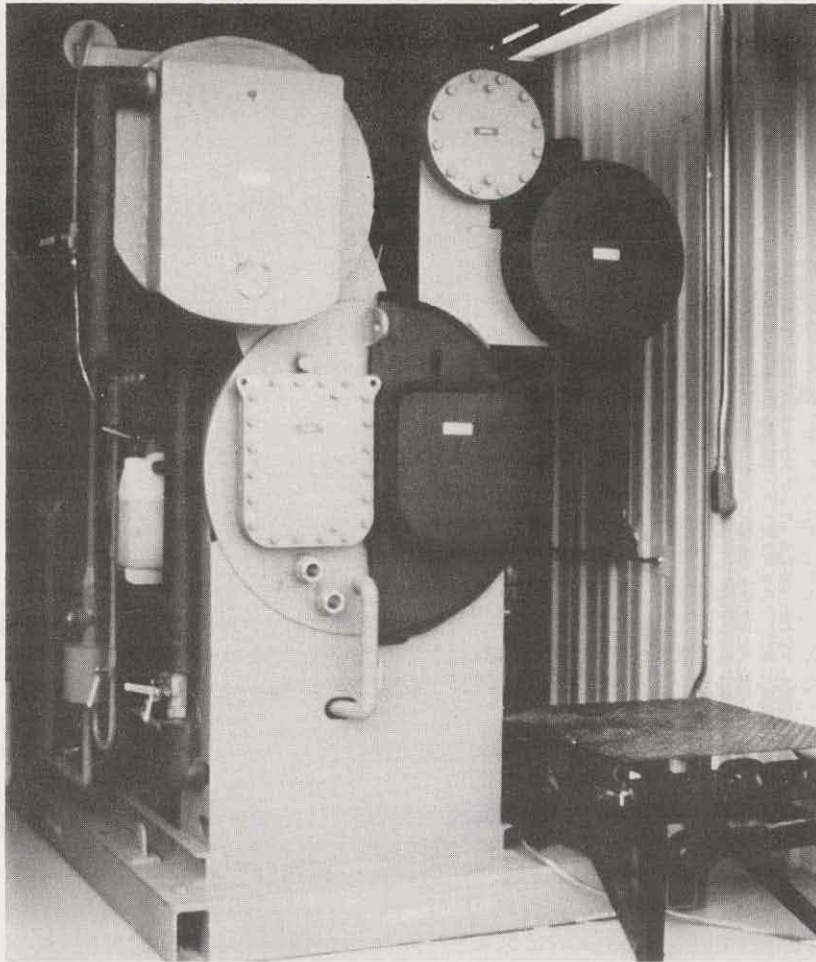


Figure 16. The PERS Absorption Chiller

In addition, cooling to the space can also be provided by the heat pump system. If the storage tank temperature is not low enough, the water can be routed from the storage tank through the heat pump evaporator before going to the fan coil unit.

Separate evaluations by Oregon State University and Energy Systems Division of Carrier Corporation found that the heat pump used to recover waste thermal energy from the transformer had better performance than that of a typical air-to-air heat pump, but that modifications would be needed in the coupling between the transformer oil and refrigerant to recover significant amounts of waste energy. Measurement was in terms of coefficient of performance for heating (COP), arrived at by dividing the heating of space, or output, by the overall electrical energy input delivered to the heat pump. During the

two-week winter test period the unit operated with an average COP of 2.75, as compared with the anticipated design goal of 4.6, primarily because the top oil temperature rise (the difference between the ambient air temperature and the transformer oil temperature) was not consistently high enough for efficient waste heat recovery.

The performance of the absorption chiller was evaluated during August 1978, and was expressed in terms of cooling capacity and coefficient of performance for cooling (COP). Cooling capacity is the cooling provided to the storage tank; COP is capacity divided by the rate of energy decrease in the collector fluid going through the generator of the chiller. COP during the evaluation period ranged from 0.60 to 0.73, which compared favorably with the design goal of 0.70. Cooling capacity ranged from 28 to 49 kW (8 to 14 tons). Data cited above are from the Oregon State University evaluation; similar results were arrived at by the Energy Systems Division of Carrier Corporation.

A proposal for further improvements, modifications, and testing of solar assisted air conditioning in the substation Control House has been submitted to BPA by the Mechanical Section of the Division of Substation and Control Engineering for FY 1981. Both the Oregon State and Carrier evaluations suggested changes in the system which were subsequently made in developing commercial prototypes installed in Tyler, Texas, and BPA's Big Eddy substation.

#### PROTOTYPE MODULAR SOLAR ABSORPTION AIR CONDITIONING SYSTEM

The Tyler, Texas Installation: Evaluation of the PERS System data resulted in Carrier Corporation's developing a second generation absorption chiller which had improved design and cost reduction features. As a result of the Department of Energy's interest in testing solar-assisted heating and cooling in a southern climate, in October 1979 a system was installed at Carrier Corporation's manufacturing plant in Tyler, Texas. A modular factory-assembled package which minimized field engineering and installation time and expense was developed. The package, which included programmable mini-computer controls, pumps, and internal wiring and piping, was mounted on a skid to facilitate ease of transportation and installation.

Other modifications of the system included the addition of an improved heat exchanger, higher efficiency pumps, and a cooling tower to replace municipal water as a means of cooling for the absorption chiller. Because the Department of Energy wanted to see how an absorption chiller would perform using flat plate solar collectors, these were substituted for the tubular collectors.

During the summer, the flat plate collectors supply heated water which is pumped into a 535-gallon storage tank. The tank is smaller than those used at the Ross and Big Eddy substations, but it is adequately sized for applications in a warm climate where there is an almost continuous cooling load. When the water in the tank reaches 180°F, it is used to drive a 15-ton capacity lithium bromide absorption chiller that chills the water and provides direct cooling to a fan coil unit in the plant. The water cycled through the generator of the chiller is then returned to the collectors. Because little heat backup was needed, the system uses steam heat exchange from the plant to provide hot

water as an alternate energy source in place of hot water from the collectors at night or on cloudy days when solar energy is not available.

Monitoring takes place in a separate equipment house and is done by manual readings of watt/hour meters and a multi-point digital temperature indicator. Programmable mini-computer controls are monitored by telephone line from Carrier Corporation in Syracuse, New York. Total solar insolation at the site is measured by a pyranometer. Carrier Corporation is performing data analysis, with monthly progress reports being sent to BPA. Evaluation began in October 1979 and was completed October 1980.

The Big Eddy Installation: Partially funded by the Department of Energy, a solar assisted heating and cooling system was installed at the BPA Big Eddy Substation at The Dalles, Oregon. This system is similar to that installed at Tyler, Texas, in that it is a factory-assembled package mounted on a skid with programmable mini-computer controls, with pumps, and internal wiring and piping. Like its predecessor, the PERS System, the Big Eddy system utilizes an alternate heat pump subsystem to provide cooling or heating at night or on cloudy days when solar energy or stored energy is not available.

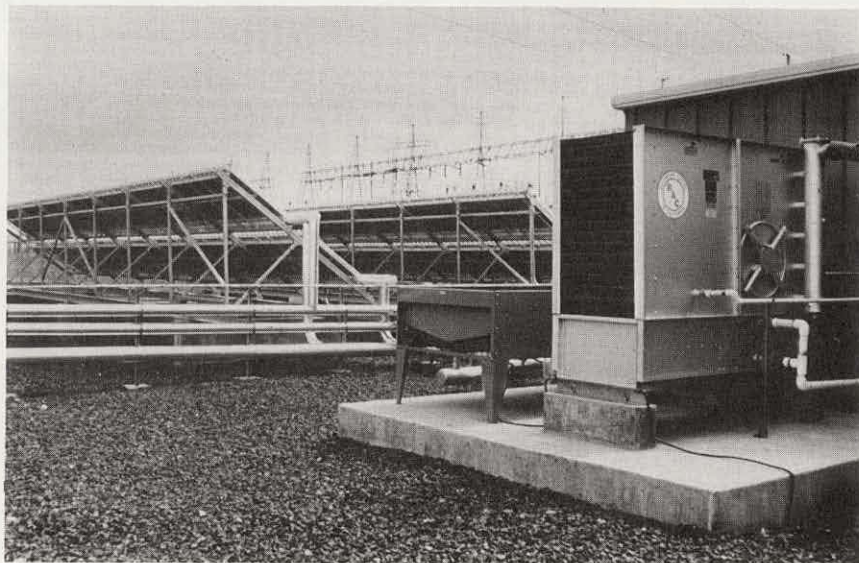


Figure 17. Solar Collectors, Heat Pump and Cooling Tower at Big Eddy Substation

The absorption cooling system at Big Eddy incorporates the same modifications made in the Tyler, Texas, installation—namely, addition of an improved heat exchanger, higher efficiency pumps, and a cooling tower to replace municipal water as a means of cooling for the absorption chiller. To reduce costs water is used as the heat transfer fluid instead of the water-ethylene-glycol mixture used at Ross Substation, with automatic draindown provided to prevent freezing.

Tests are run in a portion of the substation Control House. Monitoring is done by manual readings of watt/hour meters and a multi-point digital temperature indicator. Programmable mini-computer controls are monitored by telephone line from Carrier Corporation at Syracuse, New York. Overall solar energy available is measured by a pyranometer. Carrier Corporation is performing the data analysis, with monthly reports being sent to BPA. A one-year evaluation period is to end in April 1981.

#### SUMMARY

The PERS project was developmental in nature, having to do with performance and improvement of a complex system. As could be expected, both the waste heat recovery and solar-driven absorption chiller systems functioned erratically. However, evaluation of the PERS System identified specific weaknesses and problems in the system and its components. The knowledge gained from the project contributes to waste energy recovery and solar energy technology and has had practical application in the design of the absorption chiller systems installed at Big Eddy Substation and Tyler, Texas. These two latter projects, incorporating unitized packaging and other cost-reducing features, bring closer realization of the long range goals of the projects: production of similar systems for widespread commercial and industrial application.

The PERS System and its associated solar projects have also provided information to be used for a project by the Electrical Power Research Institute (EPRI) to retrieve transformer waste heat from a Seattle City Light substation for heating a Seattle Science Center building, and for installations of solar-assisted absorption chillers by NASA, the Solar Energy Institute, and possibly, the Department of Energy's Federal Building Program.

## ENERGY USAGE MONITORING AND CONTROL HANFORD RESERVATION

### OVERVIEW

Two other projects aimed at conserving energy in the industrial sector grew out of the Department of Energy's interest in ways of monitoring and controlling the energy used by industrial processes. These projects, involving the design and implementation of an energy usage monitoring and control system on the Hanford Reservation at Richland, Washington, are the result of a collaboration between the DOE, BPA, the DOE Richland Operations, and Rockwell International, Inc., the major contractor for operations at the Hanford Reservation. The system was designed by the Control Systems Branch of the Division of Substation and Control Engineering, which will also oversee installation and testing of the project.

Begun in September 1979, the first project, that of designing, testing, and installing an energy usage monitoring system, has been substantially completed and underwent a period of evaluation between September 19, 1980, and January 15, 1981. The second project, which will expand the system and provide a means of load management, will be operational in October 1981. The projects, the first of their kind in the United States, will provide valuable information on the feasibility and practical application of energy usage monitoring and load management and will yield data which will be used to construct energy usage profiles on a number of industrial processes. The project will also contribute to the technology of load management, as yet only its developmental stage.

### PILOT ENERGY MONITOR SYSTEM (PEMS)

The Pilot Energy Monitor System (PEMS) is a distributed network of microcomputers that gathers data on energy usage from connected meters and transmits the information to a central processing unit located at a substation on the Hanford Reservation. Since the system is monitored by a number of small computers rather than a single large one, it offers the advantages of lower cost and increased reliability. Demand meters have been installed to monitor energy usage at various locations at the Hanford site. Some of the meters collect data from buildings and substations, while others monitor energy demand by industrial equipment, such as a plasma arc cutting station and sluice and ash pumps used for waste disposal from coal-fired furnaces which generate steam for space heating.

Typically, demand meters provide pulsed information for each 0.25 kW of energy used. This data is collected by the Remote Unit (RU) to which the meter is wired, each Remote keeping an instantaneous record of the accumulated energy usage for each meter and transmitting it to a Data Gathering Unit (DGU) in the form of a 15-minute summary. The DGU keeps track of the hourly accumulated energy use and the last 15-minute demand period for each meter and in addition records a summary of the accumulated hourly energy use by all meters it supervises. Hence, the PEMS network retains a record at the DGU of the hourly energy usage by each meter which is updated every 15 minutes. The Central Processing Unit (CPU) keeps a current record of each DGU hourly report and the accumulated energy usage of all the DGU's in the network.

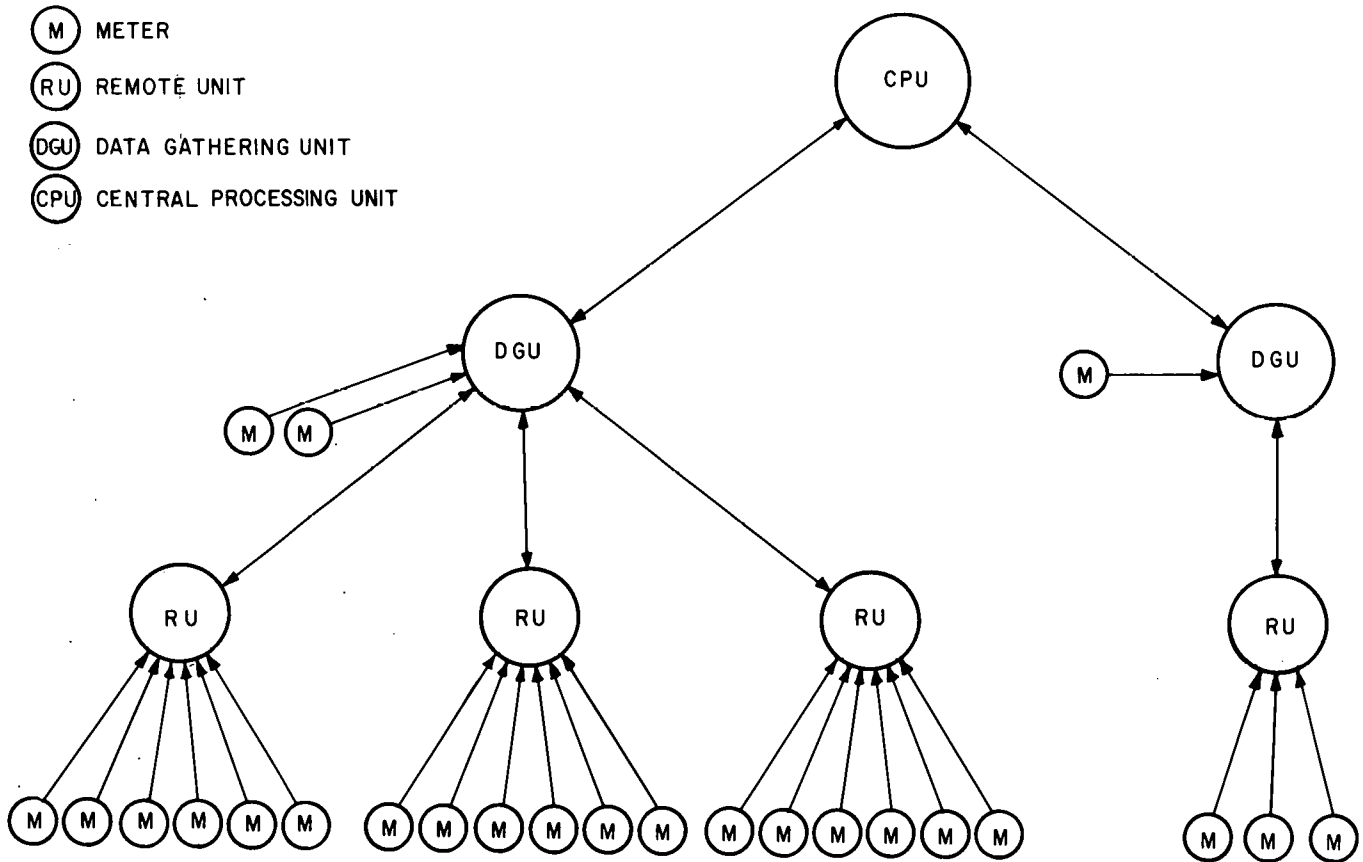


Figure 18. Pilot Energy Monitor System (PEMS) Network

Under normal operation the DGU and the CPU record hourly energy demand; however, at any time an operator at the CPU can request from the system the accumulated hourly energy use for the current hourly demand period. In addition, the operator can request a printout of periodic energy usage, but if this option is not invoked, the only printout will be the end-of-the-month energy usage summary.

While the system was designed with the capacity to expand to 1,000 meters and the capability to issue control commands for actual energy management, the prototype PEMS network was limited in scope to 30 meters to facilitate assessment of its potential. Testing of the system was done at the BPA Computer Testing Facilities between June 1 and September 1, 1980. During this period the system's performance fully met the technical requirements formulated by Bonneville Power and the Department of Energy, and the Pilot Energy Control Monitor System was subsequently delivered to the Hanford Site on September 17, 1980. Actual operation of the system began November 15, 1980, when Rockwell International completed the installation and

wiring of all demand meters in the network. Between November 15 and January 15, 1981, the system evaluated to determine its usefulness as a system was for low-cost data acquisition of instantaneous energy usage. In addition, data will be gathered for the process equipment monitored which, together with historical data, will be used to prepare an energy usage profile for each type of equipment. The energy usage profiles will ultimately be used to determine power allocations, thus providing the basis for load management.

#### THE ENERGY MONITORING AND CONTROL SYSTEM (EMCS)

The second project in energy demand monitoring done by the Control Systems Branch is the Energy Monitoring and Control System (EMCS), which will increase the number of meters in the PEMS network to 120 - four times the number in the current system - and will provide for load management of approximately ten industrial processes at the Hanford Reservation. Process equipment and air handling equipment to be monitored include industrial fans and air conditioners, sluice and ash pumps, backwash pumps, a plasma arc burner, and a vacuum furnace, all associated with day-to-day operations on the selected sites.

As in the PEMS system, energy usage will be monitored and data gathered and processed by the microcomputers in the network. But the project will also have a developmental aspect: the testing of actual energy use control. To implement this load management function, each remote will be given control of the power input to the process equipment that it monitors. When a particular piece of equipment exceeds the load allocation determined by the energy use profile, the remote can automatically curtail power until the energy use falls below the profile. In addition, power to any part of the system or to the network as a whole can be reduced automatically or by the CPU operator, according to a list of priorities, during periods of peak demand or power insufficiency. Should power be restricted, the operator of the equipment can request additional power by means of an Appeal Request from the CPU operator, who may or may not re-energize the process depending on overall energy resources. The Energy Monitoring and Control System network is shown on the next page:



## SUMMARY

The Pilot Energy Monitor System (PEMS) and the Energy Monitor and Control System (EMCS) will yield much-needed information about energy use and its management. As electrical energy becomes more expensive and less available, a great deal needs to be learned about who uses it and when, especially during hours of peak demand. Information on energy usage in the industrial sector, the major source of electrical demand in the Pacific Northwest, is of particular interest to the Department of Energy, which provided much of the funding for these projects. Currently there is no system developed which both monitors energy use and exercises a load management function. In addition to performing these functions, the PEMS prototype system and EMCS system will offer the advantages of a distributed network: low cost and reliability. Hence, these prototype systems are expected to be a valuable contribution to this as-yet-largely-unexplored area of energy conservation.

## PHOTOVOLTAIC APPLICATIONS PROGRAM

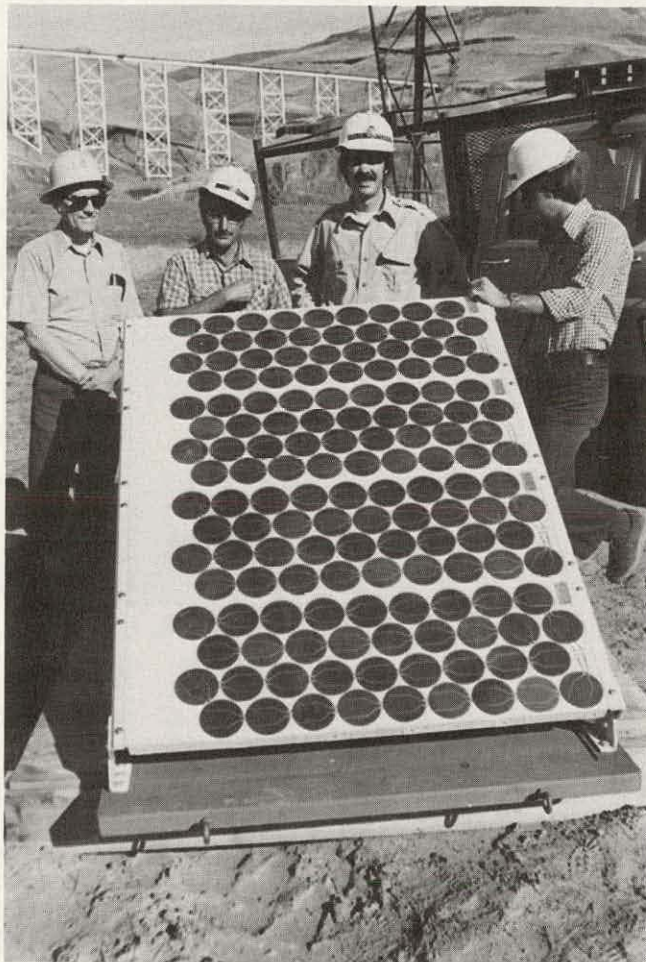


Figure 20. Photovoltaic Array

### OVERVIEW

Of the alternative generation sources in which Bonneville Power's Division of Substation and Control Engineering has been involved, solar and wind power, the use of solar cells was among the earliest applications. Dating back to 1968, the use of solar cells at remote installations needing only small amounts of power has proven a cost-effective alternative to conventional generating equipment requiring considerable maintenance for reliable operation. This use of solar cells has grown into a program of application and study having much wider potential value, not only for electrical transmission, but for industry, commercial buildings, and, eventually, residences.

Currently, the use of solar cells to convert the sun's energy directly into power on-site is not economically feasible, except in specialized situations such as remote monitoring or communications facilities. But the progress of

photovoltaic technology has been such that in the next 2 to 5 years solar cells may well be cost effective compared to conventional power sources in a range of new remote situations, and such that in the next 5 to 10 years the cells may be widely used in commercial buildings and residences where there is good solar radiation. Recognizing this trend, BPA has expanded its own use of solar cells into a sustained program of study of more advanced applications so that as photovoltaic generation becomes cost-effective there will be a field-tested, documented history of performance on which potential users might draw. This program of study was assisted by the Department of Energy's subsequent encouragement of projects under the Federal Photovoltaic Utilization Program and its partial support of test installations.

#### THE PROGRAM

Overall, Bonneville Power's involvement in photovoltaic application is along two lines: internal use of cells for its own remote facilities and monitoring needs, and demonstration of solar cells used in conventional grid-connected systems. Research and development has been directed toward practical application, rather than theory, and application suitable to conditions in the Pacific Northwest. Most of the work has been or is to be carried out on BPA's own structures, in a wide range of geographic, climatic, and operational environments. For purposes of calculating "payback" a 20-year life is used, with adjustments for inflation and similar factors. Because of Bonneville Power's considerable experience in the field, little use has been made of outside consultants.

Internal application projects include remote sensing of meteorological and stream flow conditions, and monitoring of BPA's transmission system; demonstration projects involve use of solar cells in water pumping and in augmenting the grid-connected electrical supply of buildings. Sensing of meteorological and stream flow conditions by photovoltaic-powered equipment is on-going, installations having been completed between 1968 and 1973. The monitoring of BPA's transmission system by such equipment is to be operational by May, 1981. The two demonstration projects--water pumping and a 10 kW supplementary power supply for a building--are to be operational in August-September 1981. Each of the demonstration projects are to undergo a 3-year test period.

#### STATUS OF PROJECTS

The status of each of the projects comprising the Photovoltaic Applications Program is described below, beginning with those serving Bonneville Power's own internal needs.

Hydromet Installations: Begun in 1968 and completed in 1973, "Hydromet" consists of solar cell arrays installed to provide power for 13 remote stations measuring stream flow and meteorological conditions. Data provided by these stations are used for forecasting the hydroelectric power supply for the BPA system. Replacing earlier generators and batteries, solar cells have proven both cost effective and reliable. One of the photovoltaic arrays was removed from service because its station was no longer needed; the others have

continued to operate well, requiring only occasional checking and minor adjustment.

BPA has tested the retired unit to determine its present power output, which will be compared with the manufacturer's original performance specifications to see if any degradation has occurred over the life of the system. This exercise should provide some needed data which will be useful in designing future photovoltaic installations.

Microwave Repeater: Another internal application of solar cells is a microwave repeater which will augment the existing BPA Microwave System. Since the range of microwave radio transmission is limited by terrain and distance, repeaters function as an intermediary link between stations, receiving and amplifying signals.

Located at a site called Signal Hill, the prototype photovoltaic repeater will relay signals between Big Eddy Substation and Wasco Radio Station. A contract with GTE/Lenkurt will implement installation of the system, scheduled for August 1981. Beginning in October 1981 a one-year evaluation will assess the reliability of the components of the system, as well as the overall system design.

Under ideal solar and temperature conditions the repeater's solar cells can generate 300 watts of electricity, providing ample energy to power the system. At night and during other periods when the sun's energy is not available, storage batteries supplement the photovoltaic array. A unique feature of the repeater is its simplicity: the system consists of a photovoltaic array, storage batteries, amplifiers, and antenna mounted on a metal tower. This simplicity reduces construction costs - the system can be installed for 25% of the cost of a conventional repeater - and requires little maintenance. Further, since the system does not require buildings, access roads, or power lines, its impact on the environment is minimal, and it can be used in locations where it would be impossible or prohibitively expensive to install a conventional repeater.

Water Pumping Application: The first demonstration project of the Photovoltaic Applications Program is to be a solar-powered water pump system. Used in conjunction with a conventional ac electrical pump, the dc photovoltaic system will provide power for pumping water up to a holding pond. 1000 watts at full capacity, the system is expected to be a valuable supplement to the conventional electrical supply for irrigation, the pumping of well water, feeding of livestock, and other agricultural applications. Furthermore, the system is to be portable—mounted on a trailer or skid—so that it can be used at other sites as a portable power supply, for instance a construction site needing water to replace vegetation disturbed by use of heavy equipment.

In addition, the trailer-mounted system will also serve as a portable photovoltaic classroom to acquaint the public with solar cell technology and BPA's experience with its applications. Displayed at state and county fairs, energy fairs and the like, the system can be used to power fans, air conditioners, and other home appliances to demonstrate the range of potential residential uses.

The project is now in its preliminary design stage. A consultant is currently under contract, with the participation of Oregon State University and Jefferson County, Oregon, Extension Service likely. A contract for final design, construction, and installation should be issued by December 1980, with the system in operation for a three-year testing beginning August 1981. Evaluation of tests will be by BPA and, probably, Oregon State University.

Redmond Maintenance Headquarters: This demonstration project is to install a 10 kW solar cell array on the roof of BPA's Redmond Maintenance Headquarters as supplementary power for the building's ac supply. Approximately 1000 square feet in size, the array will produce dc power which is to be inverted to ac and used in the building, or, if all its power is not needed (as on weekends), fed into the regional electricity grid. The significance of a 10 kW unit is that the power requirements of the average household, except for space heating and cooling, could be met with an array of this size. However, more than potential residential use is to be studied. During the three-year testing period to begin in August 1981, the efficiency and reliability of the components and overall system will be evaluated and the amount of power generated at different times of the year will be determined. Aside from how much electricity is generated by solar cells, the project would seek to answer a number of questions about feed-back into a grid-connected system, qualities of wave shape, power factor, harmonic distortion, interference with telephones, radios, and television sets, and impact on maintenance.

Funding for the project will be shared by Bonneville Power Administration and the Department of Energy. The installed cost of the project is to be about \$250,000, of which \$200,000 is to be funded by the Department of Energy. The remainder of the installed costs, and all operation, maintenance, and installation costs over the three-year span of testing, are to be paid by Bonneville Power Administration. The system is to be installed August-September 1981.

#### SUMMARY

Thus far, the Photovoltaic Applications Program has limited its activities to the overriding purpose of providing a regional history of performance for various uses of solar cells, so that when the economics of solar cells allows for their wider application, as appears very likely to be the case, there will be a firm basis on which to gauge their value in the Pacific Northwest. While Bonneville Power's own use of solar cells has been rather specialized, much has been and will be learned about remote photovoltaic installations from the Hydromet and Microwave Repeater systems. It is true that the cells have attractive advantages: the more closely load and supply are matched, the more efficient a disbursed generation system can be; cells lower transmission costs and need no on-site storage of power. At the same time, some concern has been raised about using solar cells in applications connected to the utility grid. As the only entity involved in extensive research and development of photovoltaic applications in the Pacific Northwest, and because of its extensive electric power experience, Bonneville Power is in the unique position of addressing such difficulties so that solar cells may one day be a valuable alternative source of energy in the region.

Status and final reports on demonstration projects will appear after the three-year testing periods and assimilation and analysis of data. Notice of their upcoming publication dates will be announced in subsequent editions of this Interim Report.

MOD-2 WIND GENERATORS  
GOODNOE HILLS



Figure 21. MOD-2 Wind Generator

OVERVIEW

As part of its participation in a national effort to develop alternative, renewable sources of energy, Bonneville Power Administration is involved in two wind generation projects, the study of small wind energy conversion machines and the study and development of large wind turbines supplying power to existing local and regional electrical networks. The second of these, installation and study of the performance of three large wind turbine generators at Goodnoe Hills, near Goldendale, Washington, and overlooking the Columbia River, has been a major joint undertaking by BPA, The Department of Energy, NASA, and the prime contractor, Boeing Engineering and Construction Company of Seattle, Washington. Through its participation in the Regional Wind Energy Assessment Program, the Thermal Engineering Staff at BPA identified the Goodnoe Hills area as the site of the project and worked with

Boeing engineers on the layout of the turbine. Substantial contributions to the project were also made by the Division of Transmission Engineering, Division of Land, Division of Materials and Procurement, Division of Administrative Services, Division of Construction, Division of Laboratories, Division of Plant Services, and the Walla Walla Area. The MOD-2 project, then, is the result of agency-wide involvement and cooperation. Yet the Division of Substation and Control Engineering was among those who contributed their efforts. Ours was the responsibility for designing the substation, Visitor's Center, and communication facilities, as well as for developing the site and access roads. For this reason, and because the project reflects BPA's commitment to the development of alternative sources of energy, a description of the MOD-2 project is included in this report.

Beginning with a 1977 award by NASA to Boeing Engineering and Construction for design, fabrication, installation and checkout of three MOD-2 wind turbine generators, the Goodnoe Hills project is well underway and is to be in full operation by mid-1981. A significant milestone in the project was December 22, 1980, when the first generator's blades were rotated; the next is January, 1981, when acceptance tests of the first machine are to be completed. The second and third machines are scheduled to be in place and operating by March and May of 1981, respectively. Once operating, the MOD-2 units will undergo a testing period of two years. The project will yield valuable data on wind generation and integration of wind power electricity into an existing grid. The project will also provide data on performance and mechanical features that will aid in the design of future, larger wind generators, such as the multi-megawatt MOD-5, now in its early design stages, and in the design of "wind farms", or collections of wind generators. Even as they make these contributions to the technology of wind generation, the MOD-2 units are expected to be a valuable addition to BPA's power sources, repaying their cost over their 30-year life span.

#### THE MOD-2 PROJECT

The MOD-2 project consists of design, fabrication and monitoring the performance of three wind turbine generators, each with a rated output of 2500 kW. The MOD-2 wind turbine is a two-bladed, horizontal axis machine with a 300-foot diameter of rotation. The blades drive a turbine generator housed, along with gears and controls, in a horizontal nacelle; the nacelle is mounted on top of a 200-foot steel shell tower in such a manner that blades can always face the wind.

The turbine is designed to operate a mean annual wind speed of at least 14 mph. It becomes operational at wind speeds of 14 mph. and will "feather," or change the pitch of the blade tips so as to stop rotation, at wind velocities greater than 45 mph. At a rated wind speed of 27.5 mph., the turbine will generate 2.5 megawatts of electricity, enough for about 750 homes. The entire unit, its tower attached to a large concrete foundation, can withstand wind velocities of up to 120-125 mph. It operates unattended and is automatic in its various modes of operation, which are standby, startup, operate, shutdown, and lockout. Remote monitoring and start/stop control will be managed by BPA's Dittmer Control Center in Vancouver, Washington. Power generated by the unit is transferred by sliprings and metallic cable to a transformer and switch-gear at the base of the tower, through buried cable to the substation,

and on out to the utility network via a 69 kV transmission line. Each prototype turbine costs 4.6 million dollars.

The MOD-2 is composed of the tower, rotor, and four subsystems housed in the nacelle: Drive Train, Yaw Bearing and Drive, Hydraulics, and Electronic Controls. The rotor is attached to a hub with a teeter bearing which allows for dumping some of the load off the rotors. From a lowspeed (17.5 rpm) shaft in the Drive Train Subsystem, energy from the rotor is transferred through a gearbox to the highspeed (1800 rpm) shaft which turns the generator at the rear of the nacelle.

The function of the Yaw Bearing and Drive subsystem is to enable 360° rotation of the nacelle on a horizontal plane so that the rotor with blades will face the wind. This rotation is controlled by two sensors on top of the nacelle which detect wind direction independently of that caused by the rotor blades and automatically track into the oncoming wind, plus or minus seven degrees. Pitch and yaw control are provided by the Hydraulic subsystem. The Electronic Control subsystem provides the sensing, computation, and commands necessary for unattended operation of the wind generator. The controller is a microprocessor which starts the generator when wind speed is within prescribed limits. After start-up it computes blade pitch and nacelle yaw commands to provide maximum power output for varying wind conditions.

The three MOD-2 prototype units will be situated in a triangular pattern, with 3,000 feet, or ten times rotor diameter, between the two most distant units. In addition to the wind turbines, the Goodnoe Hills installation has two meteorological towers--BPA's 198-foot unit and Battelle Pacific Northwest Laboratory's 350-foot unit--a BPA substation with a 69 kV transmission line, a Visitor's Center and a small 2 kW wind turbine generator. Power from the wind turbines will feed directly into the Klickitat County Public Utility District distribution network, which in turn is connected to BPA's Goldendale Substation. Major maintenance work on the units is to be done by Boeing Engineering and Construction; routine maintenance and monitoring of the units' performance is to be done by BPA, with continuous data transmitted to BPA's Dittmer Control Center in Vancouver, Washington.

In addition to coordinating its portion of the project and preparing the site, BPA was involved in site selection, an important factor in the performance of the wind turbines. The Goodnoe Hills site was chosen after more than three years of study of potential wind farm locations in the Pacific Northwest, a study conducted by the Department of Atmospheric Sciences of Oregon State University under the direction of the Thermal Engineering Staff. Out of the various sites identified by the OSU study--other Columbia Gorge areas, parts of the Cascade Crest, parts of the Oregon Coast--the Goodnoe Hills location was the most promising, in terms of cost of development as well as natural wind potential. Winds at Goodnoe Hills average about 16.5 mph at ground level, and about 18 mph at the height of the turbines' rotor hubs. Winds at the site blow between 14 and 45 mph about 53% of the time, most steadily between February and September. Throughout the year, wind speeds at Goodnoe Hills are above 15 mph 55% of the time, and above 25 mph 25% of the time--most promising for machines that reach their maximum output of 2500 kW when wind velocity is 28 mph at their rotor hubs. Due to the natural advantages of the site, the MOD-2 turbines are expected to produce 8 to 9.3 million kWh annually for each machine.

The overall goals of the project are both developmental and investigative. The name of the units, MOD-2, indicates their place in a genealogy of development, and it is expected that they will contribute a good deal to design of future large wind turbine generators such as the MOD-5, as well as provide a commercial machine marketable now. (Boeing may market the MOD-2, expecting that with production of the 100th unit of the machine, cost per unit will be such that electricity can be generated for approximately 4 cents per kWh.)

The project will also offer an opportunity to investigate a number of factors concerning performance of the units, production of electricity, and integration of the power they produce into an existing grid, and to explore potential problems such as unwanted harmonics, or electrical resonances, environmental considerations, and the impact of air turbulence in the wake of one machine on the capacity of another machine downwind from it. In addition to such areas of investigation there is the larger question of storage of energy from wind generation. Since the turbines operate intermittently, storage of their peak production is required. Tied into a hydroelectric power system such as the Federal Columbia River Power System, however, wind turbines may not present a storage problem: water can be stored, rather than electricity. Flow through dam turbines can be diminished during periods when wind generators are supplying large amounts of electricity. The water would be stored behind the dams and then released at a later time to generate more hydroelectric power. These and other kinds of performance experience will be gained by monitoring the operation of the MOD-2 units over the project's two-year period of study.

#### STATUS OF THE PROJECT

As of this writing, site selection and preparation have been completed, including erection of meteorological towers, foundations for the turbine towers, and access roads. The substation was completed August 15, 1980, the Visitor's Center October 31, 1980. Approximately three miles of 69 kV transmission line have been built by BPA personnel. Installation of the MOD-2 units themselves is now in progress and is to be completed May-June 1981, when the project's test period will begin.

Installation of the wind turbine generators is in two stages: ground level assembly of the nacelle and test operation of the turbine, with simultaneous construction of the tower, and raising of the Nacelle and rotor to the top of the tower for final fitting and operation of the unit. The ground level assembly allows for running through the operating controls of the system and simplifies checking of mechanical parts, culminating in integration tests, or complete testing of the assembled inner parts of the nacelle. Installation and checkout of the first unit were completed November 24, 1980, and its blades turned for the first time on December 22, 1980. Totally, testing of the first unit and auxiliary equipment will have taken seven months. The installation of the Nacelle is shown on the following page:



Figure 22. Installation of the Nacelle

A similar process is currently underway for units #2 and #3 of the project. Acceptance tests for unit #2 are scheduled for February-March, 1981, and for unit #3 April-May, 1981. All three machines are to be operational May 29, 1981. Monitoring of their operation is to begin in June, 1981. Progress reports are to be submitted to NASA every three months. A final report is to be written soon after completion of the project in June, 1983.

#### SUMMARY

The Goodnoe Hills MOD-2 project will provide a good deal of needed information on wind generation and its integration into an existing power grid, and will contribute, as well, to the ongoing development of multi-megawatt wind turbines. The concept of "wind farms" utilizing a clean, renewable resource is an attractive one whose value was recognized in the Federal Wind Energy Program initiated in 1973 under the auspices of the National Science Foundation and in subsequent investment in prototype equipment by the Department of Energy and NASA. But there are many questions to be answered

before the concept becomes a reality. The Goodnoe Hills project should provide answers to a number of them, even as it provides energy which may well pay for its initial investment over the 30-year life span of the wind turbines. Just how cost effective the MOD-2 turbines are remains to be seen, and a certain amount of the investment in them is a price that must be paid for development of a substantial national energy resource. The manufacturer's expected cost of producing electricity by wind generation--four cents per kWh with the 100th MOD-2--compares favorably with the projected cost of nuclear and other kinds of non-hydroelectric power in the 1980's, between four and five cents per kWh. BPA's part in the development of this wind turbine, then, may have been cost-effective in terms of dollars alone. More important, its participation will have helped open the way for use of wind as a commercially feasible power source, both in the Pacific Northwest and the nation at large.

A final public report will be published separately by BPA in cooperation with NASA upon completion of the project. Meanwhile, more information on the wind turbines is available in the BPA Department of Energy publication, MOD-2: Two Northwest Windpower Projects, Big and Small (March, 1980) and from their manufacturer, Boeing Engineering and Construction Company, P.O. Box 3707, Seattle, Washington 98124.

ENERGY CONSERVATION RESEARCH AND  
DEVELOPMENT IN THE DIVISION OF SUBSTATION AND CONTROL  
ENGINEERING: FUTURE DIRECTIONS

The variety of work on energy conservation in Bonneville Power's Division of Substation and Control Engineering is considerable. Study ranges from near-primary research through testing of applications to development of prototype equipment. And, as with any dynamic research and development program, new ideas are generated from studies currently underway; new directions emerge. In the future, as in the past, Bonneville Power Administration's emphasis will be first of all on cost-effective applications of technology, on bringing its resources to bear on the tasks of reducing electrical energy consumption and meeting future demands for power in the Pacific Northwest.

Future research and development under consideration involve so many aspects of energy savings and alternative modes of electrical generation that only a few can be mentioned in this report. Currently proposed are projects which will:

- . Study measures to prevent air infiltration.
- . Evaluate an economical solar energy storage device.
- . Develop a "House Doctor" program--trained technicians to diagnose energy losses and recommend solutions--for utilities and others.
- . Reduce peak load through shut-off of water heaters during hours of heavy electrical use.
- . Test existing or develop Home Energy Management Systems which enable the homeowner to save energy.
- . Test a heating-only heat pump to see what savings can be gained over use of the conventional heating-cooling heat pump.
- . Develop a program for automatically reducing commercial indoor lighting as daylight increases.
- . Install, test, and evaluate photovoltaic cell applications over a wide geographic area.
- . Develop uses for waste heat generated by nuclear plants.

Nor are new research and development projects all. Perhaps the most interesting future directions to be taken are not by Bonneville Power Administration, but rather, by researchers, utilities, agencies, and industries whose own development in energy conservation and alternative generation have benefitted from our work. It is gratifying to know that our testing of the heat pump water heater assisted a Northwest utility in deciding to offer its customers interest-free loans for installing such equipment; that our experience with waste heat recovery is benefitting a similar project in a

Seattle utilities substation; and that our work on wind generation at Goodnoe Hills is a direct contribution to commercial development—in fact, NASA considers the units used in our project to be prototype commercial equipment, not merely experimental machines. While it is the nature of our work not to measure its effectiveness by immediate, dramatic results, but, rather, by long-range, accumulative impact, it is worthwhile to point up some of the early signs of this impact on energy conservation in the Pacific Northwest and the nation.

Just as important, it is worthwhile to inform those interested in energy conservation of what we are doing so that they may benefit from our work. That is why there will continue to be reports on our various projects and why there will be future editions of this publication.

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