Summary of Annual Cycle Energy System Workshop I Held October 29-30, 1975, at Oak Ridge, Tennessee

OAK RIDGE NATIONAL LABORATORY
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Summary of

Annual Cycle Energy System Workshop I

Held October 29-30, 1975, at Oak Ridge, Tennessee

H. C. Fischer, Editor

J. C. Moyers
E. C. Hise
E. A. Nephew

July 1976

Energy Conservation Section
Energy Division

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OAK RIDGE NATIONAL LABORATORY
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ABSTRACT

The Annual Cycle Energy System (ACES) concept provides space heating, air conditioning, and water heating by means of a heat pump and an energy storage tank. Heat is removed in winter from the water in the tank and is added during the following summer.

A workshop was held on October 29-30, 1975 in Oak Ridge, Tenn. to disseminate information on ACES. This report gives summaries of the presentation, which covered technical, economic, and institutional aspects of the concept.

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INTRODUCTION

This report summarizes the presentations at the Annual Cycle Energy System (ACES) Workshop held in Oak Ridge, Tennessee, on October 29-30, 1975. Since the discussion sessions were not tape recorded, a verbatim account of the proceedings is not available. The purpose of the workshop was to disseminate information about the ACES concept and to promote awareness of its advantages. There was a broad representation of disciplines at the workshop, which attested to the appeal of the concept. Present at the meeting were representatives from major components manufacturers, designers of heating and cooling systems, architectural and engineering firms, heat transfer equipment manufacturers, utilities, consumers, the National Bureau of Standards, the Oak Ridge Chamber of Commerce, control systems manufacturers, refrigeration systems manufacturers bankers, marketing interests, the National Governors' Conference, and the Southern Interstate Nuclear Board. Table 1 provides a breakdown of the participating groups and organizations, and Appendix A lists the individuals attending the Workshop.

Table 1. Participating organizations at the ACES Workshop

Type of organization	Number of organizations	Number of people
Manufacturers of systems	7	14
Manufacturers of components	4	8
Utilities	3	15
Builders	2	2
Contractors	3	3
Universities	2	3
Consulting engineers	2	2
Trade association	1	1
Consumers	1	2
Press	1	1
Public interest groups	3	3
Government agencies		
Energy Research and Development Administration		4
Federal Energy Administration		1
National Bureau of Standards		2
Veterans Administration		2
Oak Ridge National Laboratory		3

The Annual Cycle Energy System is designed to provide space heating, air conditioning, and domestic water heating for residential and commercial applications. The energy transfer is by an electrically driven heat pump that obtains its heat from water stored in an underground, insulated tank.

Most of the water is frozen during the winter heating season, and the stored ice provides air conditioning in the summer. Because both the heating and cooling outputs of the heat pump are utilized, the annual coefficient of performance of the system can be as high as 5. The ACES concept seeks to balance the energy requirements of a building over a complete annual cycle. This can be done in about 80% of the country, where the energy requirements for heating and cooling can be brought into balance for a well-insulated building. In the North, where the heating and cooling loads are not in balance, the use of solar panels or outside air coils may be required. Some compensation for the imbalance can also be achieved by reducing the insulation of the ice bin. In the South, occasional operation of the compressor as an off-peak ice maker may be necessary in the summer.

The basic ACES concept is described more fully in a paper presented at the 10th Annual Intersociety Energy Conversion Engineering Conference held at Newark, Delaware, on August 19, 1975. Copies of this paper, *The Annual Cycle Energy System*, by Harry C. Fischer of the Energy Division of the Oak Ridge National Laboratory (ORNL) can be obtained by writing to the Industrial Cooperation Office at ORNL, P.O. Box X, Oak Ridge, Tennessee 37830.

Development of the Annual Cycle Energy System at ORNL is sponsored by the Energy Research and Development Administration (ERDA), the Department for Housing and Urban Development (HUD), and the Federal Energy Administration (FEA) as part of an overall energy conservation research program. A demonstration house is being built on the University of Tennessee campus to demonstrate the ACES concept and to gather data on system performance. Construction of this demonstration house should be completed by May 1976. The ACES approach is among the few major energy conservation strategies that can be effective in the near-term future. For this reason, there is an urgency for commercialization of ACES systems as soon as possible.

1. INTRODUCTORY REMARKS

F. L. Culler, *Deputy Director, Oak Ridge National Laboratory*

The group was welcomed to the first workshop on the ACES system by Mr. Culler on behalf of the Oak Ridge National Laboratory; the Union Carbide Corporation, Nuclear Division; the Energy Research and Development Administration; and other current and former sponsors of the ACES program, including the Department of Housing and Urban Development and the Federal Energy Administration.

Although the ACES concept is not new and did not evolve from research conducted at Oak Ridge National Laboratory, it is an idea whose time has come. At this time of great national concern for energy, Oak Ridge National Laboratory is fortunate to have been introduced to the concept by Harry C. Fischer, who conceived of the idea some years ago. A year of exploratory development work at ORNL has shown that ACES offers a practical way to reduce energy consumption in many areas of the country. Furthermore, the ACES system is simple enough to be used soon.

Engineers at Oak Ridge National Laboratory are impressed with the energy conservation potential of the ACES system and are pleased with the enthusiastic response it has received. The opinion at ORNL is that the ACES concept is technically sound; there is an urgency for its perfection and early application to help conserve scarce energy resources. However, it is important to keep in mind several factors that will affect, and perhaps limit, the rate at which ACES systems can be introduced:

1. Although the idea of ACES is basically simple, and although, on first analysis, the system can be assembled from components and subsystems already developed or on the market, the actual ACES system is complex.

2. Each installation of ACES requires specific design. The system as a whole may not be marketable as a package by a single group of manufacturers.

3. The actual installation designed by architects or engineers must take into account the structure, soil characteristics, weather cycles, solar radiation availability, and other job-specific variables.

4. The system will have more complex operating requirements than the average homeowner is accustomed to.

5. The system will almost certainly require more initial capital than other systems; its economy depends upon lower operating and energy costs that accrue during its operating lifetime. The idea of total lifetime cost and payout has not yet become an accepted basis for comparison by a large segment of the public. Therefore, the introduction of the ACES system may occur slowly and may require incentives.

6. The system must enter, without gross failures, a highly competitive market where alternative systems of proven reliability are available at lower initial cost.

In light of the foregoing observations, it would be appropriate for future workshops to consider the following areas in addition to discussing ACES technology:

1. Explore the requirements for proving components and establishing reliability, preferably before attempting to challenge the existing markets.

2. Develop an outline of the required systems tests, data requirements, criteria for performance, and design standards needed to produce a commercially viable and reliable basis for ACES. Where it is impossible to do this, procedures for establishing these requirements must be set up.

3. Consider establishing a clearinghouse for information during the development phase. The clearinghouse should be staffed adequately to check calculations, to develop and publish data, and possibly to provide a laboratory for proving candidate components and designs.

This clearinghouse might evolve to a formal center for establishing standards and criteria in association with the established technical and trade organizations.

4. Realize now that the idea is not yet customer-oriented. Consider the necessity for tests and supporting development in such areas as: (a) water quality, corrosion, microorganisms, scaling; (b) controls that minimize customer adjustments and switching; (c) lifetime of various components; (d) maintenance (no allowances made in costs); (e) hazards — refrigerant quantity and distribution for direct expansion.

5. Consider the necessity for backup heating systems, such as standby electric heaters.

6. Explore the question of how fast the system can be introduced as more knowledge of reliability, lifetime, performance, and costs is gained.

7. Define, if possible, the role of a centralized development group such as exists at ORNL-UT.

2. DESCRIPTION OF ACES

Harry C. Fischer, *Consultant, Energy Conservation Program, Oak Ridge National Laboratory*

A general schematic diagram of an ACES for a multizone or multifamily dwelling is shown in Fig. 1. In the original ACES conception, all of the heat required to heat a building was obtained by freezing water; the ice formed was saved to provide summer air conditioning. This approach cannot satisfy all climatic conditions, however, and must be modified in geographical areas where an imbalance exists in the annual heating and cooling requirements of a building. Modifications to the basic ACES system can be made by varying the size of the water storage bin or the solar energy collector and by employing different modes of system operation to meet changing, seasonal load requirements. The design objective for an ACES is to determine the proper combination of components and component capacities that will yield a minimum lifetime cost for the system and yet fully meet the air conditioning and heating requirements of the building.

To assist in ACES design and economic optimization studies, a computer program that calculates the thermal load of a building as a function of time has been used at ORNL. This calculation is made on the basis of imput data that include the specifications of the builidng and hour-by-hour weather tape data, which are availabe for any geographical area of the country. Using a computer program developed at ORNL, the calculated thermal load function is then integrated over time to produce a thermal bank account for the building. The rate of ice formation, of solar energy collected, of required capacity of auxiliary heating or cooling units, and of required energy input is then computed for the particular ACES system being investigated. In this manner, the computer program can be used to identify the ACES design having minimum energy or minimum capital cost. In order to have confidence in the results, it is imperative to have reliable cost data for equipment components of the system. Thus a primary objective of this workshop was to develop realistic cost figures for the ACES equipment package.

The ACES system depicted in Fig. 1 envisions the use of an outdoor coil as a condenser in the summer for the nighttime dissipation of heat. In the winter, the coil is used as an air evaporator when the air temperature is high enough to give a better coefficient of performance (COP) than would be obtained with the ice-freezing evaporator. The system can also be provided with a solar panel to collect solar energy and deliver it for storage in the ice bin. This would make it possible, in northern locations, to reduce the size of the ice bin and would improve the COP of the system. Current investigations at ORNL deal with the possible use of an automatic ice maker as the heat pump in an ACES system. The idea appears to have merit, at least for large systems. Figure 2 shows a schematic for this type of ice maker/heat pump application. The tentative specifications for such a unit, manufactured by the Turbo Refrigerating Company, are listed in Table 2. Preliminary cost figures indicate that the automatic ice maker would have a great advantage in northern climates, where it would operate more than 2000 hr per heating season. The excess ice, not needed for summer air conditioning, could either be sold or discarded.

Table 2. Projected specifications of a 12-plate heat pump/ice maker[a]

Performance as an ice maker	
Ice production 70° water	9.17 tons/24 hr
Ice production 45° water	10.63 tons/24 hr
Heating capacity	228,251 Btu/hr at 105°F condensing
Power consumption	19.4 kW
COP heating	3.45
Performance as a water chiller	
Water chilling capacity 120 gpm 44° to 40°	20.4 tons
Heating capacity	320,375 Btu/hr at 105°F condensing
Power consumption	22.15 kW
Cop heating	4.24

[a]Turbo Refrigerating Company, Denton, Texas 76201.

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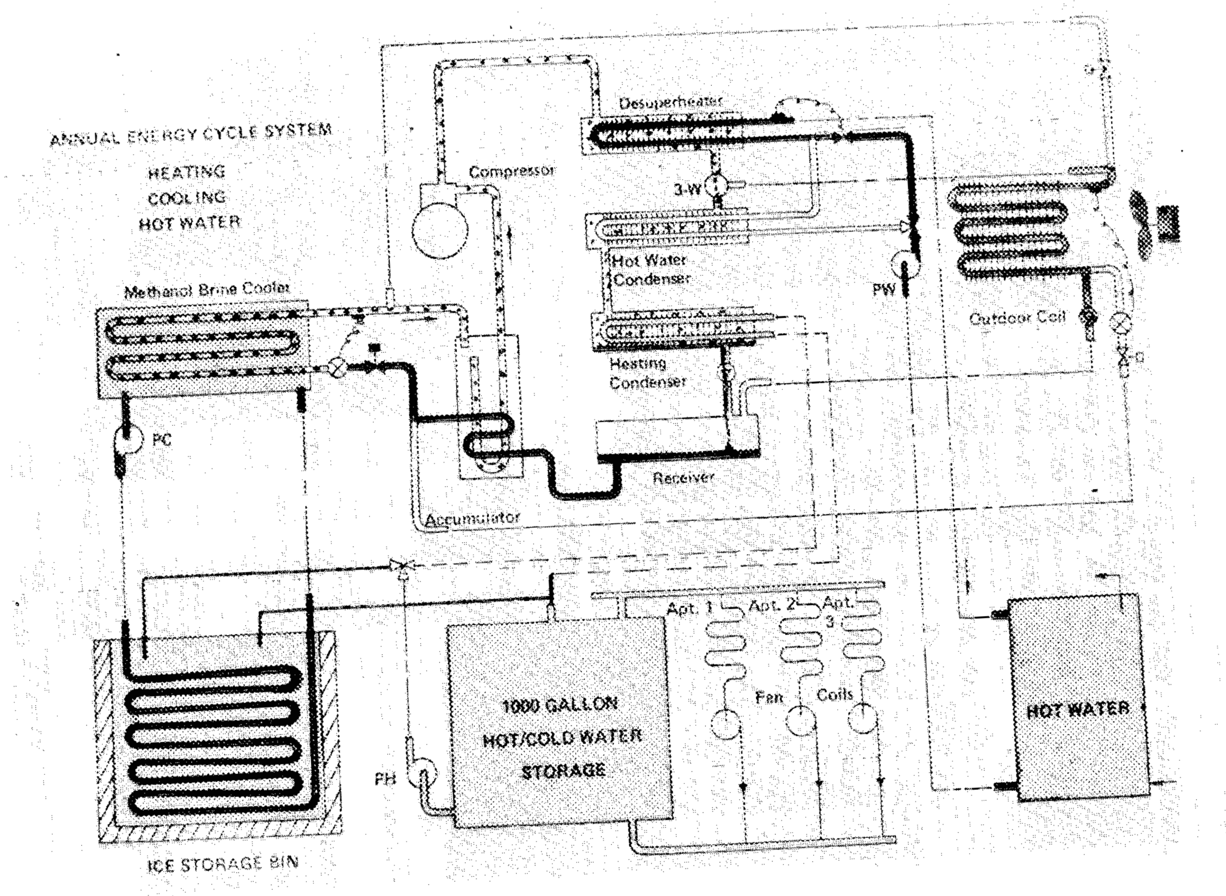

Fig. 1. ACES equipment schematic for a multifamily dwelling.

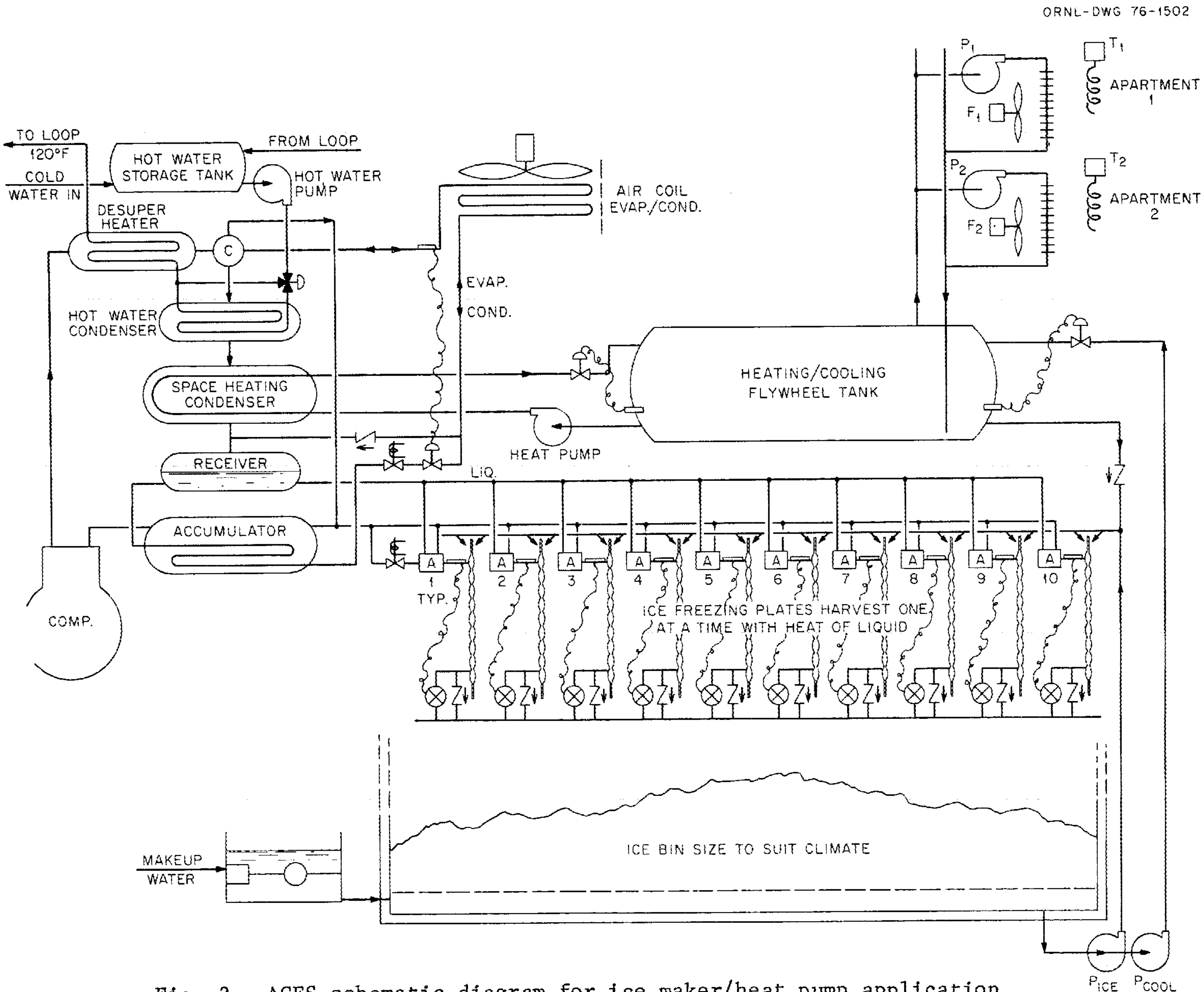

Fig. 2. ACES schematic diagram for ice maker/heat pump application to multifamily dwellings.

3. RESIDENTIAL DEMONSTRATION

E. C. Hise, Sr., *Development Specialist,*
Energy Conservation Program, Oak Ridge National Laboratory

The demonstration residence shown in Fig. 3 is being constructed in Knoxville, Tennessee, as one of several houses in the Tennessee Energy Conservation in Housing (TECH) program sponsored jointly by the Oak Ridge National Laboratory, the University of Tennessee, and the Tennessee Valley Authority. Completion is anticipated in early April 1976. This single-family residence has the following characteristics:

1. frame construction,
2. two levels,
3. 1800 ft^2 of living area,
4. three bedrooms and two baths, and
5. forced-air heating and cooling.

The design is intended to appear to be a conventional house, except for several features relating to the thermal envelope:

1. sidewalls of 2 x 6-in. construction to accept 6 in. of insulation;
2. 12-in. batting insulation in the floor over the ice bin;
3. 6-in. batting insulation in the remainder of the floor;
4. all windows doubled glazed; and
5. exterior doors of 2-in. urethane, metal cased, with magnetic weather strip;

and relating to the heating-cooling system:

6. a 2400-ft^3 tank in the basement and
7. a 200-ft^2 radiant/convector panel.

Most people will probably be startled when they first see a basement one-fourth full of ice. On the other hand, they will probably regard the radiant/convector coil as an attractive architectural feature.

The ACES components characteristics are the following:

1. ice bin — 19 x 17 x 7-1/2 ft (inventory of 2400 ft^3);
2. ice coils — 1300 lin ft of 1/2-in.-diam tubing;

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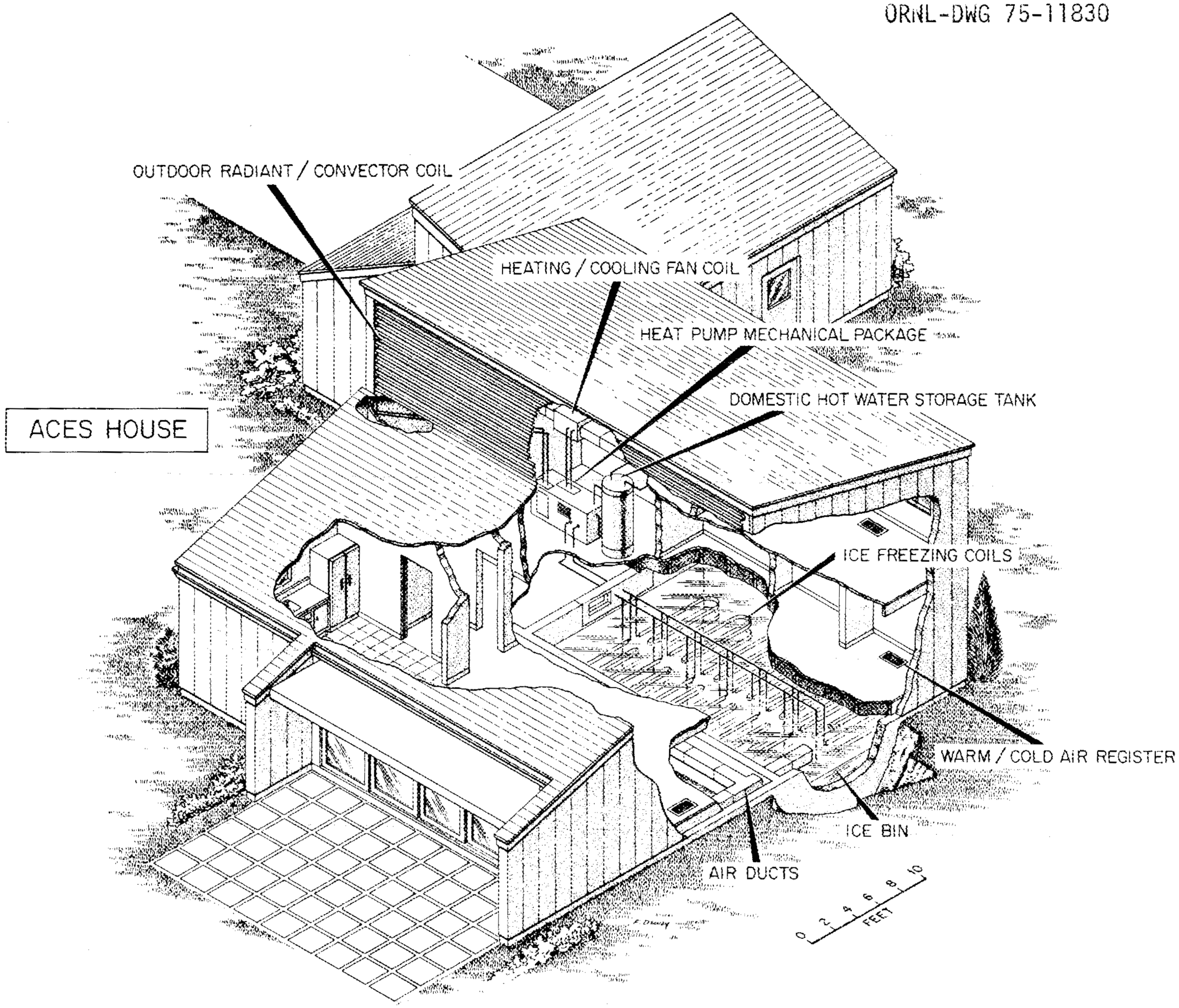

Fig. 3. Cutaway view of TECH ACES demonstration house.

3. radiant/convector — 26 tubes, 32 ft long;

4. heat pump — 30,000 Btu/hr heating output; and

5. tubing — aluminum, 1/2-in. diam, with coextruded axial fin 3-in. wide overall (used on ice coils and radiant/convector).

In the Knoxville climate (3500 degree-days), the ice bin is large enough to supply the entire heating season without requiring auxiliary input from the radiant/convector coil. The resulting ice will last late into the cooling season. Following the exhaustion of the ice, the compressor will be operated at night, when the ambient temperature is below 75°F, to store cold water in the bin. The waste heat from the compressor will be rejected by the radiant/convector panel. The components of the demonstration ACES system are sized to permit operation simulating other climates and other modes of control. A data acquisition system will log the performance of the system and its components on an hourly basis.

4. ERDA R&D IN BUILDING CONSERVATION

Nina Cox, *Division of Buildings and Industry, ERDA, Washington, D.C.*

A few words on how energy is used in buildings in the United States today will indicate where the biggest opportunities concerning energy conservation exist.

Thirty-two percent of all energy used in the United States was consumed in the buildings sector. Of this, 70% is consumed in residential structures and 30% in commercial structures. The profile of the primary energy use in the buildings sector can be summarized as follows: 57% used for space heating and air conditioning; 33% used for operating equipment, including hot water heating, home appliances, and office equipment; and 10% used for lighting.

Studies have shown that as much as 40% of the energy consumed in buildings is wasted due to inadequate construction, poor operating practices, inefficient equipment, and unnecessary lighting, heating and cooling levels.

The buildings sector offers opportunities to reduce energy use now. The measures can be grouped in three classes according to whether they involve changes in operation procedures for buildings and appliances, changes in energy efficiency of equipment and appliances, or changes in energy efficiency of the building itself.

The Buildings Program at ERDA became an authorized and funded program July 1, 1975. The Federal Non-Nuclear Energy Research and Development Act of 1975 directs ERDA to conduct activities designed to "advance urban and architectural design to promote efficient use in residential and commercial sectors, improvements in home design, and insulation technologies, small thermal storage units and increased efficiency in electrical appliances and lighting fixtures."

The objectives of the Buildings Program are to conduct R&D activities to foster acceptance of energy-saving technology and more effective energy use in buildings and community systems; to show technical feasibility; to minimize life-cycle energy consumption with minimum impact on standard of living and on life-cycle cost; and to increase consumer awareness and acceptability (full-scale demonstration of promising energy technology to determine performance, energy impact, influence on environment, and environmental effects, etc.).

The Buildings Program has three major subunits: (1) buildings, which consists of three elements — residential buildings, commercial buildings, and performance standards; (2) community systems, which will perform R&D related to energy-efficient integrated systems, new community forms, and land-use changes for mid- and long-term energy conservation; and (3) technology and appliances: R&D on residential and commercial appliances, and the technology element of this area, supports all program elements and includes R&D on individual technologies which can be integrated into other subprogram units.

The ERDA-supported ACES Program is just one example of the programs that will be carried out — putting a system together with available components in an innovative and energy-efficient manner. The concept is currently being carried out in Europe (heating a swimming pool while making ice for an ice skating rink).

5. THE APPLICATION OF HEAT PUMPS AND STORAGE TO ENERGY CONSERVATION AND LOAD MANAGEMENT

R. G. Werden, *President, Robert G. Werden and Associates, Jenkintown, Pennsylvania*

A number of observations on the contribution that heat pumps and thermal storage systems can make toward energy conservation were presented by Mr. Werden.

1. Numerous feasibility studies have been made by Mr. Werden over the years, which clearly demonstrate the economic viability of heat pump systems. The work has resulted in the design and installation of several large-scale commercial and industrial applications — 100 to 1200 tons. The economic feasibility studies were all conducted on the basis of life-cycle costs.

2. In many instances, the results of the studies indicated that proposed design installations were nearly, but not quite economically, feasible. With today's rapidly rising fuel prices, these systems would now undoubtedly be fully economic. Two other factors contribute to making formerly marginal systems feasible.

a. The improved thermal integrity of the building envelope reduces the building's peak heating load faster than the peak cooling load. This increases the cooling-to-heating ratio, a cardinal index of feasibility.

b. The heat pump system trades a higher initial investment for lower operating costs. This trade-off is an advantage in today's market conditions, particularly when fuel prices are rising at a faster rate than charges for capital investment. This economic trend is likely to continue into the forseeable future.

3. The incremental investment cost of a heat pump system over a conventional heating-and-cooling system is not nearly as great as that of a completely solar heating-and-cooling system. Consequently, the combined amortization and operating cost of the heat pump system will probably be less that that for a solar system. This would probably be true in spite of the fact that the solar system has a negligible operating cost.

4. The heat pump concept, with or without thermal storage, not only conserves energy but promises to be an effective technique for load management. This advantage would be lost, however, if consumer advocates are successful in persuading public utility commisions to abandon tariff structures providing lower rates for off-peak energy usage. These tariff structures presently reward investors in high-load-factor systems, such as the heat pump (with storage) system. On the other hand, rate inversion of the unit price, also favored by consumer advocates, would favor the heat pump system because it consumes less energy.

High-load-factor systems must be adopted if the United States is to build a viable national energy network. All engineers were, encouraged by Mr. Werden to speak out in favor of earned rate tariffs based on load factor. A program of public education is needed to combat the reticence, ignorance, and complacency that have prevented a more widespread adoption of heat pump systems. The layman can sense and feel the heat produced by a flame, an electric heater, or even the sun's rays, but he does not understand heat pumps. This is true even though he has one in his own kitchen — the household refrigerator.

It will cost more for an architect/engineer team to design a heat pump system than a traditional system. The conventional fee structure, however, does not take this into account. As a result, the average architect or engineer is reluctant to recommend the installation of a heat pump system because it increases his costs. But the heat pump system, with all of its advantages, can be and has been applied successfully without auxiliary resistance heating.

6. UTILITY LOAD MANAGEMENT AND ENERGY CONSERVATION

Dr. Jeffrey H. Rumbaugh, *Senior Staff Engineer, Potomac Electric Power Company, Washington, D.C.*

A brief description of the characteristics of the Potomac Electric Power Company (PEPCO) system, including the Company's ability to go to a predominantly coal-burining system within the constraints of the existing transportation system, was given by Dr. Rumbaugh.

The effects of conservation in the PEPCO system were described: decreases of 7.7% in energy sales and 4.8% in peak demand, compared with 1973. Conservation and load management, although used synonymously, are totally different. Conservation means reduction in usage, whereas load management implies that some capability exists for the control of loads by mechanisms including load control, peak shifting, and load shaping, with the current primary techniques designed for peak limiting. Each utility is an entity in itself with its characteristics dictated by the components of its load; so different formats of load management are needed for different utilities.

There is a real need in the utilities for true-load management systems that provide both energy displacement and load-leveling capability. One specific approach is the use of solar-assisted heat pumps in conjunction with thermal storage for both space heating and air conditioning. This system, which uses off-peak electric energy, can provide both energy and capacity savings. The ACES system goes one step beyond this approach, conceptually, by balancing loads on a seasonal rather than a diurnal basis.

Some of the more obvious potential benefits of load management include the deferral of generating capacity additions, the use of the most efficient existing generators with attendant fuel savings, an improved system load factor, and a more equitable pricing based on demand and energy. There are two formats proposed to date for load management: (1) the utilization of storage devices for off-peak storage/on-peak use and (2) control over the customer's use of energy. However, there are numerous unanswered questions regarding the economic, social, and technical implications for each of these options.

7. INSTITUTIONAL — COMMERCIAL DEMONSTRATION

Nathan R. Feldman, *Director, Mechanical Engineering Service, Office of Construction, Veterans Administration, Washington, D.C.*

The Veterans Administration (VA) recognizes the need for planning and for prompt action to avert our veterans' hospitals from being adversely affected by the serious energy crisis that now exists.

In an effort to solve the problem, the VA has done all the obvious things, such as developing new design criteria, using existing technology such as heat recovery wheels, run-around coils, load shedding, etc.

The following are some of the projects in the development stage at the present time:

1. solar energy for heating, domestic hot water, and cooling ($9 million program);

2. heat pumps in conjunction with solar energy;

3. total energy systems;

4. selective energy systems;

5. continuous-duty standby system; and

6. modified annual cycle energy system.

In addition to innovative systems and new hardware in energy conservation, the VA believes that better analytical tools are needed for predicting hospital energy consumption for new construction. In conjunction with the University of Pittsburgh, the Veterans Administration Load Using Energy System (VALUES) computer program is being developed.

In conclusion, the VA is committed to a program of energy conservation. The engineers are a dedicated group and will do all they can to continue to give good health care to our veterans and at the same time conserve energy for the national interest.

The specific project planned for the ACES is a 60-bed nursing home to be built in Wilmington, Delaware, as part of the Veterans Administration Hospital complex. This will have an 85-ton heat pump and will operate with a partial-size ice bin supplemented with a solar collector and an outdoor air coil.

8. MECHANICAL EQUIPMENT PACKAGE

Herb Lindahl, *Manager of Advanced Engineering, Bohn Aluminum and Brass, Heat Transfer Division, Danville, Illinois*

The ACES package is a very versatile unit. As a heat pump, it provides for heating, cooling, and hot water by merely changing water and brine fluid flow directions. There can be the following different modes of operation:

1. winter space heating, hot water heating, and ice building without solar collection;

2. winter space heating and hot water heating with solar storage in the water bin;

3. winter solar collection in the water bin;

4. winter water heating and ice building;

5. summer cooling by circulating cold brine from the storage bin;

6. summer cooling and hot water heating plus added cooling to storage bin;

7. summer hot water heating plus added cooling to the storage bin; and

8. added cooling to storage bin in summer by operating the compressor at night and dissipating the heat to the outdoor collector.

The ACES mechanical equipment is assembled as a package unit consisting of a compressor, aluminum tube brine cooler, aluminum tube water-heating condenser, copper tube desuperheater and water heating condenser, hot water circulating pump, heating circulating pump, and brine-cooler circulating pump, all equipped with necessary mechanical and electrical controls. This package unit has been assembled, charged with refrigerant, and tested. The package unit is ready to be coupled by interconnecting piping to the ice storage bin and a solar collector and/or an outdoor fan coil.

Bohn Aluminum and Brass Company is prepared to supply ACES in 15- through 250-hp sizes, composed of components currently in production. Bohn is experienced in producing complete, factory-assembled packages. Aluminum tubes with aluminum fin heat coils, compatible with other aluminum tubing used in the brine circuits, are also available. The aluminum-extruded solar collector surface can also be supplied as a component for ACES installations. Bohn also builds air handlers for commercial-type installations.

The ACES appears to be ideal for conserving energy and balancing the demand loads at the electric power generating plants. Figure 4 shows a schematic diagram for the ACES package that Bohn is making for the ACES Demonstration House in Knoxville, Tennessee.

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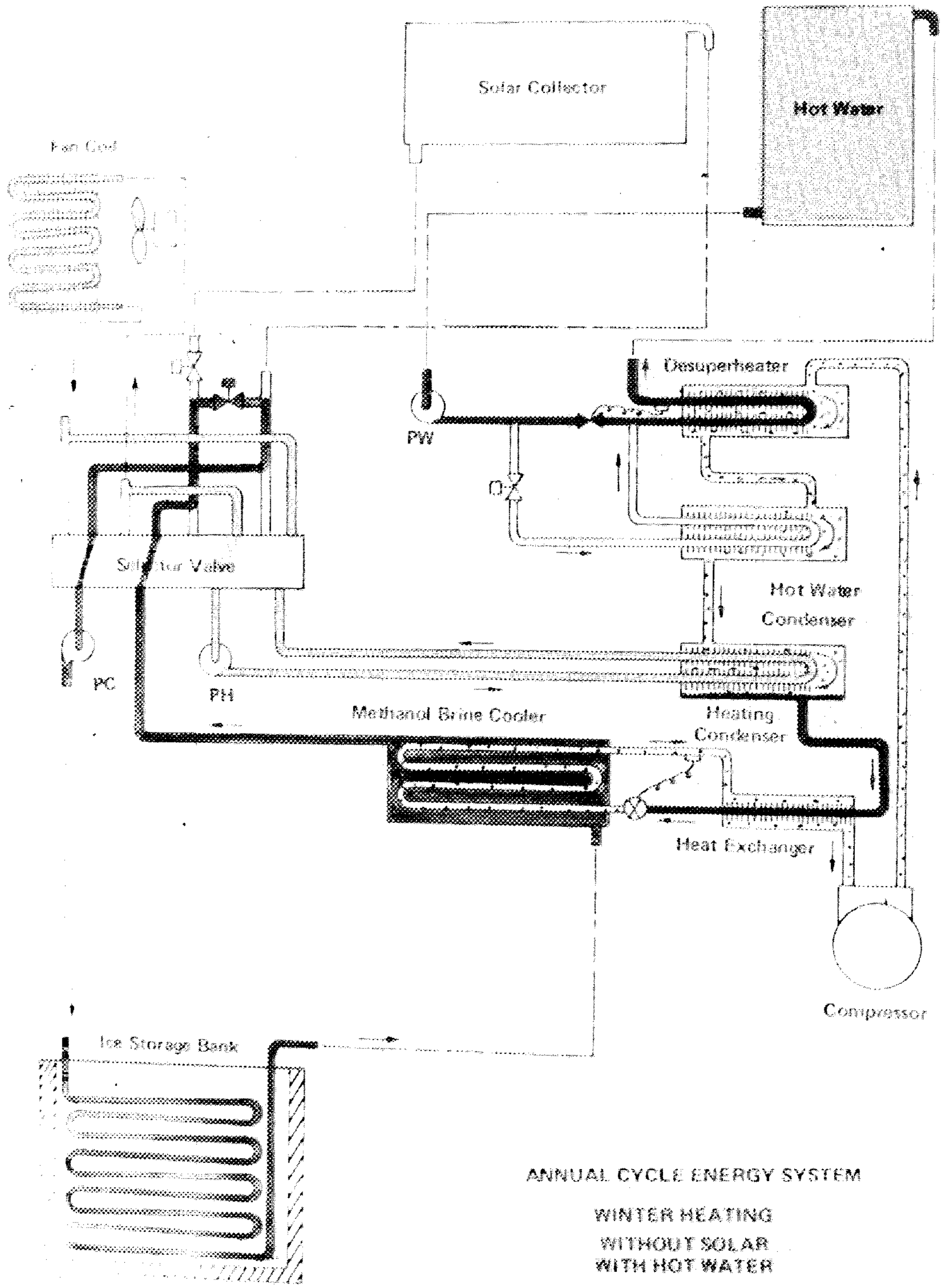

Fig. 4. Schematic equipment diagram for TECH ACES demonstration house showing equipment in the heating mode without solar collectors in operation.

9. SYSTEM COMPONENTS

Ed Bottum, *President, Refrigeration Research, Inc., Brighton, Michigan*

In the early days of every new industry, components have become available for experimenters to use in building systems. For example, in the early days of radio (later hi-fi), off-the-shelf components and materials appeared with which systems could be built on a custom basis.

One of the reasons refrigeration and air conditioning people were not moving more rapidly toward the use of solar heating was a lack of components. Someone must take the lead in making available these components so that experimenters and developers can build energy-conserving systems, whether they be solar or other types. Refrigeration Research, Inc., has added three new lines of heat exchangers to the regular lines of refrigeration liquid-to-suction-gas heat exchangers that they have produced for many years. They added a desuperheater to the line for heating domestic hot water from the superheated gas coming off a heat pump, and they now make evaporator-chillers and water cooled condensers. Both of these equipment items can be used in energy-conserving heat pump operations.

In addition to the manufacturing of components within their own plant, Refrigeration Research is stocking for resale components manufactured by others. These components include pumps, foam form blocks, extruded aluminum finned tubing, DuPont Tedlar, and 3M Black Velvet paint. Although probably all of the items offered in their catalogue are available in some form from scattered sources, until now, these components could not be purchased from one source.

As early as some 16 years ago, when Refrigeration Research first joined the U.S. section of the International Solar Energy Society (ISES), it was inevitable that the fields of refrigeration, air conditioning, and solar energy would someday become a single field.

Refrigeration Research distributed its first Solar Energy Catalogue at the ASHRAE show in January 1975. At the time, this was done with a certain amount of apprehension and misgiving. However, the decision to do so has proven correct, as evidenced by the tremendous interest the industry has shown in solar energy components.

The refrigeration industry makes extensive use of the hydrogen-copper brazing process. Probably well over 85% of all of the receivers, mufflers, and accumulators, up through and including 6-in. outside diameter, are made in the hydrogen-copper brazing process. The reason for this is that clean parts of uniform quality can be made inexpensively. If there are several joints to be brazed, the entire assembly can be carried through the furnace on a belt in a hydrogen-reducing atmosphere, and all the joints are brazed at once. If the part has been properly prepared, all hand brazing is eliminated, and the parts come out of the furnace cleaner than when they entered. Depending upon the part, as many joints as desired can be brazed at one time. For this reason, Refrigeration Research, Inc., is making extensive use of the hydrogen brazing furnace in making solar components.

Originally, Refrigeration Research did not plan to manufacture solar collector plates. However, about a year ago they needed some for a test system but could not find what they wanted readily available. At that time, they decided that it would be easier to make up some steel and hydrogen-copper braze for their test. They were pleasantly surprised with the results of the test. Not only were they able to braze eight tube ends into a manifold header at each end, but they were also able to braze eight steel tubes to the steel plate and copperize the plate surface at the same time. The resulting bond between the tube and plate is a pure filet of copper, which is 7/16 in. wide. Tubes cannot be pulled off without destroying them and cannot be melted off with less than 2000°F. This procudure is useful in making inexpensive steel manifolds that may be used on the ACES. Steel manifolds can be made in diameters of 1-1/4 in., and any number of steel nipples can be brazed into the header in one operation.

Mr. Bottum concluded his remarks by reviewing some of the components that they will have available in stock or can make on a custom basis for the ACES. These components are listed in their third solar component catalogue for 1975, which was distributed for the first time last week in the Chicago Builders show and here at the Oak Ridge ACES Workshop. These components include:

1. desuperheating heat exchangers;
2. radiant/convector material of extruded aluminum tube, which can be also used in ice coils;
3. refrigerant liquid suction line heat exchangers;
4. manifolds and headers;
5. suction line accumulators;
6. chiller-evaporators;
7. foam form blocks for onsite construction of water or ice tanks; and
8. condensers for water heating.

10. ARCHITECTURAL AND STRUCTURAL COMPONENTS

Ben S. Adams, *Vice President, Crouch & Adams, Inc., Oak Ridge, Tennessee*

The problem of constructing an ice storage bin for an ACES application was discussed by Mr. Adams. The original paper by Harry Fischer suggests several types of alternative storage bins, making use of existing and familiar building materials and constructed according to conventional methods. Mr. Adams concurred with Mr. Fischer's opinion that the construction of an ice storage bin would pose no special construction problems and that no conflicts with building codes were likely to be encountered. If rock or unstable soil conditions are found during excavation, it is relatively simple to redesign the ice bin or build another type of bin at reasonable expense. The ice storage bin must be watertight, should be well insulated, and should afford access to the interior. An arrangement must be provided to hold down the coils, that is, to counteract the buoyancy of the coils when covered with ice. The force required to hold the coils down is not great and will not be a problem.

An extremely well-constructed ice bin can be made using precast walls, beams, and slabs on a poured-in-place concrete foundation and floor slab. If, after the structure has been properly insulated, it is found not to be watertight, corrective action can be taken by applying waterproofing or by installing a plastic liner. The foam-form system of bin construction uses several very common elements such as expanded polystyrene units and expanded metal. These units fit together to form a self-insulating basis for a monolithic, reinforced concrete wall. This method of construction is particularly well suited for building an ACES ice storage bin. If a wall is found not to be watertight after construction, it can easily be waterproofed by parging or lining.

The solar convector must be exposed to the sunlight and must have a free flow of air around it. Therefore, it becomes an architectural consideration as much as an engineering conern. Many alternative configurations of the solar convector are possible which are both pleasing and functional. Figures 5 to 8 are sketches of possible solar convectors showing some very basic applications. Many design options are available for construction of the collector, such as a solar fence, mansard roof, or solar screen limitor. The application for retrofit or remodeling of older, conventional systems is almost limitless. The two major requirements for solar convectors are that they should generally face south in the Northern Hemisphere and that they should be any color except white.

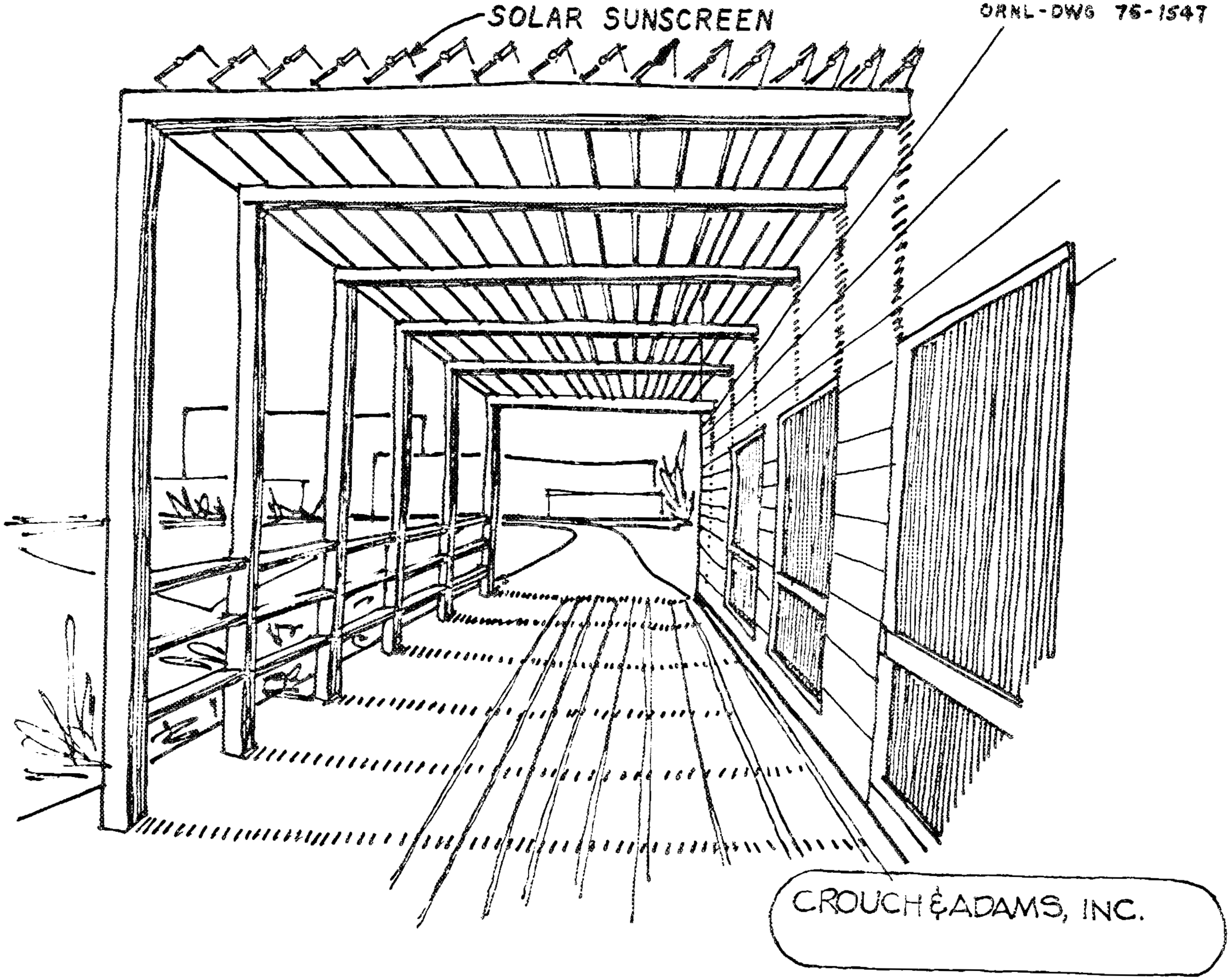

Fig. 5. Solar panels incorporated into a sunscreen.

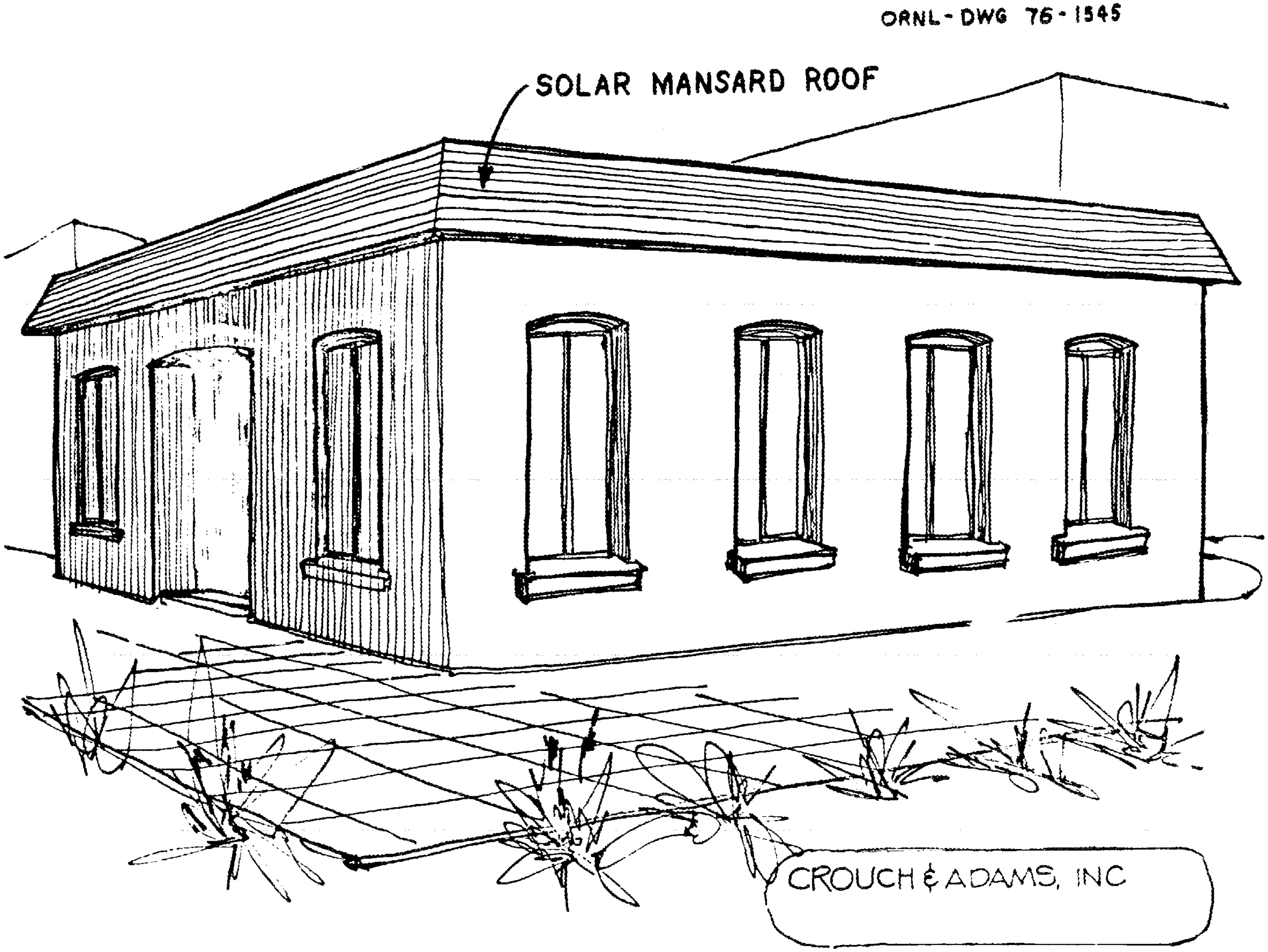

Fig. 6. Solar panels incorporated into a mansard roof.

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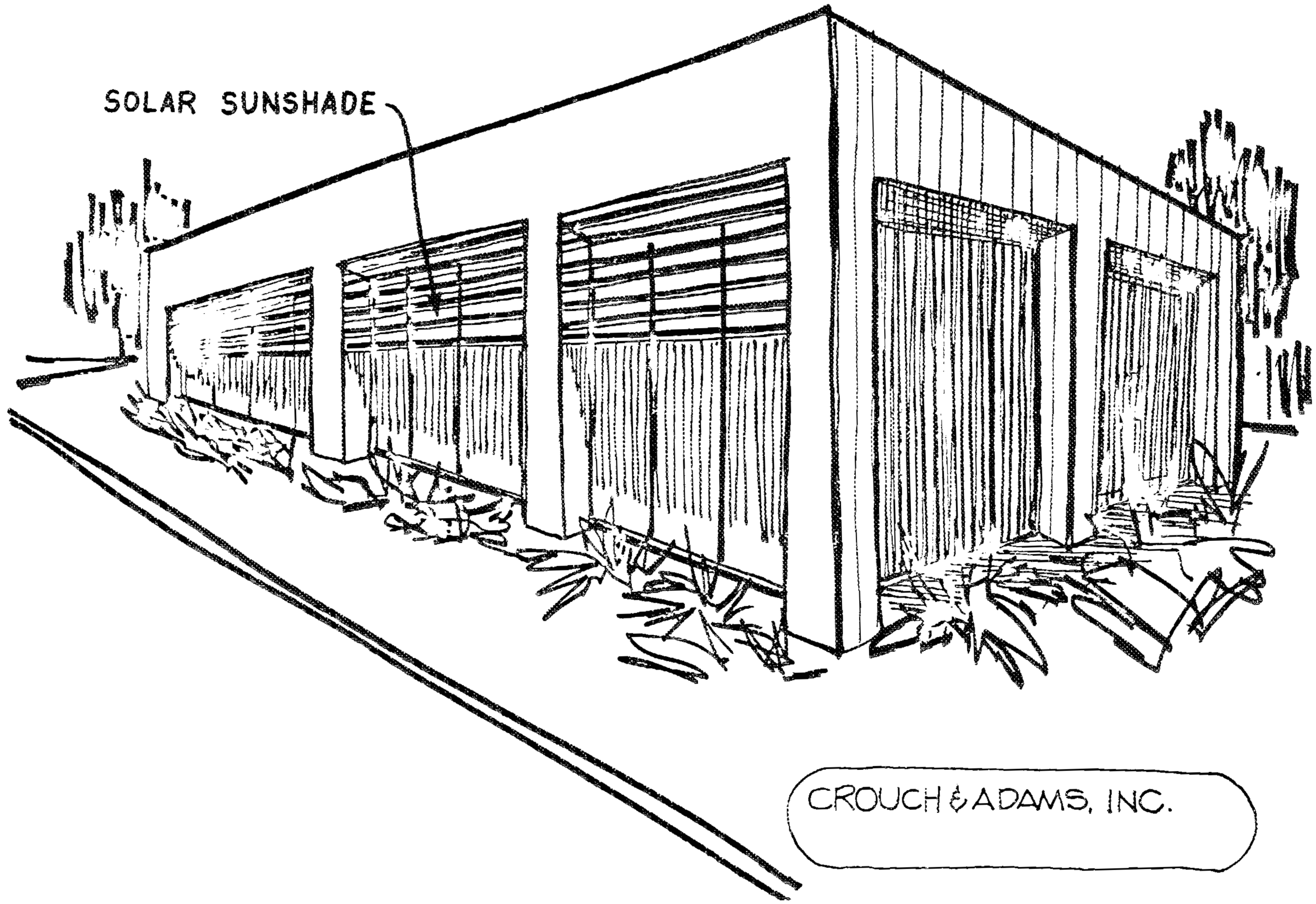

Fig. 7. Solar panels incorporated into a sunshade.

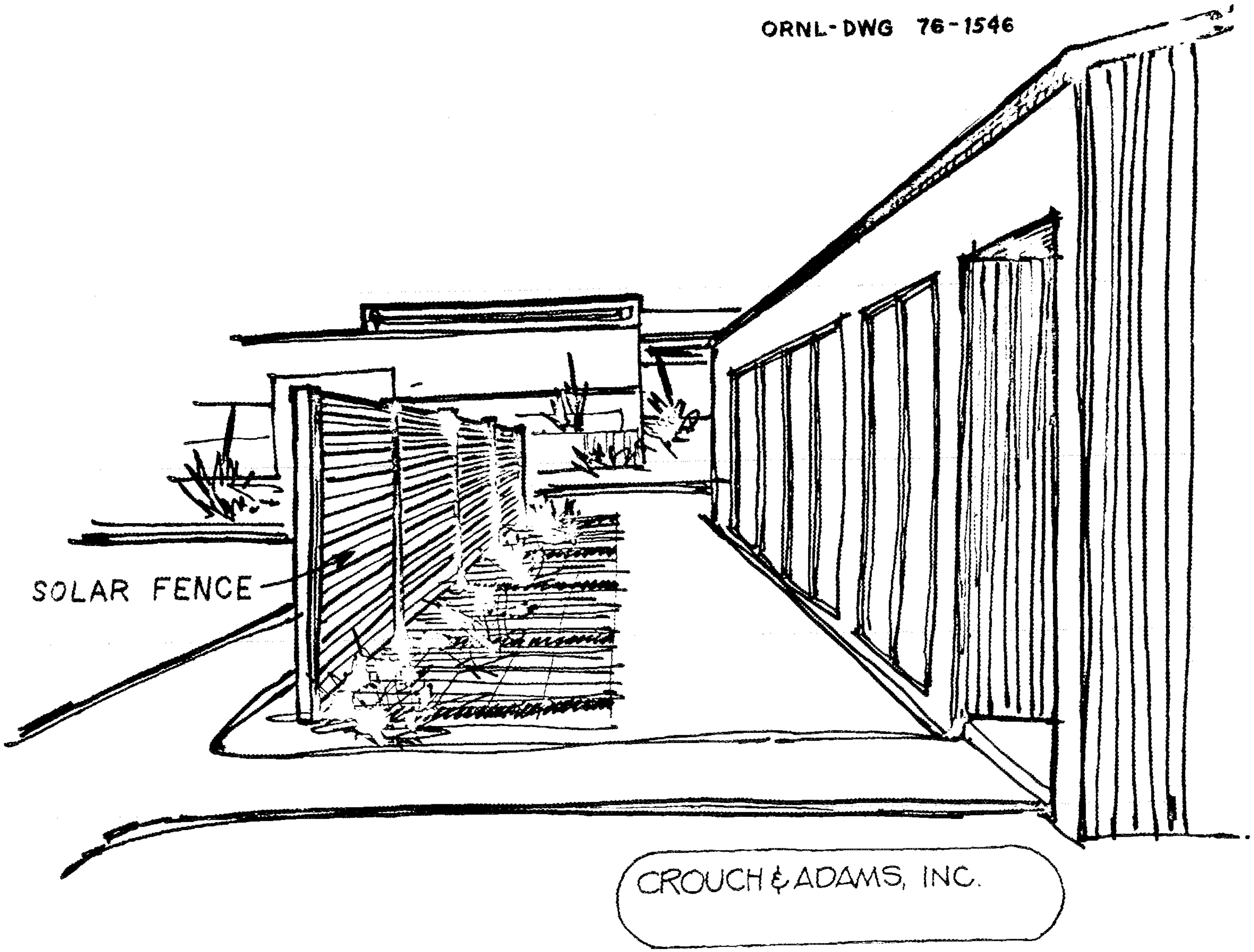

Fig. 8. Solar panels incorporated into a fence.

11. FEDERAL INCENTIVES FOR ENERGY CONSERVATION

David Rosoff, *Energy Conservation in Buildings, Federal Energy Administration, Washington, D.C.*

There are a number of ways the government can attempt to promote energy conservation practices among the general public. These include (1) voluntary methods based on exhortation, persuasion, and education; (2) semivoluntary methods which rely on statutory incentives such as the provision of tax credits, loan subsidies, grants, etc.; and (3) mandatory methods such as rationing, curtailment of energy usage, and the imposition of required standards.

There is increasing public support for the general goals of energy conservation, and the importance of retrofitting existing homes with more efficient, energy-saving devices is well recognized. The President has proposed, and Congress is considering, a rebate to homeowners as an incentive for retrofit measures to reduce energy consumption. The Federal Energy Administration regards the retrofitting of homes as a major energy conservation goal, as do many other government agencies. The major electric and gas utility associations and many individual gas and electric utility companies are also actively promoting energy conservation in homes. Some manufacturers are already advertising on television and radio and in newspapers to encourage people to retrofit their homes with energy conserving features. More such industrial efforts can be expected. All the states and many cities have energy conservation offices and engage in a number of different energy conservation programs. Under one state program, nearly 100 homes of low-income families have been retrofitted. The mounting pressure of high monthly bills for heating and cooling can be expected to stimulate even greater homeowner interest in the program. While no one can predict future fuel prices with certainty, many experts believe that prices will continue to rise at an annual rate of 10 to 15% in the foreseeable future. All these factors combine to create a favorable climate for the retrofit industry.

Why retrofit homes? Retrofitting existing homes with energy conserving features has a major energy conservation potential. Energy used in existing housing accounts for more than one-fifth of the toal energy used. There are about 47.5 million single-family detached dwellings in the country. Much of the existing housing inventory was built when energy was readily available and cheap. In the late 1950s, interest in central residential air conditioning and electric heating combined to provide a new viewpoint with respect to thermal insulation for new homes. It was not until then that the manufacture of insulation became a major industry and that double glazing or storm windows was considered for new housing. However, energy was relatively cheap, and extensive thermal insulation was not widely justifiable on an economic basis.

Perhaps 75%, or about 35 million, existing single-family detached homes were built prior to 1960. There is little doubt that it would be economically justifiable to provide additional thermal protection to many of these homes and to some of those built after 1960. It is estimated that retrofitting just half of these homes with economically justifiable features to conserve energy would save the equivalent of 650,000 to 1,000,000 barrels of oil per day.

The role of the government in promoting these energy conservation techniques is obvious in those cases where there is no profit motivation on the part of the private producers. The promotion of energy conservation is a major federal concern. An important problem facing the FEA is the collection of data on the feasibility, cost, and reliability of proposed retrofit measures in order to promote public confidence in, and acceptance of, energy conservation practices. Before incentives can be created, the barriers must be studied.

12. FINANCING RESIDENTIAL ENERGY CONSERVATION

Don Maxwell, *President, Bank of Oak Ridge, Oak Ridge, Tennessee*

Peter Drucker once said, "We can be sure that the future will be different, and furthermore, different than we expect." In years past, the United States has been very fortunate in benefiting from cheap energy. However, the oil embargo in 1973 and the crisis that erupted at that time have made it necessary that our posture with respect to energy consumption be changed. Otherwise, the cost is going to be excessive over the next several decades.

The ability to devise technologies to overcome crisis situations has been of great significance in the history of this nation. Familiar to all is the story of the use of whale oil in the 1800s and how its exorbitant rise in price made it necessary to develop alternative sources of energy. Undoubtedly, this same story will be repeated with other kinds of energy in solving the current energy problem.

Information and services must be provided to educate people on the need for energy conservation in our society. It is highly unlikely that there will ever again be cheap energy. Rather, as energy costs continue to rise, energy conservation will increase through many different avenues, including changing life styles. From the broad point of view, the Annual Cycle Energy System appears to be a significant method for reducing energy consumption over the next several decades, thereby lessening the strain on the manufacturing industry. Since approximately 16 million residences could conceivably be fitted with an ACES, it would appear that the potential savings in both cost and energy are extremely great.

Recognizing the excessive demands for capital formation in the future for energy research, development, and commercialization, it appears likely that banking, savings and loan associations, and mortgage bankers are going to find it necessary to cooperate in providing financing for energy conservation. Two areas of particular interest to the Bank of Oak Ridge are real estate financing of new homes and providing leadership in the utilization of home improvement loans.

The cost estimates shown in Table 3 are based on 4¢/kWhr for the price of electricity (the current price in the Eastern Seaboard) and an annual inflation rate of 8%. Column 3 of the table shows the cost of operating an electrically heated, electric air conditioned, and electric hot-water-heated home through 1995. Column 4 shows the cost of an ACES-equipped home with a full-tank ACES. Column 5 shows a modified, or small-tank, ACES. These columns include extra mortgage payments for the ACES equipment.

Table 4 shows the payback of a $3000 ACES Retrofit into an existing home, assuming current interest rates and assuming that Congress passes legislation, allowing depreciation of approved energy conservation equipment over a period of five years. This shows that with five-year depreciation the cost of ACES equipment could be paid out of savings in five years.

Table 3. Cost estimates

Year	Energy cost[a] (¢/kWhr)	Resistance heat cost[b]	Full-tank ACES cost[c]	Modified ACES cost[d]
1975	4.00	$ 709	$ 524	$ 442
1976	4.32	765	540	464.40
1977	4.66	826	557	488
1978	5.04	893	576	514.80
1979	5.44	964	596	542.80
1980	5.87	1.040	617.50	572.90
1981	6.34	1,124	641	605.80
1982	6.85	1,214	666.50	641.50
1983	7.40	1,312	694.50	680
1984	7.99	1,416	723.50	721.30
1985	8.63	1,530	755.50	766.10
1986	9.32	1,652	790	814.40
1987	10.07	1,785	827.50	866.90
1988	10.87	1,927	867.50	922.90
1989	11.748	2,082	911.40	984.36
1990	12.68	2,248	958	1,049.60
1991	13.70	2,439	1,009	1,121
1992	14.80	2,624	1,064	1,198
1993	15.98	2,833	1,123	1,280.60
1994	17.26	3,060	1,187	1,370.20
1995	18.64	3,304	1,256	1,466.80
Total cost for 20 years		$35,747	$16,884.90	$17,514.36
Cost savings for 20 years			$18,862.10	$18,232.64

[a]Electric energy charge starting at 4¢/kWhr and inflating at a rate of 8% per year.

[b]Electric heating, cooling, and hot water bill for a resistance electric heated house, with electric air conditioner and electric hot water heater (17,725 kWhr).

[c]ACES energy costs based on 5000 kWhr/year + $324/year for extra mortgage payments on a 9%, 20-year mortgage (ACES extra cost — $1500).

[d]ACES (small tank) costs based on 7000 kWhr/year + $162 for extra mortgage payments on a 9%, 20-year mortgage (ACES extra cost — $1500).

Table 4. Home improvement loans cost data

Year	Energy cost[a] (¢)	Resistance electric heat cost[b]	ACES system energy cost ($/year)	Payments on $3,000 5-year loan[c]	Annual depreciation[d]	Annual interest	Net cash savings[e]	Average cash savings (5 years)
1975	4	$ 709	$ 200	$ 800.76	$ 600	$ 200.76	$ 709.17	$796.73
1976	4.32	765	216	800.76	600	200.76	749.17	
1977	4.66	826	233	800.76	600	200.76	793.17	
1978	5.04	893	252	800.76	600	200.76	841.17	
1979	5.44	964	272	800.76	600	200.76	892.00	
		$4,157	$1,173	$4,003.80	$3,000	$1,003.80	$3,984.68	

[a] Electric energy charge starting at 4¢/kWhr and inflating at a rate of 8% per year.

[b] Electric heating, cooling, and hot water bill for a resistance electric heated home, with electric air conditioning and electric hot water heater (17,725 kWhr/year).

[c] Home Improvement Loan annual payments including interest on $3000 loan to install ACES equipment.

[d] Annual 20% depreciation, if allowed by Congress, as an incentive for installation of energy conserving equipment.

[e] Net cash savings on utility cost, depreciation, and interest based on $16,000 gross income of family of four on annual tax return if 20% depreciation is allowed by Congress.

13. REMARKS ON INDUSTRIAL COOPERATION

Carol J. Oen, *Industrial Cooperation Program, Union Carbide Corporation, Nuclear Division*

The purpose of the UCC-ND Industrial Cooperation Program is to assist in transferring the results of tax-supported R&D activities of government laboratories to private industry and to state and local government. The responsibilities of the ORNL Industrial Cooperation Office are to transfer ORNL R&D, such as ACES.

The workshop participants received descriptive materials on the Industrial Cooperation Program, including an index of all Industrial Cooperation bulletins issued to date. Industrial Cooperation bulletins briefly describe technologies that were developed at each of the four UCC-ND plants. Transfer efforts are also made through the printed media, exhibits at meetings, seminars, and workshops such as this one.

The Industrial Cooperation staff serves as the in-house advocate for private industry. Requests for any additional information or assistance should be directed to:

Mel Koons
UCC-ND
P.O. Box Y
Oak Ridge, Tennessee 37830
615-483-8611, ext. 3-5979

Carol Oen
ORNL
P.O. Box X
Oak Ridge, Tennessee 37830
615-483-8611, ext. 3-0121

14. FORUM ON FINANCING OF ACES INSTALLATION

Don Maxwell (Leader), *President, Bank of Oak Ridge, Oak Ridge, Tennessee*

The discussion centered on whether lending institutions adequately consider life-cycle costs in determining the advisability of granting loans for buildings. The purchaser of an energy-efficient building will be better able to repay a loan. Is this fact taken into account in determining the maximum amount and the terms of the loan?

Speaking from the banker's viewpoint, Mr. Maxwell stated that this factor would be considered and that the additional cost of an Annual Cycle Energy System would be included in the total value of the building. For example, a typical residential home with a conventional heating and cooling system might cost $44,000, whereas the same home with an ACES might cost $48,000. Current practice with conventional loans (non-FHA and non-VA) is to lend 75% of the value of the home with the owner's equity, through down payment, being 25%. The amount the lending agency would loan would be $33,000 for the conventional home or $36,000 for the ACES-equipped home. Required owner's equity would be $11,000 or $12,000 respectively.

The enhanced ability to repay the loan is reflected in the larger amount that the lending agency is willing to loan. Therefore, the risk to the lending institution has not changed, and the loan interest rate would not change. The incentive for installing an ACES, as offered by the lending agency, is limited to making the capital available at prevailing interest rates.

Home improvement loans, insured by FHA, are availabe for modifications and improvements to existing homes. According to Mr. Maxwell, items that can be covered by these loans are specifically listed by FHA.

Steps should be taken as soon as possible to get ACES equipment added to the FHA list of equipment that can be covered by home improvement loans.

15. FORUM ON MARKETING, INSTALLATION, AND WARRANTIES

Richard F. Todd (Leader), *National Environmental Systems Contractors Association*

The question under discussion was "How to get ACES to the marketplace?" There was a concensus that it would be easier and more satisfactory to develop initially the commercial, institutional, multifamily, and light commercial markets than the market for single-family residences. The reasons for this are the following:

1. The commercial market is more sophisticated and is accustomed to considering life-cycle costs.

2. Commercial systems are normally engineered and custom assembled.

3. Commercial systems are more likely to benefit appreciably from a reduction in charges resulting from lower energy consumption.

The development of this commercial market would require at least adequate design, economic information, and an educational program for consulting engineers and commercial contractors.

The barriers to the development of the single-family dwelling market seem to be:

1. The public does not fully understand the concept of life-cycle cost.

2. The American practice of moving frequently discourages long-return investment.

3. The public believes that solar energy is just around the corner.

4. Governmental disincentives would be created as a result of increased property taxes. (The homeowner who invests more money to conserve energy is penalized by a higher property tax.)

5. The conventional residential heating and air conditioning contractor is not presently equipped to install the ACES.

In spite of these barriers, two builders, Gerry Corrigan of Des Moines, Iowa, and Alvah Ehrman of Hamburg, New York, expressed their willingness to construct and market several ACES homes in order to gain experience with the system.

16. FORUM ON ACES DESIGN OPTIMIZATION

Harry C. Fischer (Leader), *Consultant, Energy Conservation Program, Oak Ridge National Laboratory*

The main purpose of this forum was to explain the procedure for designing an ACES installation when a computer is not available. To illustrate the procedure, a group of eight townhouses located near Washington D.C. was selected. The results of heating load calculations for these buildings are available, and data on average weather conditions in the Washington, D.C. area are given in the Department of Navy Manual, NAVFAC P89. This manual contains tabulations of meteorological data recorded at Andrews Air Force Base, Washington, D.C. Pertinent tables from this publication are reproduced in Appendix B. Figure 1 shows a schematic diagram of the ACES installation considered for the townhouses.

First, a careful calculation must be made of the building's heating and cooling loads for design-day conditions. These calculated design loads for an individual townhouse were already available to us and are given below:

1. design heating load (15°F design temperature) = 183,583 Btu/hr,
2. maximum cooling load (95°F design temperature) = 124,415 Btu/hr, and
3. domestic water heating load (120°F design temperature) = 12,500 Btu/hr.

Assumption at ORNL is that an indoor temperature of 70°F is desired and that the building heating load can be calculated as a function of the ambient, outdoor temperature. This is done by multiplying the design heating load by the ratio of the actual temperature difference across the shell of the building to the temperature difference that would exist under design-day conditions. That is, the building heating load is equal to 183,583 x $(70 - T_o)/(70 - 15)$ Btu/hr, where T_o is the actual outside temperature in degrees Fahrenheit. The gross heat load of an individual townhouse can then be calculated for any given month, providing data on temperatures and the duration time of these temperatures are known. Using the weather data of Appendix B, the procedure is illustrated in Table 5, where the gross heat load of a townhouse building is calculated for the month of January. The results show that the amount of heat required to maintain the indoor temperature of the townhouse at 70°F throughout the month of January is 100,631,000 Btu.

Table 5. Calculated heating load for eight-unit townhouse in Washington, D.C., using bin method

Temperature range (°F)	January hours in this range	ΔT below 70°F	3338 Btu/hr/°F x hr x ΔT below 70°F = Btu
65/69	2	3	20,000
60/64	5	8	134,000
55/59	12	13	521,000
50/54	22	18	1,322,000
45/49	42	23	3,224,000
40/44	106	28	9,907,000
35/39	144	33	15,862,000
30/34	165	38	20,929,000
25/29	105	43	10,415,000
20/24	65	48	10,415,000
15/19	45	53	7,961,000
10/14	23	58	4,453,000
5/9	7	63	1,472,000
0/4	1	68	226,000
			91,517,000
Water heater load: 12,250 Btu/hr x 744 hr = +			9,114,000
			100,631,000 Btu

The total heat dissipated by the building is supplied from internal heat sources, solar radiation entering through windows, and the heating system of the building. Assuming that four people occupy each apartment and consume 400 kWhr/month for lights and appliances, the total heat supplied to the townhouse by internal sources is 13,894,000 Btu/month. The amount of solar energy entering the building through south-facing windows is estimated using insolation data provided in Appendix C. Here, it is seen that an insolation rate of 1397 Btu/ft^2/day can be expected in the Washington, D.C. area during January. Since an individual townhouse has 584 ft^2 of south-facing window area, the total solar heat gain for the building amounts to 584 ft^2 x 1397 Btu/ft^2/day x 31 days, or 25,291,000 Btu during the month. Subtracting the heat supplied by internal sources and by solar radiation from the gross heat load gives a net load of 61,446,000 Btu that must be supplied by the central heating system.

If one assumes that the townhouse central heating system consists of an ACES installation, similar to the one shown in Fig. 1, which utilizes a heat pump having a coefficient of performance (COP) equal to 3.5, then the compressor motor furnishes 28.6% (1/COP) of the delivered heat, and the ice bin (or outside air coil) furnishes the remaining 71.4%. Therefore, the amount of heat that must be extracted from the water (or air) by the heat pump to meet the January heating requirements of the building is 0.714 x 61,446,000 Btu, or 43,872,000 Btu. The latent heat of fusion that must be extracted from water at 32°F to form 1 ft^3 of ice is about

8200 Btu. Hence, supplying all the January heating load of the townhouse by freezing water would result in the formation of (43,872,000 Btu/8200 Btu/ft^3), or 5350 ft^3 of ice.

The required size of the ice storage bin can be reduced by employing unglazed solar panels to collect and store solar energy in the ice bin. If this is done, the thermal storage capacity of the tank can be reduced to about 17,015,000 Btu, or to the equivalent of about 12 days of the January load. The minimum size required for the ice bin would then be 17,015,000 Btu/8200 Btu/ft^3 of ice, or 2075 ft^3. The solar panel area that would be required to completely replenish the energy extracted from the water storage bin during January is 43,872,000 Btu/1397 Btu/ft^2day x 31 days, or 1013 ft^2. (This assumes the solar panel operates at 100% efficiency.) An unglazed solar panel with a 36°F fluid would actually be operating below the average outdoor temperature in Washington, D.C., in January. Since such a panel would have an efficiency of about 0.96, a solar energy collection area of about 1050 ft^2 should be sufficient. A solar collector of this size could be constructed as two 66-ft-long sections of an 8-ft-high solar fence spaced 16 ft apart to prevent shadow interference.

The heat pump selected for the townhouse example has an output of 212,000 Btu/hr, at an evaporator temperature of 20°F and a condensing temperature of 105°F. The evaporator, therefore, requires (212,000 Btu/hr x 0.714), or 151,370 Btu/hr, from the water storage bin. The heat transfer coefficient for the ice bin coils, when surrounded by a 3-in.-thick layer of ice, is given in Appendix D. For 3/4-in.-OD tubes spaced on 6-in. centers, the lowest heat transfer coefficient that would be encountered when the ice is fully formed is 3.2 Btu/ft/°F/hr. Appendix E shows the design of a typical brine freezing coil that is now commercially available. The composition of the brine is determined by the design temperature for the specific geographical location, as shown in Appendix F. The brine enters the coils at a temperature of about 25°F and returns to the chiller at a temperature of about 27°F. Under these conditions, the logarithmic mean temperature difference (LMTD) is (2/ln 5/7), or about 6F°. Therefore, the rate of heat flow from the water to the brine is (3.2 x 6), or 19.2 Btu/hr per foot of tubing. The total length of tubing required is (151,370/19.2), or 7784 ft. For the minimum-size water storage bin considered above (7884 ft/2075 ft^3), or 3.8 ft of tubing are required for each cubic foot of ice bin volume. This requirement can be met by installing the tubes horizontally in the water storage tank, with the centers of the tubes spaced on a 6-in. grid in the vertical plane.

A number of modifications to the basic ACES depicted in Fig. 1 can be made, if needed. The required volume of the ice storage bin can be varied by employing different combinations of solar panels and air-to-air heat pump arrangements. It should be kept in mind, however, that a heat pump with an outdoor air coil operating as an evaporator has a lower COP than an ice-to-air heat pump, if the ambient air temperature is below 48°F. The reason for this is that the fan power expended to move the air through the outdoor coil cannot be recovered, whereas the pumping power for circulating water in an ice-to-air heat pump installation can be recovered. This is not meant to imply that air-to-air heat pumps should not be used in applications where space for solar panels and large ice bins simply is not available.

To some extent, solar panels may be used to substitute for water storage bin capacity. For example, in Washington, D.C., in January, 1 ft^2 of solar panel can collect 1397 Btu/day, or up to 43,307 Btu of solar energy for the month. The volume of water bin yielding the same amount of energy is (43,307 Btu/8200 Btu/ft^3 of ice), or 5.28 ft^3. Because unglazed solar panels, of the type used for ACES, cost \$2.00 to 2.50/ft^2, whereas water bins with coils cost \$0.90 to 1.50/ft^3, the solar panel appears to have the lowest cost per unit of delivered energy. However, the solar panel also requires some form of thermal storage capacity. Furthermore, the ACES ice bin also provides summer air conditioning, reducing the annual energy costs. This advantage makes it possible to accept additional capital costs for ice bin construction. For example, in areas where electricity costs 4¢/kWhr, each 1000 kWhr of energy saved annually for air conditioning has a value of \$40. At a 12% fixed annual charge for capital, \$333 in extra capital costs can be spent to achieve this energy savings, without incurring an economic penalty. This extra expenditure in capital appears justified in view of today's rapidly escalating fuel costs. In effect, the unknown, but rising, rate of inflation for energy costs is traded for a fixed charge rate for capital costs.

Although the preceding example of an ACES design calculation applies specifically to the Washington, D.C., area, the procedure can be readily extended to other geographical locations, providing the necessary data on solar radiation and climatical conditions are available. Appendix G provides solar radiation data for 71 locations in the United States and Canada. Levels of solar radiaton at other site locations can be obtained by interpolation, using the solar radiation maps provided in Appendix H. Bin weather data for a large number of sites in the United States (including Alaska and Hawaii) are listed in the Department of Navy Manual, NAVFAC P89.

17. COST OF EARLY PRODUCTION ACES

Harry C. Fischer, *Consultant, Energy Conservation Program, Oak Ridge National Laboratory*

During the Workshop, several requests were made for an estimate of the cost of equipping a single-family dwelling with ACES in 1976. A manufacturer, a contractor, and a builder agreed to cooperate in making a preliminary estimate of the cost for installing a full ACES in an 1800 ft^2 Washington, D.C., home having a design heating load of 30,000 Btu/hr and a design cooling load of 24,000 Btu/hr. These hurriedly prepared estimates of the cost of a full ACES are presented in Table 6. Following the conference, several attendees prepared a similar estimate

Table 6. Cost of ACES for single-family home with 1800 ft^2 in Washington, D.C., with full annual cycle (no solar panel) in 1976 pilot production quantities

Energy usage, 5600 kWhr/year			
Heat pump package[a]			$1422
24 ft x 24 ft x 5.5 ft tank (3168 ft^3) under garage:			
Bottom slab material	$288		
Labor	75		
Profit	25		
Subtotal	$388	$ 388	
Span deck (in place)	$766		
Profit	75		
Subtotal	$841	$ 841	
Additional wall 4 to 6 ft	$140	$ 140	
Insulation 2-in. urethane	$544		
Labor	50		
Profit	50		
Subtotal	$644	644	
Total cost of tank		$2013	$2013
Duct system installation		800	800
Ice bin coil (14 coils, each 88 ft long)			
30¢/ft fabricated		369.60	
2 headers for coils		44	
Subtotal		$ 413.60	$ 413.60
Labor (4 man-days at $16/hr) to assemble coils and connect headers and supports		512	512
Labor (4 man-hours at $16/hr) to set heat pump package		64	64
Labor (4 man-hours at $16/hr) to run brine lines to ice storage bank		64	64
Labor (2 man-hours at $16/hr) to run lines from heat pump to domestic water storage tank		32	32

Table 6 (continued)

Energy usage, 5600 kWhr/year		
Labor (4 man-hours at $16/hr) for control wiring	64	64
Total		$5384.60
Less cost of conventional heating, cooling, and hot water system		-1600.00
Net premium for ACES (full-size tank)		$3784.60

[a]The heat pump package includes an outdoor air coil condenser to be used in summer. The heat pump is used as an off-peak air conditioner in the event that ice inventory is depleted before the end of cooling season.

of the costs of installing an alternative ACES having less water storage capacity. These estimated costs for a small-tank ACES are shown in Table 7. As expected, the calculations show that it is much less expensive to install a small tank than a large one. The annual energy consumption, however, will be greater for the small-tank ACES.

Table 7. Estimated current cost of small-tank ACES for single-family 1800 ft^2 in Washington, D.C.

Energy usage, 7500 kWhr/year		
Heat pump		$1422
8 ft x 8 ft x 8 ft (512 ft^3) tank made from pressure treated wood panels with 3.5-in. bead board insulation		
5 panels at $70 each	$350	
20-mil vinyl liner	130	
Evacuation, sand bottom, and backfill	100	
Total tank cost	$580	$ 580
12 ft x 88 ft coils x 0.30/ft fabricated	$343	
Manifolds for coils	44	
Total cost for manifolds	$387	$ 387
Duct system installed price	$800	$ 800
800 ft of solar panel coil	$150	
Manifolds for solar panels	44	
Coil material price total	$194	$ 194
Labor assembly and installation cost for ice storage bank for 512 ft^3 tank (16 man-hours at $16/hr)	$256	
Makeup and mount outdoor coil (16 man-hours at $16/hr)	$256	
Set heat pump package (4 man-hours at $16/hr)	$ 32	
Run brine lines to tank and solar panel and water lines to hot water storage tank (10 man-hours at $16/hr)	$160	
Control wiring (4 man-hours at $16/hr)	64	
Total labor cost	$768	$ 768
Total cost		$4151
Less cost of conventional heating, air conditioning, and hot water system		1600
ACES premium		$2551

Since the time the Workshop was held, a detailed analysis of the energy requirements of the two systems has been made. This analysis was performed by means of a computer program that utilizes Washington, D.C., weather tape data to compute and sum heating and cooling loads over an annual cycle. The results show that the large-tank ACES has an annual energy consumption of 5600 kWhr, whereas that of the small-tank ACES is 7500 kWhr. The differential cost of energy, at 4¢/kWhr for electricity, is $76. With capital costs at 12% annual charge, the energy savings for the large-tank system would justify additional capital expenditures up to $633. The differential cost of installation, however, is ($5384 - $4151), or $1233. This indicates that the small-tank ACES would produce a better rate of return on investment during the first year. However, if electricity prices continue to escalate, the full ACES could become the preferable choice.

The annual energy consumption of a conventional system employing electric resistance space and water heating and a central air conditioner with an energy-efficiency ratio (EER) equal to 6.5 is calculated to be 21,143 kWhr for the home being considered. Thus the energy savings of the small-tank ACES is (21,143 kWhr - 7500 kWhr), or 13,643 KWhr. This constitutes a relative energy savings of 13,643 ÷ 21,143, or 64%. At 4¢/kWhr, the savings amount to 13,643 x 0.04 = $545.72 yearly at present rates. The premium cost of small-tank ACES = $2551.00. This means that it has a no-interest payback time of 2551 ÷ $545.72 = 4.6 years. For the full ACES the energy savings are:

conventional kWhr	21,143
ACES full size	5,600
savings	15,543 kWhr

The percentage savings of 15,543 ÷ 21,143 = 73.5% and 15,543 x 0.04 = $621.72 at 4¢/kWhr. The no-interest payback out of savings is $3,784.60 ÷ $621.72 = 6.1 years.

18. ICE MAKER/HEAT PUMP DEVELOPMENT

Bill Hagen, *President, Turbo Refrigerating Company, Denton, Texas*

Mr. Hagen described Turbo's plans for converting their commercial ice makers into heat pump/ice makers. Since the heat pump feature is most needed in the winter when water temperatures are low, Turbo is changing from water harvesting to heat-of-liquid harvesting. This change results in a 12-min freezing cycle, with one-sixth of the plates defrosting or harvesting together while the compressor continues to freeze the other five-sixths of the plates. This should result in the highest evaporator temperature and the highest COP as a heat pump, with a minimum of strain on the compressor.

A simple timer operation will sequence the plates, and since the ice produced will not be of "commercial" quality, no "breaker" will be employed. The thin (∿1/4 in.) plates will fall from the machine into a bin and will "skitter" across the bin, forming an ice pile with a low angle of repose and a density of approximately 35 lb/ft^3.

Present calculations indicate that as an ice maker, the COP should be about 3.45 or higher. As a water chiller operating between 45 to 40°F, The COP should be 4.24 assuming a 105°F condensing temperature.

The overall dimensions for a unit with a heat output of 228,000 Btu/hr are 96 in. high x 94 in. wide x 33 in. deep. Additional specifications are provided in Figs. 9 and 10 and in Table 2.

The ice maker would be operating at its maximum production rate with 1/4-in.-thick ice. This thickness of ice is satisfactory for the production of heat and cooling which Turbo is seeking through use of the heat pump/ice maker concept.

ORNL-DWG 76-1659

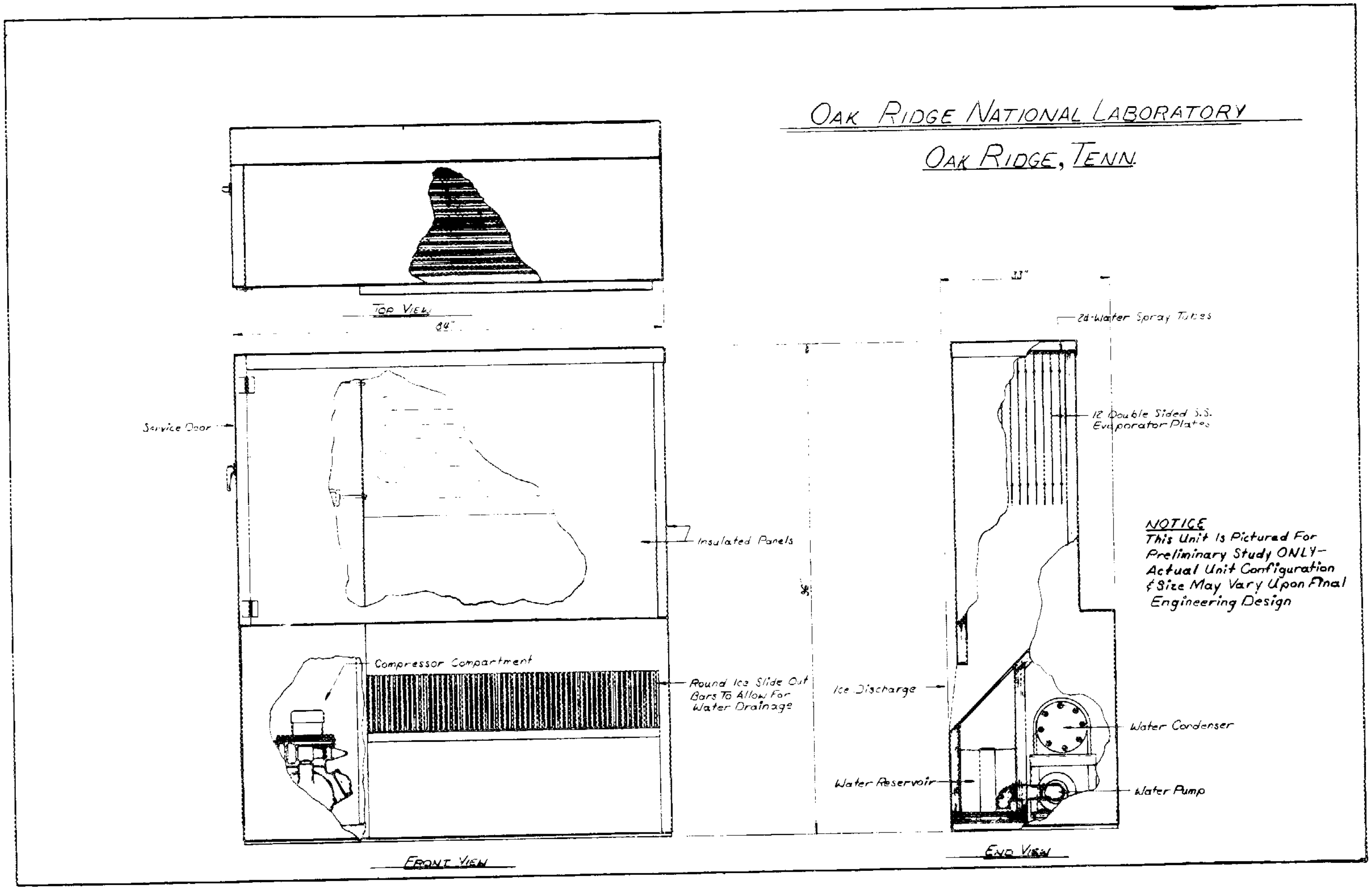

Fig. 9. Outline drawing of Turbo ice maker/heat pump.

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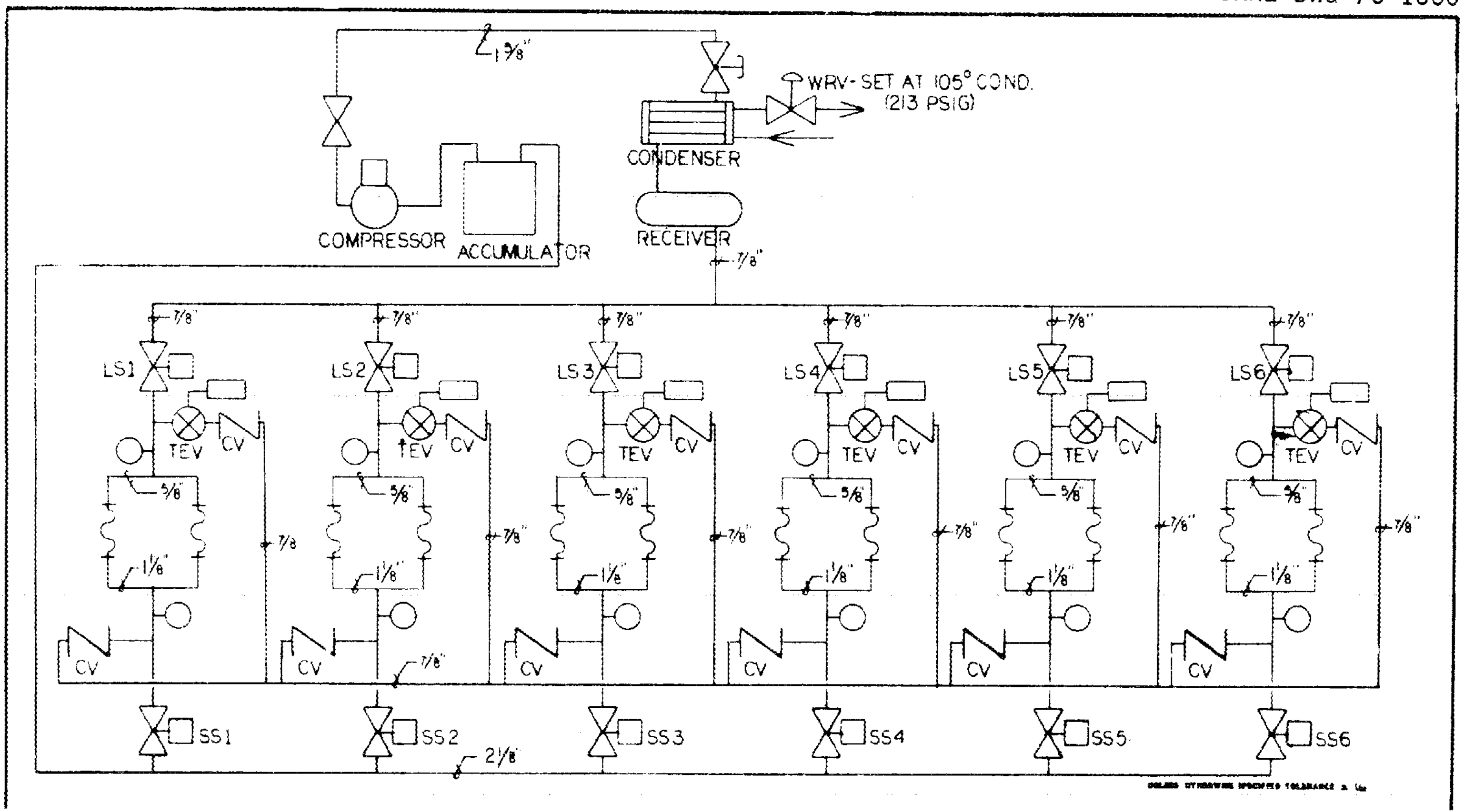


Fig. 10. Piping schematic for 10-plate heat pump/ice maker.

SUMMARY OF WORKSHOP

1. No <u>fundamental</u> technical problems in the way of an ACES program can be foreseen at the present time.

2. No building code compliance problems can be foreseen at this time.

3. Union jurisdictional problems can be foreseen in the area of solar collector and ice bin installations.

4. Warranties are an area of concern to both manufacturer and contractor in the early stage of commercialization. Government warranty insurance should be explored at least during the initial production period to help consumers who are reluctant to try a new system such as an ACES.

5. Government tax incentives are not required in high-energy cost areas (>4¢/kWhr) if lending institutions, builders, and homeowners can be convinced to use lifetime costs as the basis for making construction and lending decisions.

6. Commercial and industrial applications appear to have fewer roadblocks in the way of early commercialization.

7. Utilities could be of great help if they would realize the potential of ACES in load management and would help promote the concept.

8. Time-of-day metering combined with high energy cost will probably be a strong incentive for the commercialization of ACES.

9. Government tax incentives may be needed in all areas of the country to encourage retrofitting of exisiting buildings with energy-conserving ACES equipment.

10. Cost figures developed at the workshop indicate a five- to six-year payback out of energy savings which should make the system saleable for new construction if the owner and lender agree to put in the system with the lowest lifetime cost.

11. As soon as ACES equipment is on the market, FHA should be approached to add ACES to the list of home improvements that qualify for FHA-insured home improvement loans.

12. Architects see no problems in designing buildings for ACES installations.

13. Contractors and engineers will have to be trained in the calculation of energy budgets, ice bin construction, and piping and solar panel design. The need for an ACES design workbook became obvious.

14. A need for the publication of solar radiation tables for various cities of the country was expressed. These tables should be calculated for all vertical walls as well as horizontal surfaces and should be published on a month-by-month basis for average solar energy received for each location.

15. Utilities expressed interest in the load management capabilities of ACES but were noncommittal about pushing ACES without more experience with the equipment.

16. Component makers stand ready to manufacture the special ACES components as soon as the manufacturers of the package equipment create the specifications.

17. Friedrich Group of Weil-McClain announced that they would have pilot production quantities of heat pump packages available in the latter part of 1976.

18. Bohn Aluminum & Brass Heat Transfer Division of Gulf + Western said that they can furnish system packages of a 10-ton capacity and higher at the present time.

19. Peerless of America announced prior to the workshop that they were prepared to make 3/4-in.-OD aluminum serpentine coils on 6-1/8-in. centers from present tooling and that other centers could be acquired for nominal tooling charges.

20. A partial list of potential and current suppliers of ACES components and systems was compiled (see Appendix I).

APPENDICES

Appendix A

ACES WORKSHOP PARTICIPANTS

Roy C. Abbott, Manager, Advanced Technological Operation, General Electric Company, Appliance Park AP6-208, Louisville, Kentucky 40225

Ben S. Adams, Crouch and Adams, Inc., 106 Administration Road, Oak Ridge, Tennessee 37830

Joel F. Bailey, University of Tennessee, Knoxville, Tennessee 37916

Peter J. Ball, Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832

James Baroff, National Governor's Conference, Energy Program, 1150 17th Street, NW, Room 705, Washington, D.C. 20036

Steve Barry, ERDA, Oak Ridge Operations — Engineering

Al Bedinger, Environment Center, University of Tennessee, 346 South Stadium Building, Knoxville, Tennessee 37916

Jerry Blevins, ERDA, Federal Office Building, Room 2045, Oak Ridge, Tennessee 37830

Harold H. Boesenberg, Commonwealth Edison Co., P.O. Box 767, Chicago, Illinois 60690

E. W. Bottum, Refrigeration Research, Incorporated, 525 N. Fifth Street, P.O. Box R, Brighton, Michigan 48116

Richard A. Bulley, Commonwealth Edison Company, P.O. Box 767, Chicago, Illinois 60690

R. S. Carlsmith, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830

Joseph Chi, National Bureau of Standards, Code 462-02, Washington, D.C. 20234

Gerry Corrigan, 6512 Washington Avenue, Des Moines, Iowa 50322

Nina Cox, Division of Buildings and Industry, ERDA, 1016 16th Street, NW, Room 404, Washington, D.C. 20545

F. L. Culler, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830

Gordon Duffey, Air Conditioning and Refrigeration, P.O. Box 6000, Birmingham, Michigan 48012

Lou Dunlap, Oak Ridge Chamber of Commerce, 1400 Oak Ridge Turnpike, Oak Ridge, Tennessee 37830

W. E. Dunlap, UCC-ND Engineering

Eldon G. Ehlers, Chief of Technology Utilization and Information Dissemination, ERDA, Energy Conservation Division, 1610 16th Street, NW, Washington, D.C. 20036

Alvah D. Ehrman, Ehrman's Heating and Plumbing, 504 Pleasant Avenue, Hamburg, New York 14075

Nathan R. Feldman, Director, Mechanical Engineering Service, Office of Construction, Veteran Administration, Washington, D.C. 20420

H. C. Fischer, Oak Ridge Y-12 Plant, P.O. Box Y, Oak Ridge, Tennessee 37830

Robert Frye, 1807 Hemmeter Road, Saginaw, Michigan 48603

Dieter Grether, Vice President, Engineering, Friedrich Group, Weil-McLain Co., Inc., P.O. Box 1540, San Antonio, Texas 78295

Gerald Groff, Associate Director, Research Division, Carrier Corporation, Carrier Parkway, Syracuse, New York 13201

W. F. Hagen, President, Turbo Refrigerating Company, P.O. Box 396, Denton, Texas 76201

Robert Hamby, UCC-ND Engineering

E. C. Hise, Oak Ridge Y-12 Plant, P.O. Box Y, Oak Ridge, Tennessee 37830

George Keleshian, Advance Cooler Manufacturing Corporation, P.O. Box 287, Clifton Park, New York 12065

Herbert S. Lindahl, Manager, Advanced Engineering, Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832

Ferdinand Lisi, Veterans Administration, Washington, D.C. 20420

John B. Marious, Office of Tributary Area Development, 128 Evans Building, Tennessee Valley Authority, Knoxville, Tennessee 37902

Don Maxwell, President, Bank of Oak Ridge, P.O. Box 509, Oak Ridge, Tennessee 37830

Vincent Mei, Dole Refrigeration, 5910 N. Pulaski Road, Chicago, Illinois 60646

Leonard Morris, Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832

J. C. Moyers, Oak Ridge, Y-12 Plant, Oak Ridge, Tennessee 37830

Daniel Myers, Refrigeration Systems Co., Inc., 611 State Street, Newburgh, Indiana 47630

Jim Norvell, ERDA, Oak Ridge Operation — Engineering

Otto J. Nussbaum, Director of Engineering and Research, Halstead and Mitchell, Division of Halstead Industries, Inc., P.O. Box 1110, Scottsboro, Alabama 35768

Billy Owens, Federal Energy Administration, Ben Franklin Station, 12th and Pennsylvania Avenue, NW, Washington, D.C. 20461

Bradley A. Peavy, National Bureau of Standards, Washington, D.C. 20234

Ronald K. Randall, Staff Associate, General Electric Co., 3135 Easton Turnpike, Fairfield, Connecticut 06431

William E. Rapp, Jr., Vice President, Halstead and Mitchell, Division of Halstead Industries, Inc., Highway 72, W, Scottsboro, Alabama 35768

A. A. Robinson, Heatron, Inc., P.O. Box 54, York, Pennsylvania 17405

David Rosoff, Acting Director, Federal Energy Administration, Buildings R&D Programs, Ben Franklin Station, 12th and Pennsylvania Avenue, NW, Washington, D.C. 20461

David P. Ross, Southern Interstate Nuclear Board, 7 Dunwoody Park, Suite 104, Atlanta, Georgia 30341

Jeffrey H. Rumbaugh, PEPCO, 1900 Pennsylvania Avenue, NW, Washington, D.C. 20068

A. Carl Schmidt, Climate Master Products, Division of Weil-McLain Co., Inc., 200 W. Commercial Boulevard, Ft. Lauderdale, Florida 33309

Ronald Schnacke, Refrigeration Systems Co., Inc., 611 State Street, Newburgh, Indiana 47630

R. H. Shanaman, Heatron, Inc., P.O. Box 54, York, Pennsylvania 17405

Mrs. E. D. Shipley, P.O. Box 700, Knoxville, Tennessee

Ruth Skidmore, 103 Daniel Lane, Oak Ridge, Tennessee 37830

Don Spethmann, Honeywell, Inc., 1500 W. Dundee, Arlington Heights, Illinois

Daniel Spring, ORAU, Institute for Energy Analysis, P.O. Box 117, Oak Ridge, Tennessee 37830

Robert Tamblyn, President, Engineering Interface Limited, 1200 Sheppard Avenue, E, Toronto, Ontario MSK 2R8, Canada

Richard F. Todd, Nesca, 1501 Wilson Boulevard, Arlington, Virginia 22207

Tom Waldrop, Energy Opportunities Consortium, Oak Ridge and Knoxville, Tennessee

Theodore R. Walker, Tennessee Valley Authority, 523 Power Building, Chattanooga, Tennessee 37401

Donald J. Walukas, Manager Energy Conservation, Systems Research, Research Laboratories, Westinghouse Electric Corporation, Research and Development Center, Pittsburgh, Pennsylvania 15235

J. E. Weldy, Marketing Consultant, General Electric Co., 3135 Easton Turnpike, Fairfield, Connecticut 06431

Robert G. Werden, Werden Associates, Box 414, Jenkintown, Pennsylvania 19046

Michael Zion, Penjerdel Refrigeration Co., 15 Union Hill Road, West Conshohocken, Pennsylvania 19428

APPENDIX B

APPENDIX B

ANDREWS AFB WASHINGTON DC

Mean Frequency of Occurrence of Dry Bulb Temperature (°F) With Mean Coincident Wet Bulb Temperature (°F) For Each Dry Bulb Temperature Range

COOLING SEASON

Temperature Range (°F)	MAY Obsn/Hour Gp			MAY Total Obsn	MAY Mean Coincident Wet Bulb (°F)	JUNE Obsn/Hour Gp			JUNE Total Obsn	JUNE Mean Coincident Wet Bulb (°F)
	02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01		
100/104							0		0	80
95/99							3	0	3	78
90/94		5	0	5	71	0	19	1	20	75
85/89	0	18	1	19	70	2	43	7	52	73
80/84	1	32	8	41	67	8	55	21	84	70
75/79	5	38	18	61	64	21	48	42	111	67
70/74	19	41	33	93	62	54	36	61	151	66
65/69	37	48	50	135	60	65	20	54	139	62
60/64	53	36	52	141	56	50	12	33	95	58
55/59	56	18	43	117	52	28	4	17	49	54
50/54	41	9	28	78	48	12		4	16	50
45/49	26	2	12	40	44	0			0	46
40/44	9	1	3	13	39					
35/39	1	0	0	1	35					
30/34	0			0	32					

Temperature Range (°F)	JULY Obsn/Hour Gp			JULY Total Obsn	JULY Mean Coincident Wet Bulb (°F)	AUGUST Obsn/Hour Gp			AUGUST Total Obsn	AUGUST Mean Coincident Wet Bulb (°F)
	02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01		
100/104		0		0	77					
95/99		3	0	3	75		1	0	1	76
90/94	0	29	1	30	75		25	1	26	75
85/89	3	66	10	79	73	1	52	7	60	73
80/84	14	73	36	123	71	8	68	24	100	71
75/79	43	47	68	158	70	33	59	62	154	69
70/74	96	23	83	202	68	92	31	85	208	68
65/69	61	6	42	109	64	68	10	45	123	63
60/64	26	1	8	35	59	33	2	19	54	59
55/59	5		0	5	54	11		5	16	55
50/54						2		0	2	50
45/49						0		0	0	47
40/44										
35/39										
30/34										

Temperature Range (°F)	SEPTEMBER Obsn/Hour Gp			SEPTEMBER Total Obsn	SEPTEMBER Mean Coincident Wet Bulb (°F)	OCTOBER Obsn/Hour Gp			OCTOBER Total Obsn	OCTOBER Mean Coincident Wet Bulb (°F)
	02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01		
100/104										
95/99		0		0	78					
90/94		8		8	74		0			75
85/89	0	26	1	27	73		2		2	73
80/84	3	40	9	52	71		10	0	10	68
75/79	13	43	29	85	68	0	21	2	23	65
70/74	40	51	47	138	66	4	41	9	54	62
65/69	58	38	53	149	62	12	44	25	81	59
60/64	42	20	46	108	57	36	49	44	129	56
55/59	44	11	32	87	53	49	41	53	143	52
50/54	25	3	17	45	49	51	30	52	133	48
45/49	11		4	15	45	45	8	35	88	43
40/44	3		2	5	40	31	2	21	54	39
35/39	1		0	1	36	15	0	6	21	35
30/34						5		1	6	30

APPENDIX B (continued)

HEATING SEASON

Temperature Range (°F)	NOVEMBER					DECEMBER					JANUARY					FEBRUARY					MARCH					APRIL					ANNUAL (TOTAL—ALL MONTHS)				
	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)	Obsn/Hour Gp			Total Obsn	Mean Coincident Wet Bulb (°F)
	02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01			02 to 09	10 to 17	18 to 01		
100/104																																0		0	78
95/99																																7	0	7	76
90/94																											2	0	2	71	0	88	3	91	74
85/89																											8	0	8	67	6	214	26	246	72
80/84		0		0	68																	1		1	61	0	13	3	16	64	33	291	101	425	68
75/79		3		3	65		0		0	62												5	0	5	59	2	13	8	23	61	117	279	230	626	65
70/74	0	7	1	8	60		0		0	61			0	0	64		0		0	58	0	9	1	10	57	4	19	12	35	59	311	261	333	905	63
65/69	4	18	5	27	59	0	4	1	5	58	0	1	1	2	60		3	1	4	58	2	10	3	15	55	13	29	20	62	57	319	230	299	848	60
60/64	9	33	17	59	55	2	9	3	14	55	1	3	1	5	55	0	6	3	9	54	5	16	9	30	52	23	33	25	81	54	281	220	260	761	56
55/59	20	43	24	87	51	4	13	7	24	51	2	7	3	12	50	3	13	4	20	51	7	21	15	43	48	28	34	35	97	50	256	205	240	701	52
50/54	30	44	41	115	46	11	21	13	45	47	3	14	5	22	45	6	18	9	33	46	12	29	21	62	44	36	43	43	122	46	229	209	232	670	47
45/49	39	39	42	120	42	16	29	24	69	42	5	24	13	42	41	12	23	17	52	41	21	47	36	104	41	48	28	44	120	42	224	200	225	649	43
40/44	51	30	45	126	38	26	43	33	102	38	24	51	31	106	37	20	41	34	95	38	47	47	55	149	37	47	15	37	99	38	257	229	258	744	38
35/39	42	16	39	97	33	44	48	46	138	33	43	51	50	144	33	37	45	45	127	33	63	37	52	152	33	27	2	11	40	34	273	197	250	720	34
30/34	31	6	17	54	30	53	41	48	142	29	59	48	58	165	29	58	40	55	153	29	52	16	37	105	30	11	1	2	14	29	268	152	219	639	30
25/29	9	1	6	16	24	34	25	33	92	24	39	24	42	105	24	45	19	31	95	24	23	8	12	43	24	1		0	1	26	151	78	124	353	24
20/24	4	0	3	7	20	31	12	27	70	19	32	14	19	66	19	21	10	14	45	19	10	2	6	18	20						98	39	68	205	19
15/19	1		0	1	15	19	3	11	33	15	20	9	16	45	15	11	4	8	23	15	6	0	1	7	16						58	16	37	111	15
10/14	0			0	12	7	0	2	9	10	14	2	7	23	11	8	2	3	13	10	0			0	13						30	4	13	47	10
5/9						1			1	7	5	0	2	7	6	3	0	0	3	6											8	1	2	11	6
0/4											1		0	1	2	0			0	2											1		0	1	2

Source: *Engineering Weather Data*, NAUFAC P89, U.S. Government Printing Office, Washington, D.C., June 15, 1967.

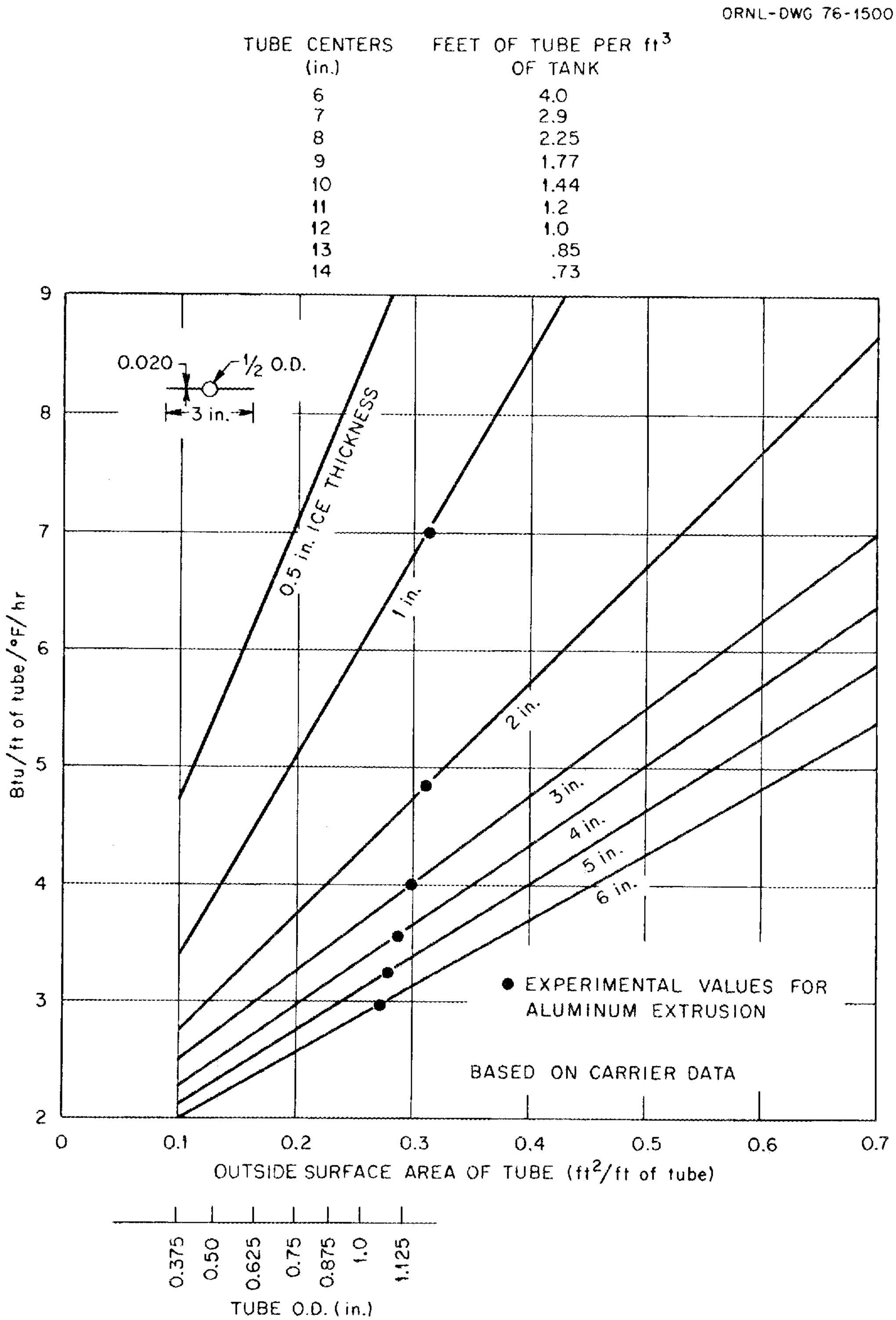
APPENDIX C

APPENDIX C

Insolation data (24-hr averages) for Washington, D.C., computed from solar radiation data provided in Appendix G

	Surface			
	Horizontal ($Btu/ft^2/day$)	N vertical ($Btu/ft^2/day$)	E-W vertical ($Btu/ft^2/day$)	S vertical ($Btu/ft^2/day$)
January	632.4	107.5	784.2	1397.6
February	901.5	135.2	1036.7	1298.2
March	1255.0	188.3	1380.5	1091.9
April	1600.4	256.1	1600.4	784.2
May	1846.8	350.9	1699.1	572.5
June	2080.8	457.8	1872.7	561.8
July	1929.9	386.0	1756.2	598.3
August	1712.2	291.1	1678.0	821.9
September	1446.1	231.4	1561.8	1272.6
October	1083.4	173.3	1224.2	1527.6
November	763.5	129.8	931.5	1656.8
December	594.1	101.0	778.3	1574.4

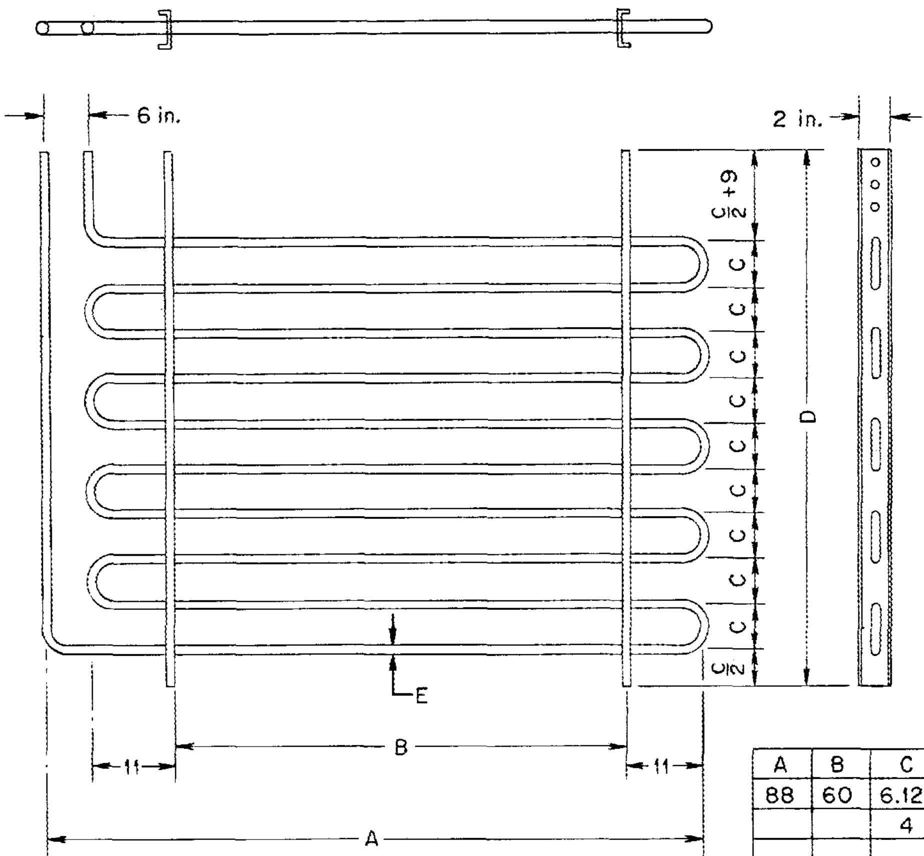
APPENDIX D



Heat transfer rate vs surface area of tube for various thicknesses of ice on tubes, based on ORNL experiments and outside film coefficients obtained from Carrier System Design Manual, pp. 1-82.

APPENDIX E

ORNL-DWG 76-1501



PEERLESS OF AMERICA INC.
5800 N. PULASKI RD.
CHICAGO, ILL. 60646
IS TOOLED TO MAKE
THIS COIL AS SHOWN

A	B	C	D	E	MATERIAL	NO.	LENGTH
88	60	6.125	69 1/4	.7500	ALUMINUM	1	86 ft
		4		.7500	ALUMINUM	2	
						3	
						4	
						5	

ACES — 20 serpentine coil for ice building.

APPENDIX F

APPENDIX F

Brine properties

Design temperature (°F)	Brine	Solution (by wt) (%)	Density (lb/ft^3)	Specific heat (Btu/lb-°F)	Thermal condition ($Btu/hr-ft^2$-°F/ft)	Viscosity (centi-poises)	Freezing point (°F)	Boiling point (°F)	Gpm/ton/10° rise	h_b [a]	V_b [b]	Relative cost per gal of solution
30	Sodium chloride	12	68.2	0.86	0.28	2.2	17.5	215	2.55	941	1.61	1
	Calcium chloride	12	69.2	0.83	0.32	2.4	19.0	213	2.62	971	1.78	3
	Methanol water	15	61.5	1.00	0.28	3.2	13.5	187	2.45	781	2.63	13
	Ethanol water	20	61.0	1.04	0.27	5.5	12.0	189	2.37	621	4.60	20
	Ethylene glycol	25	64.7	0.92	0.30	3.7	12.9	217	2.52	775	2.92	42
	Propylene glycol	30	64.5	0.94	0.26	8.0	13.0	216	2.47	525	6.35	43
15	Sodium chloride	21	72.8	0.80	0.25	4.2	1.0	216	2.57	693	2.90	1
	Calcium chloride	20	74.8	0.72	0.31	4.8	1.0	214	2.77	730	3.28	5
	Methanol water	22	60.4	0.97	0.26	5.3	4.5	182	2.56	599	4.44	19
	Ethanol water	25	61.0	1.02	0.25	8.2	4.5	187	2.41	504	6.85	25
	Ethylene glycol	35	66.0	0.86	0.28	6.8	0.0	219	2.65	576	5.25	60
	Propylene glycol	40	65.3	0.89	0.24	20.0	-4.2	218	2.58	103	*c*	58
-5	Calcium chloride	25	78.4	0.67	0.29	10.3	-21.0	215	2.85	513	6.75	6
	Methanol water	35	60.0	0.89	0.23	9.9	-22.0	176	2.82	98	8.40	30
	Ethanol water	36	60.6	0.95	0.22	13.5	-16.0	183	2.62	97	*c*	35
	Ethylene glycol	45	67.4	0.79	0.25	17.2	-15.5	223	2.82	103	*c*	78
	Propylene glycol	50	66.5	0.83	0.23	80.0	-29.0	222	2.72	98	*c*	75

-30	Calcium chloride	30	82.1	0.63	0.28	27.8	-47.0	216	2.90	110	[c]	8
	Methanol water	45	60.0	0.80	0.22	18.0	-45.0	171	3.13	91	[c]	39
	Ethanol water	52	59.5	0.81	0.19	20.2	-50.0	179	3.11	83	[c]	50
	Ethylene glycol	55	69.0	0.73	0.22	75.0	-43.0	227	2.98	93	[c]	97
	Propylene glycol	60	67.2	0.77	0.21	700.0	-55.0	227	2.90	91	[c]	90

[a]h_b = coefficient of heat transfer between brine and surface (Btu/hr-ft^2-°F), at 7 fps velocity for 0.554-in. ID tubing.

[b]V_b = minimum brine velocity (fps), at Re = 3500 for 0.554-in. ID tubing.

[c]Above 10 fps.

Source: Carrier System Design Manual, Table 10, pp. 4-28.

APPENDIX G

RADIATION AND OTHER DATA FOR 71 LOCATIONS IN THE UNITED STATES AND CANADA

$\overline{H}$ = Monthly average daily total radiation on a horizontal surface, Btu/day-ft^2

V = Monthly average daily radiation on a south-facing vertical surface

$\overline{K}_t$ = The fraction of the extra terrestrial radiation transmitted through the atmosphere

t_o = Ambient temperature, °F.

		January	February	March	April	May	June	July	August	September	October	November	December
Albuquerque, N.M.	$\overline{H}$	1150.9	1453.9	1925.4	2343.5	2560.9	2757.5	2561.2	2387.8	2120.3	1639.8	1274.2	1051.6
Lat. 35°03' N	V	2188.1	1862.8	1471.9	993.7	685.4	641.1	647.0	100.4	1654.8	2069.8	2395.5	2380.1
El. 5314 ft	$\overline{K}_t$	0.704	0.691	0.719	0.722	0.713	0.737	0.695	0.708	0.728	0.711	0.684	0.704
	t_o	37.3	43.3	50.1	59.6	69.4	79.1	82.8	80.6	73.6	62.1	47.8	39.4
Apalachicola, Florida	$\overline{H}$	1107	1378.2	1654.2	2040.9	2268.6	2195.9	1978.6	1912.9	1703.3	1544.6	1243.2	982.3
Lat. 40°52' N	V	1695.1	1443.7	1033.5	659.7	486.1	430.4	404.6	594.0	1089.7	1590.6	1885.0	1739.7
El. 35 ft	$\overline{K}_t$	0.577	0.584	0.576	0.612	0.630	0.594	0.542	0.558	0.559	0.608	0.574	0.543
	t_o	57.3	59.0	62.9	69.5	76.4	81.8	83.1	83.1	80.6	73.2	63.7	58.5
Astoria, Oregon	$\overline{H}$	338.4	607	1008.5	1401.5	1838.7	1753.5	2007.7	1721	1322.5	780.4	413.6	295.2
Lat. 46°12' N	V	1096.3	1169.1	1166.4	883.5	813.5	690.9	819.6	1105.6	1533.3	1453.1	1316.5	1208.5
El. 8 ft	$\overline{K}_t$	0.330	0.397	0.454	0.471	0.524	0.466	0.551	0.538	0.526	0.435	0.336	0.332
	t_o	41.3	44.7	46.9	51.3	55.0	59.3	62.6	63.6	62.2	55.7	48.5	43.9
Atlanta, Georgia	$\overline{H}$	848	1080.1	1426.9	1807	2018.1	2102.6	2002.9	1898.1	1519.2	1290.8	997.8	751.6
Lat. 33°39' N	V	1512.5	1315.8	1032.9	715.6	503.4	459.4	472.3	744.7	1124	1548	1764.1	1588.6
El. 976 ft	$\overline{K}_t$	0.493	0.496	0.522	0.551	0.561	0.564	0.545	0.559	0.515	0.543	0.510	0.474
	t_o	47.2	49.6	55.9	65.0	73.2	80.9	82.4	81.6	77.4	66.5	54.8	47.7
Bismarck, N.D.	$\overline{H}$	587.4	934.3	1328.4	1668.2	2056.1	2173.8	2305.5	1929.1	1441.3	1018.1	600.4	464.2
Lat. 46°47' N	V	1953.7	1837.6	1565.9	1073.1	930.0	875.5	962.6	1264.0	1702.2	1934.3	1961.9	1958.3
El. 1660 ft	$\overline{K}_t$	0.594	0.628	0.605	0.565	0.588	0.579	0.634	0.606	0.581	0.584	0.510	0.547
	t_o	12.4	15.9	29.7	46.6	58.6	67.9	76.1	73.5	61.6	49.6	31.4	18.4
Blue Hill, Mass.	$\overline{H}$	555.3	797	1143.9	1438	1776.4	1943.9	1881.5	1622.1	1314	941	592.2	482.3
Lat. 42°13' N	V	1471.6	1312.8	1149.9	780.5	665.6	649.8	648.1	899.9	1329.8	1508.5	1542.9	1563.3
El. 629 ft	$\overline{K}_t$	0.445	0.458	0.477	0.464	0.501	0.516	0.513	0.495	0.492	0.472	0.406	0.436
	t_o	28.3	28.3	36.9	46.9	58.5	67.2	72.3	70.6	64.2	54.1	43.3	31.5
Boise, Idaho	$\overline{H}$	518.8	884.9	1280.4	1814.4	2189.3	2376.7	2500.3	2149.4	1717.7	1128.4	678.6	456.8
Lat. 43°34' N	V	1478.5	1541.2	1352.8	1038.7	870.5	842.5	915.3	1256.3	1824.1	1907.9	1900.9	1612.6
El. 2844 ft	$\overline{K}_t$	0.446	0.533	0.548	0.594	0.619	0.631	0.684	0.660	0.656	0.588	0.494	0.442
	t_o	29.5	36.5	45.0	53.5	62.1	69.3	79.6	77.2	66.7	56.3	42.3	33.1

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Boston, Mass.	$\bar{H}$	505.5	738	1067.1	1355	1769	1864	1860.5	1570.1	1267.5	896.7	635.8	442.8
Lat. 42°22' N	$\bar{V}$	1350.8	1223.4	1078.8	739.9	667.3	627.2	645.4	876.2	1289.8	1446.2	1670.4	1449.5
El. 29 ft	$\bar{K}_t$	0.410	0.426	0.445	0.438	0.499	0.495	0.507	0.480	0.477	0.453	0.372	0.400
	t_o	31.4	31.4	39.9	49.5	60.4	69.8	74.5	73.8	66.8	57.4	46.6	34.9
Brownsville, Texas	$\bar{H}$	1105.9	1262.7	1505.9	1714	2092.2	2288.5	2345	2124	1774.9	1536.5	1104.8	982.3
Lat. 25°55' N	$\bar{V}$	1494.2	1158.1	796.5	455.5	392.1	413.5	425.6	545.5	965.4	1387.9	1476.1	1513.7
El. 20 ft	$\bar{K}_t$	0.517	0.500	0.505	0.509	0.584	0.627	0.650	0.617	0.566	0.570	0.468	0.488
	t_o	63.3	66.7	70.7	76.2	81.4	85.1	86.5	86.9	84.1	78.9	70.7	65.2
Caribou, Maine	$\bar{H}$	497	861.6	1360.1	1495.9	1779.7	1779.7	1898.1	1675.6	1254.6	793	415.5	398.9
Lat. 46°52' N	$\bar{V}$	1659.1	1699.7	1607.6	965.0	807.5	719.0	795.1	1101.0	1485.5	1510.9	1362.7	1689.9
El. 628 ft	$\bar{K}_t$	0.504	0.579	0.619	0.507	0.509	0.473	0.522	0.527	0.506	0.455	0.352	0.470
	t_o	11.5	12.8	24.4	37.3	51.8	61.6	67.2	65.0	56.2	44.7	31.3	16.8
Charleston, S.C.	$\bar{H}$	946.1	1152.8	1352.4	1918.8	2063.4	2113.3	1649.4	1933.6	1557.2	1332.1	1073.8	952
Lat. 32°54' N	$\bar{V}$	1627.9	1365.5	949.5	731.1	494.6	445.9	374.1	731.1	1118.2	1552.6	1834.1	1935.7
El. 46 ft	$\bar{K}_t$	0.541	0.521	0.491	0.584	0.574	0.567	0.454	0.569	0.525	0.554	0.539	0.586
	t_o	53.6	55.2	60.6	67.8	74.8	80.9	82.9	82.3	79.1	69.8	59.8	54.0
Cleveland, Ohio	$\bar{H}$	466.8	681.9	1207	1443.9	1928.4	2102.6	2094.4	1840.6	1410.3	997	526.6	427.3
Lat. 41°24' N	$\bar{V}$	1180.6	1084.2	1175.9	757.8	695.8	677.0	694.1	988.0	1384.6	1545.4	1309.7	1310.4
El. 805 ft	$\bar{K}_t$	0.361	0.383	0.497	0.464	0.543	0.559	0.571	0.559	0.524	0.491	0.351	0.371
	t_o	30.8	30.9	39.4	50.2	62.4	72.7	77.0	75.1	68.5	57.4	44.0	32.8
Columbia, Mo.	$\bar{H}$	651.3	941.3	1315.8	1631.3	1999.6	2129.1	2148.7	1953.1	1689.6	1202.6	839.5	590.4
Lat. 38°58' N	$\bar{V}$	1452.5	1372.0	1155.3	819.5	637.0	578.4	643.8	963.6	1510.6	1729.9	1841.3	1583.7
El. 785 ft	$\bar{K}_t$	0.458	0.492	0.520	0.514	0.559	0.566	0.585	0.588	0.606	0.562	0.510	0.457
	t_o	32.5	36.5	45.9	57.7	66.7	75.9	81.1	79.4	71.9	61.4	46.1	35.8
Columbus, Ohio	$\bar{H}$	486.3	746.5	1112.5	1480.8	1839.1	(2111)	2041.3	1572.7	1189.3	919.5	479	430.2
Lat. 40°00' N	$\bar{V}$	1126.8	1122.7	1010.2	774.5	610.6	595.3	636.9	806.8	1098.9	1365.5	1090.2	1201.6
El. 833 ft	$\bar{K}_t$	0.356	0.401	0.447	0.470	0.515	(0.561)	0.555	0.475	0.433	0.441	0.302	0.351
	t_o	32.1	33.7	42.7	53.5	64.4	74.2	78	75.9	70.1	58	44.5	34.0
Davis, Calif.	$\bar{H}$	599.2	945	1504	1959	2368.6	2619.2	2565.6	2287.8	1856.8	1288.5	795.6	550.5
Lat. 88°33' N	$\bar{V}$	1315.4	1359.6	1302.4	967.8	741.7	700.6	755.8	1110.6	1637.6	1829.4	1718.5	1452.1
El. 51 ft	$\bar{K}_t$	0.416	0.490	0.591	0.617	0.662	0.697	0.697	0.687	0.664	0.598	0.477	0.421
	t_o	47.6	52.1	56.8	63.1	69.6	75.7	81	79.1	76.7	67.8	57	48.7
Dodge City, Kan.	$\bar{H}$	953.1	1186.3	1565.7	1975.6	2126.5	2459.8	2400.7	2210.7	1841.7	1421	1065.3	873.8
Lat. 37°46' N	$\bar{V}$	2029.5	1665.0	1320.3	945.0	644.3	638.7	684.7	1040.3	1582.5	1967.4	2234.3	2231.7
El. 2592 ft	$\bar{K}_t$	0.638	0.598	0.606	0.618	0.594	0.655	0.652	0.663	0.654	0.650	0.625	0.652
	t_o	33.8	38.7	46.5	57.7	66.7	77.2	83.8	82.4	73.7	61.7	46.5	36.8

Radiation and other data for 71 locations in the United States and Canada (continued)

Location		January	February	March	April	May	June	July	August	September	October	November	December
East Lansing, Michigan	$\bar{H}$	425.8	739.1	1086	1249.8	1732.8	1914	1884.5	1627.7	1303.3	891.5	473.1	379.7
Lat. 42°44' N	$\bar{V}$	1161.0	1244.2	1113.0	692.6	664.5	654.6	664.7	921.5	1343.9	1459.1	1268.1	1272.7
El. 856 ft	$\bar{K}_t$	0.35	0.431	0.456	0.406	0.489	0.508	0.514	0.498	0.493	0.456	0.333	0.349
	t_o	26.0	26.4	35.7	48.4	59.8	70.3	74.5	72.4	65.0	53.5	40.0	29.0
East Wareham, Mass.	$\bar{H}$	504.4	762.4	1132.1	1392.6	1704.8	1958.3	1873.8	1607.4	1363.8	996.7	636.2	521
Lat. 41°46' N	$\bar{V}$	1303.1	1231.8	1118.7	742.1	625.7	641.4	632.0	875.8	1357.5	1568.6	1616.1	1638.6
El. 18 ft	$\bar{K}_t$	0.398	0.431	0.469	0.449	0.480	0.520	0.511	0.489	0.508	0.496	0.431	0.461
	t_o	32.2	31.6	39.0	48.3	58.9	67.5	74.1	72.8	65.9	56	46	34.8
El Paso, Texas	$\bar{H}$	1247.6	1612.9	2048.7	2447.2	2673	2731	2391.1	2350.5	2077.5	1704.8	1324.7	1051.6
Lat. 31°48' N	$\bar{V}$	2030.6	1801.9	1384.9	866.3	611.1	557.7	518.4	797.3	1435.6	1870.9	2136.2	1991.7
El. 3916 ft	$\bar{K}_t$	0.686	0.714	0.730	0.741	0.743	0.733	0.652	0.669	0.693	0.695	0.647	0.626
	t_o	47.1	53.1	58.7	67.3	75.7	84.2	84.9	83.4	78.5	69.0	56.0	48.5
Ely, Nevada	$\bar{H}$	871.6	1255	1749.8	2103.3	2322.1	2649	2417	2307.7	1935	1473	1078.6	814.8
Lat. 39°17' N	$\bar{V}$	1967.0	1847.1	1552.5	1069.9	749.3	728.0	733.3	1152.4	1747.7	2139.9	2393.1	2213.3
El. 6262 ft	$\bar{K}_t$	0.618	0.660	0.692	0.664	0.649	0.604	0.656	0.695	0.696	0.691	0.658	0.64
	t_o	27.3	32.1	39.5	48.3	57.0	65.4	74.5	72.3	63.7	52.1	39.9	31.1
Fort Worth, Texas	$\bar{H}$	936.2	1198.5	1597.8	1829.1	2105.1	2437.6	2293.3	2216.6	1880.8	1476	1147.6	913.6
Lat. 32°50' N	$\bar{V}$	1605.6	1416.0	1118.7	694.5	502.8	512.7	518.3	835.3	1347.0	1715.9	1954.0	1851.1
El. 544 ft	$\bar{K}_t$	0.530	0.541	0.577	0.556	0.585	0.654	0.624	0.653	0.634	0.612	0.576	0.563
	t_o	48.1	52.3	59.8	68.8	75.9	84.0	87.7	88.6	81.3	71.5	58.8	50.8
Fresno, Calif.	$\bar{H}$	712.9	1116.6	1652.8	2049.4	2409.2	2641.7	2512.2	2300.7	1897.8	1415.5	906.6	616.6
Lat. 36°46' N	$\bar{V}$	1458.2	1516.9	1345.8	939.3	698.6	659.6	686.3	1038.9	1575.6	1896.1	1828.9	1508.8
El. 331 ft	$\bar{K}_t$	0.462	0.551	0.632	0.638	0.672	0.703	0.682	0.686	0.665	0.635	0.512	0.44
	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Gainesville, Fla.	$\bar{H}$	1036.9	1324.7	1635	1956.4	1934.7	1960.9	1895.6	1873.8	1615.1	1312.2	1169.7	919.5
Lat. 29°39' N	$\bar{V}$	1582.9	1383.1	1017.4	629.5	413.2	383.6	386.5	579.2	1029.2	1346.9	1768.1	1622.9
El. 165 ft	$\bar{K}_t$	0.535	0.56	0.568	0.587	0.538	0.531	0.519	0.547	0.529	0.515	0.537	0.508
	t_o	62.1	63.1	67.5	72.8	79.4	83.4	83.8	84.1	82	75.7	67.2	62.4
Grand Junction, Colorado	$\bar{H}$	848	1210.7	1622.9	2002.2	2300.3	2645.4	2517.7	2157.2	1957.5	1394.8	969.7	793.4
Lat. 39°07' N	$\bar{V}$	1901.9	1772.8	1432.0	1011.8	737.3	722.6	758.8	1070.4	1758.6	2015.8	2138.5	2141.0
El. 4849 ft	$\bar{K}_t$	0.597	0.633	0.643	0.632	0.643	0.704	0.690	0.65	0.705	0.654	0.59	0.621
	t_o	26.9	35.0	44.6	55.8	66.3	75.7	82.5	79.6	71.4	58.3	42.0	31.4
Grand Lake, Colo.	$\bar{H}$	735	1135.4	1579.3	1876.7	1974.9	2369.7	2103.3	1708.5	1715.8	1212.2	775.6	660.5
Lat. 40°15' N	$\bar{V}$	1733.9	1713.9	1469.5	937.4	673.9	722.2	658.3	873.9	1611.6	1788.3	1799.6	1862.9
El. 8389 ft	$\bar{K}_t$	0.541	0.615	0.637	0.597	0.553	0.63	0.572	0.516	0.626	0.583	0.494	0.542
	t_o	18.5	23.1	28.5	39.1	48.7	56.6	62.8	61.5	55.5	45.2	30.3	22.6

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Great Falls, Mont.	$\bar{H}$	524	869.4	1369.7	1621.4	1970.8	2179.3	2383	1986.3	1536.5	984.9	575.3	420.7
Lat. 47°29' N	V	1797.1	1752.6	1651.0	1067.9	914.9	900.6	1021.7	1332.1	1854.4	1916.0	1938.2	1837.8
El. 3664 ft	$\bar{K}_t$	0.552	0.596	0.631	0.551	0.565	0.580	0.656	0.627	0.626	0.574	0.503	0.518
	t_o	25.4	27.6	35.6	47.7	57.5	64.3	73.8	71.3	60.6	51.4	38.0	29.1
Greensboro, N.C.	$\bar{H}$	743.9	1031.7	1323.2	1755.3	1988.5	2111.4	2033.9	1810.3	1517.3	1202.6	908.1	690.8
Lat. 36°05' N	V	1478.9	1369.8	1051.2	780.5	558.9	512.7	539.0	794.0	1229.7	1573.9	1782.3	1639.9
El. 891 ft	$\bar{K}_t$	0.469	0.499	0.499	0.543	0.554	0.563	0.552	0.538	0.527	0.531	0.501	0.479
	t_o	42.0	44.2	51.7	60.8	69.9	78.0	80.2	78.9	73.9	62.7	51.5	43.2
Griffin, Georgia	$\bar{H}$	889.6	1135.8	1450.9	1923.6	2163.1	2176	2064.9	1961.2	1605.9	1352.4	1073.8	781.5
Lat. 33°15' N	V	1556.8	1363.3	1033.4	746.4	528.3	466.8	477.0	754.6	1169.5	1597.5	1864.1	1618.3
El. 980 ft	$\bar{K}_t$	0.513	0.517	0.528	0.586	0.601	0.583	0.562	0.578	0.543	0.565	0.545	0.487
	t_o	48.9	51.0	59.1	66.7	74.6	81.2	83.0	82.2	78.4	68	57.3	49.4
Hatteras, N.C.	$\bar{H}$	891.9	1184.1	1590.4	2128	2376.4	2438	2334.3	2085.6	1758.3	1337.6	1053.5	798.1
Lat. 35°13' N	V	1708.2	1526.0	1223.5	909.4	641.2	570.9	594.3	880.4	1380.8	1698.4	1994.6	1820.6
El. 7 ft	$\bar{K}_t$	0.546	0.563	0.593	0.655	0.661	0.652	0.634	0.619	0.605	0.58	0.566	0.535
	t_o	49.9	49.5	54.7	61.5	69.9	77.2	80.0	79.8	76.7	67.9	59.1	51.3
Indianapolis, Ind.	$\bar{H}$	526.2	797.4	1184.1	1481.2	1828	2042	2039.5	1832.1	1513.3	1094.4	662.4	491.1
Lat. 39°44' N	V	1207.4	1189.7	1066.0	766.8	600.6	570.4	629.8	930.6	1386.6	1612.1	1493.5	1357.6
El. 793 ft	$\bar{K}_t$	0.380	0.424	0.472	0.47	0.511	0.543	0.554	0.552	0.549	0.520	0.413	0.391
	t_o	31.3	33.9	43.0	54.1	64.9	74.8	79.6	77.4	70.6	59.3	44.2	33.4
Inyokern, Calif.	$\bar{H}$	1148.7	1554.2	2136.9	2594.8	2925.4	3108.8	2908.8	2759.4	2409.2	1819.2	1370.1	1094.4
Lat. 35°39' N	V	2241.8	2033.3	1670.7	1131.3	805.8	741.5	755.7	1187.5	1922.2	2345.4	2641.6	2547.3
El. 2440 ft	$\bar{K}_t$	0.716	0.745	0.803	0.8	0.815	0.830	0.790	0.820	0.834	0.795	0.743	0.742
	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Ithaca, N.Y.	$\bar{H}$	434.3	755	1074.9	1322.9	1779.3	2025.8	2031.3	1736.9	1320.3	918.4	466.4	370.8
Lat. 42°27' N	V	1165.9	1256.0	1090.1	724.8	673.7	684.2	707.3	972.5	1347.6	1486.2	1231.0	1220.4
El. 950 ft	$\bar{K}_t$	0.351	0.435	0.45	0.428	0.502	0.538	0.554	0.530	0.497	0.465	0.324	0.337
	t_o	27.2	26.5	36	48.4	59.6	68.9	73.9	71.9	64.2	53.6	41.5	29.6
Lake Charles, La.	$\bar{H}$	899.2	1145.7	1487.4	1801.8	2080.4	2213.3	1968.6	1910.3	1678.2	1505.5	1122.1	875.6
Lat. 30°13' N	V	1396.6	1218.3	946.6	595.1	452.5	437.9	408.1	605.6	1093.2	1573.5	1726.0	1575.2
El. 12 ft	$\bar{K}_t$	0.473	0.492	0.521	0.542	0.578	0.597	0.538	0.558	0.553	0.597	0.524	0.494
	t_o	55.3	58.7	63.5	70.9	77.4	83.4	84.8	85.0	81.5	73.8	62.6	56.9
Lander, Wyo.	$\bar{H}$	786.3	1146.1	1638	1988.5	2114	2492.2	2438.4	2120.6	1712.9	1301.8	837.3	694.8
Lat. 42°48' N	V	2151.6	1934.6	1682.9	1104.8	813.1	854.8	862.7	1203.7	1770.5	2136.3	2252.3	2338.8
El. 5370 ft	$\bar{K}_t$	0.65	0.672	0.691	0.647	0.597	0.662	0.665	0.649	0.647	0.666	0.589	0.643
	t_o	20.2	26.3	34.7	45.5	56.0	65.4	74.6	72.5	61.4	48.3	33.4	23.8

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Las Vegas, Nev.	$\overline{H}$	1035.8	1438	1926.5	2322.8	2629.5	2799.2	2524	2342	2062	1602.6	1190	964.2
Lat. 36°05' N	$\overline{V}$	2059.2	1909.3	1530.5	1032.9	739.1	679.7	668.9	1027.2	1671.1	2097.4	2335.6	2288.9
El. 2162 ft	$\overline{K}_t$	0.654	0.697	0.728	0.719	0.732	0.746	0.685	0.697	0.716	0.704	0.657	0.668
	t_o	47.5	53.9	60.3	69.5	78.3	88.2	95.0	92.9	85.4	71.7	57.8	50.2
Lemont, Illinois	$\overline{H}$	(590)	879	1255.7	1481.5	1866	2041.7	1990.8	1836.9	1469.4	1015.5	(639)	(531)
Lat. 41°40' N	$\overline{V}$	1515.5	1414.0	1236.0	786.2	681.7	665.6	668.3	996.8	1457.2	1591.6	1613.9	1658.7
El. 595 ft	$\overline{K}_t$	(0.464)	0.496	0.520	0.477	0.525	0.542	0.542	0.559	0.547	0.506	(0.433)	(0.467)
	t_o	28.9	30.3	39.5	49.7	59.2	70.8	75.6	74.3	67.2	57.6	43.0	30.6
Lexington, Ky.	$\overline{H}$	-	-	-	1834.7	2171.2	-	2246.5	2064.9	1775.6	1315.8	-	681.5
Lat. 38°02' N	$\overline{V}$	-	-	-	887.4	665.3	-	647.9	982.1	1539.4	1837.5	-	1760.0
El. 979 ft	$\overline{K}_t$	-	-	-	0.575	0.606	-	0.610	0.619	0.631	0.604	-	0.513
	t_o	36.5	38.8	47.4	57.8	67.5	76.2	79.8	78.2	72.8	61.2	47.6	38.5
Lincoln, Neb.	$\overline{H}$	712.5	955.7	1299.6	1587.8	1856.1	2040.6	2011.4	1902.6	1543.5	1215.8	773.4	643.2
Lat. 40°51' N	$\overline{V}$	1744.1	1482.8	1238.9	814.1	652.3	640.2	648.9	998.3	1484.0	1841.0	1861.8	1896.7
El. 1189 ft	$\overline{K}_t$	0.542	0.528	0.532	0.507	0.522	0.542	0.547	0.577	0.568	0.596	0.508	0.545
	t_o	27.8	32.1	42.4	55.8	65.8	76.0	82.6	80.2	71.5	59.9	43.2	31.8
Little Rock, Ark.	$\overline{H}$	704.4	974.2	1335.8	1669.4	1960.1	2091.5	2081.2	1938.7	1640.6	1282.6	913.6	701.1
Lat. 34°44' N	$\overline{V}$	1320.5	1234.3	1008.9	697.3	516.6	479.7	517.8	800.6	1265.3	1600.7	1694.4	1563.1
El. 265 ft	$\overline{K}_t$	0.424	0.458	0.496	0.513	0.545	0.559	0.566	0.574	0.561	0.552	0.484	0.463
	t_o	44.6	48.5	56.0	65.8	73.1	76.7	85.1	84.6	78.3	67.9	54.7	46.7
Los Angeles, Ca. (WBAS)	$\overline{H}$	930.6	1284.1	1729.5	1948	2196.7	2272.3	2413.6	2155.3	1898.1	1372.7	1082.3	901.1
Lat. 33°56' N	$\overline{V}$	1682.0	1580.7	1266.1	782.5	556.1	502.9	577.3	857.2	1419.9	1663.7	1938.0	1931.8
El. 99 ft	$\overline{K}_t$	0.547	0.596	0.635	0.595	0.610	0.608	0.657	0.635	0.641	0.574	0.551	0.566
	t_o	56.2	56.9	59.2	61.4	64.2	66.7	69.6	70.2	69.1	66.1	62.6	58.7
Madison, Wis.	$\overline{H}$	564.6	812.2	1232.1	1455.3	1745.4	2031.7	2046.5	1740.2	1443.9	993	555.7	495.9
Lat. 43°08' N	$\overline{V}$	1572.8	1390.0	1281.5	819.2	681.2	707.0	735.0	1000.5	1510.2	1651.0	1521.7	1704.7
El. 866 ft	$\overline{K}_t$	0.49	0.478	0.522	0.474	0.493	0.540	0.559	0.534	0.549	0.510	0.396	0.467
	t_o	21.8	24.6	35.3	49.0	61.0	70.9	76.8	74.4	65.6	53.7	37.8	25.4
Medford, Oregon	$\overline{H}$	435.4	804.4	1259.8	1807.4	2216.2	2440.5	2607.4	2261.6	1672.3	1043.5	558.7	346.5
Lat. 42°23' N	$\overline{V}$	1164.6	1334.4	1274.4	987.6	836.7	821.8	905.1	1263.0	1702.7	1684.1	1492.2	1135.5
El. 1329 ft	$\overline{K}_t$	0.353	0.464	0.527	0.584	0.625	0.648	0.710	0.689	0.628	0.526	0.384	0.313
	t_o	39.4	45.4	50.8	56.3	63.1	69.4	76.9	76.4	69.6	58.7	47.1	40.5
Miami, Florida	$\overline{H}$	1292.2	1554.6	1828.8	2020.6	2068.6	1991.5	1992.6	1890.8	1646.8	1436.5	1321	1183.4
Lat. 25°47' N	$\overline{V}$	1737.8	1418.8	961.2	532.9	385.8	358.7	360.1	482.1	890.2	1291.2	1756.7	1814.2
El. 9 ft	$\overline{K}_t$	0.604	0.616	0.612	0.600	0.578	0.545	0.552	0.549	0.525	0.534	0.559	0.588
	t_o	71.6	72.0	73.8	77.0	79.9	82.9	84.1	84.5	83.3	80.2	75.6	72.6

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Midland, Texas	$\bar{H}$	1066.4	1345.7	1784.8	2036.1	2301.1	2317.7	2301.8	2193	1921.8	1470.8	1244.3	1023.2
Lat. 31°56' N	$\bar{V}$	1742.4	1509.5	1212.5	724.9	528.2	474.5	500.9	748.0	1334.4	1620.5	2014.4	1946.1
El. 2854 ft	$\bar{K}_t$	0.587	0.596	0.638	0.617	0.639	0.622	0.628	0.643	0.642	0.600	0.609	0.611
	t_o	47.9	52.8	60.0	68.8	77.2	83.9	85.7	85.0	78.9	70.3	56.6	49.1
Nashville, Tenn.	$\bar{H}$	589.7	907	1246.8	1662.3	1997	2149.4	2079.7	1862.7	1600.7	1223.6	823.2	614.4
Lat. 36°07' N	$\bar{V}$	1174.0	1205.6	991.7	740.3	562.2	522.7	552.0	818.1	1298.8	1603.2	1617.9	1460.7
El. 605 ft	$\bar{K}_t$	0.373	0.440	0.472	0.514	0.556	0.573	0.565	0.554	0.556	0.540	0.454	0.426
	t_o	42.6	45.1	52.9	63.0	71.4	80.1	83.2	81.9	76.6	65.4	52.3	44.3
Newport, R.I.	$\bar{H}$	565.7	856.4	1231.7	1484.8	1849	2019.2	1942.8	1687.1	1411.4	1035.4	656.1	527.7
Lat. 41°29' N	$\bar{V}$	1437.8	1366.7	1203.8	782.0	669.7	652.7	646.4	908.7	1390.1	1610.5	1639.7	1627.7
El. 60 ft	$\bar{K}_t$	0.438	0.482	0.507	0.477	0.520	0.536	0.529	0.513	0.524	0.512	0.44	0.460
	t_o	29.5	32.0	39.6	48.2	58.6	67.0	73.2	72.3	66.7	56.2	46.5	34.4
New York, N.Y.	$\bar{H}$	539.5	790.8	1180.4	1426.2	1738.4	1994.1	1938.7	1605.9	1349.4	977.8	598.1	476
Lat. 40°46' N	$\bar{V}$	1313.9	1222.3	1121.5	728.6	608.5	623.2	622.8	839.7	1293.2	1475.3	1432.6	1395.2
El. 52 ft	$\bar{K}_t$	0.406	0.435	0.480	0.455	0.488	0.53	0.528	0.486	0.500	0.475	0.397	0.403
	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Oak Ridge, Tenn.	$\bar{H}$	604	895.9	1241.7	1689.6	1942.8	2066.4	1972.3	1795.6	1559.8	1194.8	796.3	610
Lat. 36°01' N	$\bar{V}$	1197.4	1186.9	984.0	749.1	544.4	500.4	521.1	785.3	1261.1	1560.1	1558.6	1443.7
El. 905 ft	$\bar{K}_t$	0.382	0.435	0.471	0.524	0.541	0.551	0.536	0.534	0.542	0.527	0.438	0.422
	t_o	41.9	44.2	51.7	61.4	69.8	77.8	80.2	78.8	74.5	62.7	50.4	42.5
Oklahoma City, Oklahoma	$\bar{H}$	938	1192.6	1534.3	1849.4	2005.1	2355	2273.8	2211	1819.2	1409.6	1085.6	897.4
Lat. 35°24' N	$\bar{V}$	1810.9	1546.8	1188.5	797.1	545.8	555.8	583.9	941.0	1438.3	1801.5	2071.3	2064.7
El. 1304 ft	$\bar{K}_t$	0.580	0.571	0.576	0.570	0.558	0.629	0.618	0.656	0.628	0.614	0.588	0.608
	t_o	40.1	45.0	53.2	63.6	71.2	80.6	85.5	85.4	77.4	66.5	52.2	43.1
Ottawa, Ontario	$\bar{H}$	539.1	852.4	1250.5	1506.6	1857.2	2084.5	2045.4	1752.4	1326.6	826.9	458.7	408.5
Lat. 45°20' N	$\bar{V}$	1677.3	1590.0	1405.2	921.0	794.3	794.2	806.6	1092.3	1495.5	1493.1	1402.4	1596.6
El. 339 ft	$\bar{K}_t$	0.499	0.540	0.554	0.502	0.529	0.554	0.560	0.546	0.521	0.450	0.359	0.436
	t_o	14.6	15.6	27.7	43.3	57.5	67.5	71.9	69.8	61.5	48.9	35	19.6
Phoenix, Ariz.	$\bar{H}$	1126.6	1514.7	1967.1	2388.2	2709.6	2781.5	2450.5	2299.6	2131.3	1688.9	1200	1040.9
Lat. 33°26' N	$\bar{V}$	1988.9	1830.5	1411.5	935.4	668.3	601.7	571.5	892.8	1563.5	2009.0	2258.4	2175.9
El. 1112 ft	$\bar{K}_t$	0.65	0.691	0.716	0.728	0.753	0.745	0.667	0.677	0.722	0.708	0.657	0.652
	t_o	54.2	58.8	64.7	72.2	80.8	89.2	94.6	92.5	87.4	75.8	63.6	56.7
Portland, Maine	$\bar{H}$	565.7	874.5	1329.5	1528.4	1923.2	2017.3	2095.6	1799.2	1428.8	1035	591.5	507.7
Lat. 43°39' N	$\bar{V}$	1619.2	1528.2	1408.9	877.8	767.5	717.7	769.9	1054.9	1521.8	1755.6	1664.0	1801.4
El. 63 ft	$\bar{K}_t$	0.482	0.524	0.569	0.500	0.544	0.536	0.572	0.554	0.546	0.539	0.431	0.491
	t_o	23.7	24.5	34.4	44.8	55.4	65.1	71.1	69.7	61.9	51.8	40.3	28.0

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Rapid City, S.D.	$\bar{H}$	687.8	1032.5	1503.7	1807	2028	2193.7	2235.8	2019.9	1628	1179.3	763.1	590.4
Lat. 44°09' N	$\underline{V}$	2019.5	1840.4	1622.1	1057.6	826.5	796.9	839.3	1206.5	1764.0	2038.7	2201.8	2158.0
El. 3218 ft	$\bar{K}_t$	0.601	0.627	0.649	0.594	0.574	0.583	0.612	0.622	0.628	0.624	0.566	0.588
	t_o	24.7	27.4	34.7	48.2	58.3	67.3	76.3	75.0	64.7	52.9	38.7	29.2
Riverside, Calif.	$\bar{H}$	999.6	1335	1750.5	1943.2	2282.3	2492.6	2443.5	2263.8	1955.3	1509.6	1169	979.7
Lat. 33°57' N	$\underline{V}$	1808.1	1644.4	1282.3	781.2	578.2	552.1	585.0	901.1	1463.6	1830.8	2094.9	2102.1
El. 1020 ft	$\bar{K}_t$	0.589	0.617	0.643	0.594	0.635	0.667	0.665	0.668	0.665	0.639	0.606	0.626
	t_o	55.3	57.0	60.6	65.0	69.4	74.0	81.0	81.0	78.5	71.0	63.1	57.2
Saint Cloud, Minn.	$\bar{H}$	632.8	976.7	1383	1598.1	1859.4	2003.3	2087.8	1828.4	1369.4	890.4	545.4	463.1
Lat. 45°35' N	$\underline{V}$	1992.3	1839.0	1567.2	985.8	803.1	770.8	831.6	1149.8	1556.4	1622.2	1687.2	1834.7
El. 1034 ft	$\bar{K}_t$	0.595	0.629	0.614	0.534	0.530	0.533	0.573	0.570	0.539	0.490	0.435	0.504
	t_o	13.6	16.9	29.8	46.2	58.8	68.5	74.4	71.9	62.5	50.2	32.1	18.3
Salt Lake City, Utah	$\bar{H}$	622.1	986	1301.1	1813.3	-	-	-	-	1689.3	1250.2	-	552.8
Lat. 40°46' N	$\underline{V}$	1515.1	1524.0	1236.2	926.4	-	-	-	-	1619.0	1886.4	-	1620.3
El. 4227 ft	$\bar{K}_t$	0.468	0.909	0.529	0.578	-	-	-	-	0.621	0.610	-	0.467
	t_o	29.4	36.2	44.4	53.9	63.1	71.7	81.3	79.0	68.7	57.0	42.5	34.0
San Antonio, Tex.	$\bar{H}$	1045	1299.2	1560.1	1664.6	2024.7	814.8	2364.2	2185.2	1844.6	1487.4	1104.4	954.6
Lat. 29°32' N	$\underline{V}$	1589.5	1351.4	966.2	532.7	430.7	159.0	480.4	671.9	1170.1	1521.0	1663.3	1678.2
El. 794 ft	$\bar{K}_t$	0.541	0.550	0.542	0.500	0.563	0.220	0.647	0.637	0.603	0.584	0.507	0.528
	t_o	53.7	58.4	65.0	72.2	79.2	85.0	87.4	87.8	82.6	74.7	63.3	56.5
Santa Maria, Calif.	$\bar{H}$	983.8	1296.3	1805.9	2067.9	2375.6	2599.6	2540.6	2293.3	1965.7	1566.4	1169	943.9
Lat. 34°54' N	$\underline{V}$	1858.0	1652.1	1372.7	870.6	631.2	600.5	637.2	954.3	1525.6	1966.6	2183.7	2121.2
El. 238 ft	$\bar{K}_t$	0.595	0.613	0.671	0.636	0.661	0.695	0.690	0.678	0.674	0.676	0.624	0.627
	t_o	54.1	55.3	57.6	59.5	61.2	63.5	65.3	65.7	65.9	64.1	60.8	56.1
Sault Ste. Marie, Mich.	$\bar{H}$	488.6	843.9	1336.5	1559.4	1962.3	2064.2	2149.4	1767.9	1207	809.2	392.2	359.8
Lat. 46°28' N	$\underline{V}$	1602.2	1641.1	1559.3	992.2	877.0	821.6	886.6	1146.1	1411.3	1520.8	1263.5	1493.5
El. 724 ft	$\bar{K}_t$	0.490	0.560	0.606	0.526	0.560	0.549	0.590	0.554	0.481	0.457	0.323	0.408
	t_o	16.3	16.2	25.6	39.5	52.1	61.6	67.3	66.0	57.9	46.8	33.4	21.9
Sayville, N.Y.	$\bar{H}$	602.9	936.2	1259.4	1560.5	1857.2	2123.2	2040.9	1734.7	1446.8	1087.4	697.8	533.9
Lat. 40°30' N	$\underline{V}$	1444.6	1429.6	1183.8	788.1	641.7	655.0	647.0	896.8	1372.3	1621.9	1644.4	1534.4
El. 20 ft	$\bar{K}_t$	0.453	0.511	0.510	0.498	0.522	0.564	0.555	0.525	0.530	0.527	0.450	0.447
	t_o	35	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Schenectady, N.Y.	$\bar{H}$	488.2	753.5	1026.6	1272.3	1553.1	1687.8	1662.3	1494.8	1124.7	820.6	436.2	356.8
Lat. 42°50' N	$\underline{V}$	1338.3	1273.7	1056.0	707.8	598.2	579.8	589.0	849.6	1163.9	1348.4	1175.5	1203.6
El. 217 ft	$\bar{K}_t$	0.406	0.441	0.433	0.413	0.438	0.448	0.454	0.458	0.426	0.420	0.309	0.331
	t_o	24.7	24.6	34.9	48.3	61.7	70.8	76.9	73.7	64.6	53.1	40.1	28.0

Radiation and other data for 71 locations in the United States and Canada (continued)

		January	February	March	April	May	June	July	August	September	October	November	December
Seattle, Wash.	$\bar{H}$	282.6	520.6	992.2	1507	1881.5	1909.9	2110.7	1688.5	1211.8	702.2	386.3	239.5
Lat. 47°27' N	$\bar{V}$	967.8	1048.2	1194.7	991.5	872.4	788.3	903.8	1131.1	1461.0	1364.6	1299.6	1044.5
El. 386 ft	$\bar{K}_t$	0.296	0.355	0.456	0.510	0.538	0.508	0.581	0.533	0.492	0.407	0.336	0.292
	t_o	42.1	45.0	48.9	54.1	59.8	64.4	68.4	67.9	63.3	56.3	48.4	44.4
Seabrook, N.J.	$\bar{H}$	591.9	854.2	1195.6	1518.8	1800.7	1964.6	1949.8	1715	1445.7	1071.9	721.8	522.5
Lat. 39°30' N	$\bar{V}$	1346.6	1265.5	1068.3	779.2	586.1	544.2	596.6	863.5	1314.9	1567.7	1614.0	1431.4
El. 100 ft	$\bar{K}_t$	0.426	0.453	0.476	0.481	0.504	0.522	0.530	0.517	0.524	0.508	0.449	0.416
	t_o	39.5	37.6	43.9	54.7	64.9	74.1	79.8	77.7	69.7	61.2	48.5	39.3
Spokane, Wash.	$\bar{H}$	446.1	837.6	1200	1764.6	2104.4	2226.5	2479.7	2076	1511	844.6	486.3	279
Lat. 47°40' N	$\bar{V}$	1542.0	1699.2	1454.8	1169.4	983.5	926.2	1070.4	1400.6	1833.9	1653.2	1651.3	1229.7
El. 1968 ft	$\bar{K}_t$	0.478	0.579	0.556	0.602	0.603	0.593	0.684	0.656	0.616	0.494	0.428	0.345
	t_o	26.5	31.7	40.5	49.2	57.9	64.6	73.4	71.7	62.7	51.5	37.4	30.5
State College, Pa.	$\bar{H}$	501.8	749.1	1106.6	1399.2	1754.6	2027.6	1968.2	1690	1336.1	1017	580.1	443.9
Lat. 40°48' N	$\bar{V}$	1224.6	1159.6	1052.8	715.8	615.2	634.6	633.4	884.9	1282.1	1536.7	1392.2	1304.3
El. 1175 ft	$\bar{K}_t$	0.381	0.413	0.451	0.448	0.493	0.539	0.536	0.512	0.492	0.496	0.379	0.376
	t_o	31.3	31.4	39.8	51.3	63.4	71.8	75.8	73.4	66.1	55.6	43.2	32.6
Stillwater, Okla.	$\bar{H}$	763.8	1081.5	1463.8	1702.6	1879.3	2235.8	2224.3	2039.1	1724.3	1314	991.5	783
Lat. 36°09' N	$\bar{V}$	1522.7	1439.2	1165.7	759.4	529.9	544.4	591.2	896.9	1400.7	1723.6	1951.3	1864.4
El. 910 ft	$\bar{K}_t$	0.484	0.527	0.555	0.528	0.523	0.596	0.604	0.607	0.599	0.581	0.548	0.544
	t_o	41.2	45.6	53.8	64.2	71.6	81.1	85.9	85.9	77.5	67.6	52.6	43.9
Tampa, Fla.	$\bar{H}$	1223.6	1461.2	1771.9	2016.2	2228	2146.5	1991.9	1845.4	1687.8	1493.3	1328.4	1119.5
Lat. 27°55' N	$\bar{V}$	1768.2	1439.5	1025.8	596.3	448.8	405.0	385.4	525.6	1002.4	1447.4	1899.7	1859.5
El. 11 ft	$\bar{K}_t$	0.605	0.600	0.606	0.602	0.620	0.583	0.548	0.537	0.546	0.572	0.590	0.589
	t_o	64.2	65.7	68.8	74.3	79.4	83.0	84.0	84.4	82.9	77.2	69.6	65.5
Toronto, Ontario	$\bar{H}$	451.3	674.5	1088.9	1388.2	1785.2	1941.7	1968.6	1622.5	1284.1	835	458.3	352.8
Lat. 43°41' N	$\bar{V}$	1293.9	1180.3	1155.3	798.3	713.4	691.7	724.3	952.5	1369.2	1418.2	1291.5	1254.3
El. 379 ft	$\bar{K}_t$	0.388	0.406	0.467	0.455	0.506	0.516	0.539	0.500	0.493	0.438	0.336	0.346
	t_o	26.5	26.0	34.2	46.3	58	68.4	73.8	71.8	64.3	52.6	40.9	30.2
Tucson, Arizona	$\bar{H}$	1171.9	1453.8	-	2434.7	-	2601.4	2292.2	2179.7	2122.5	1640.9	1322.1	1132.1
Lat. 32°07' N	$\bar{V}$	1939.3	1670.8	-	889.5	-	528.5	498.3	791.7	1476.0	1854.6	2175.3	2207.0
El. 2556 ft	$\bar{K}_t$	0.648	0.646	-	0.738	-	0.698	0.625	0.640	0.710	0.672	0.650	0.679
	t_o	53.7	57.3	62.3	69.7	78.0	87.0	90.1	87.4	84.0	73.9	62.5	56.1
Upton, N.Y.	$\bar{H}$	583	872.7	1280.4	1609.9	1891.5	2159	2044.6	1789.6	1472.7	1102.6	686.7	551.3
Lat. 40°52' N	$\bar{V}$	1428.5	1355.0	1221.4	826.0	665.3	677.9	660.1	939.7	1416.8	1670.8	1654.7	1627.7
El. 75 ft	$\bar{K}_t$	0.444	0.483	0.522	0.514	0.532	0.574	0.557	0.542	0.542	0.538	0.448	0.467
	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7

Radiation and other data for 71 locations in the United States and Canada (continued)

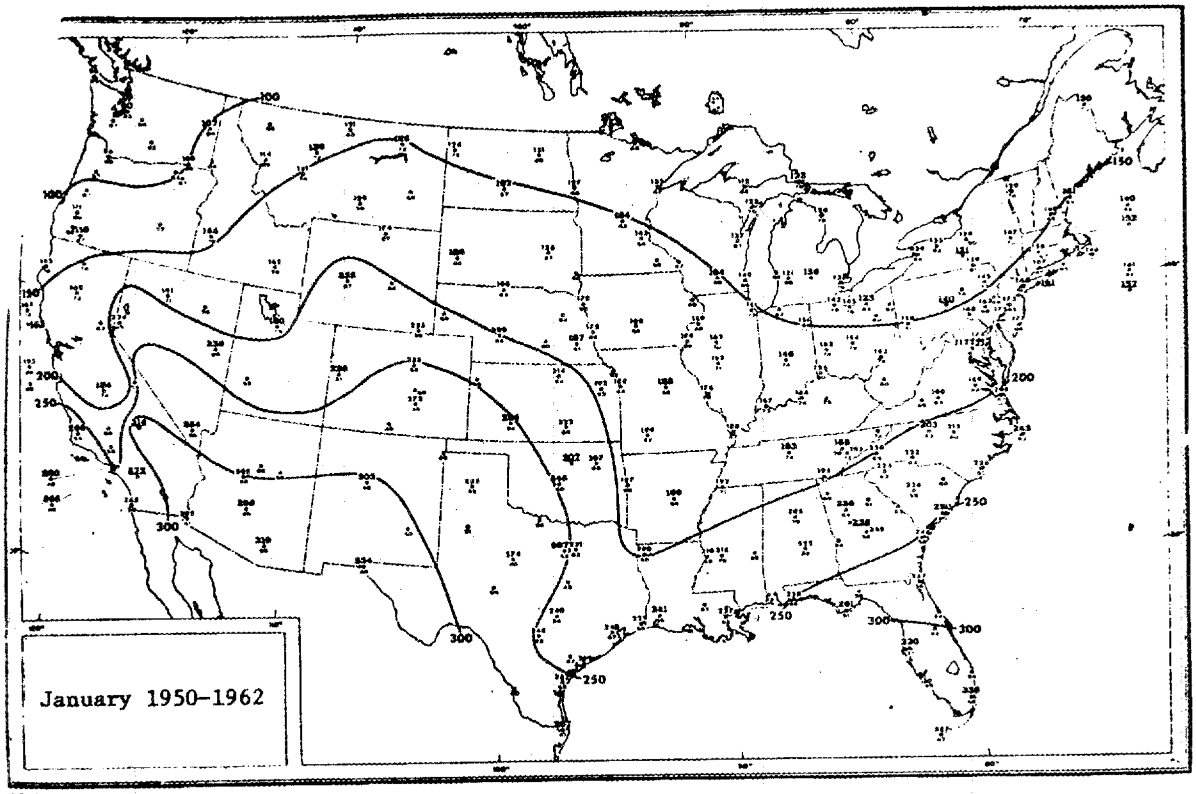
		January	February	March	April	May	June	July	August	September	October	November	December
Washington, D.C. (WBCO)	$\overline{H}$	632.4	901.5	1255	1600.4	1846.8	2080.8	1929.9	1712.2	1446.1	1083.4	763.5	594.1
Lat. 38°51' N	V	1404.2	1309.2	1097.7	800.2	585.5	562.9	575.5	841.0	1288.0	1552.8	1667.5	1586.2
El. 64 ft	$\overline{K}_t$	0.445	0.470	0.496	0.504	0.516	0.553	0.524	0.516	0.520	0.506	0.464	0.460
	t_o	38.4	39.6	48.1	57.5	67.7	76.2	79.9	77.9	72.2	60.9	50.2	40.2

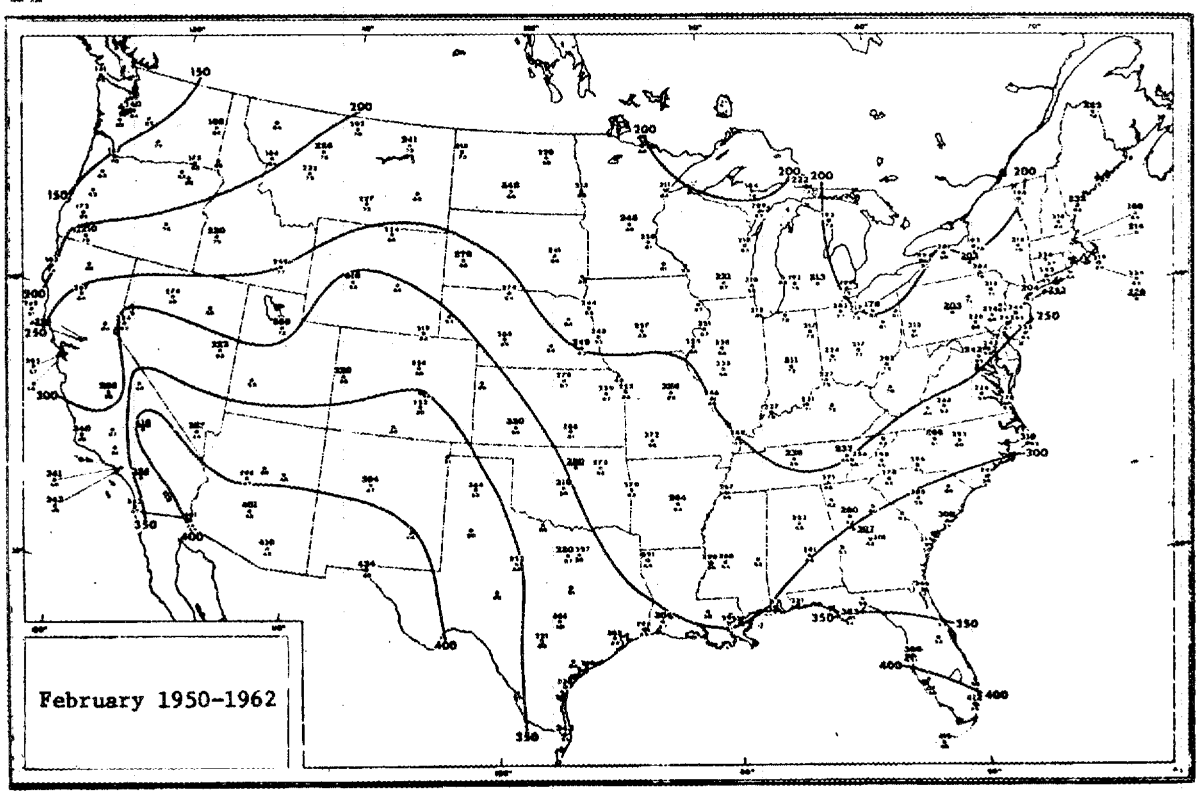
Source: Benjamin Y. H. Liu and Richard C. Jordan, "A Rational Procedure for Predicting the Long-Term Average Performance of Flat Plate Solar-Energy Collectors," *Solar Energy* 7(2): 53-74 (1963).

APPENDIX H

Source: Iven Bennett, "Monthly Maps of Mean Daily Insolation for the United States," Vol. 9, No. 3, pp. 145-152 in *Proceedings of Solar Energy Society Conference, Phoenix, Arizona, March 15-17, 1965.*

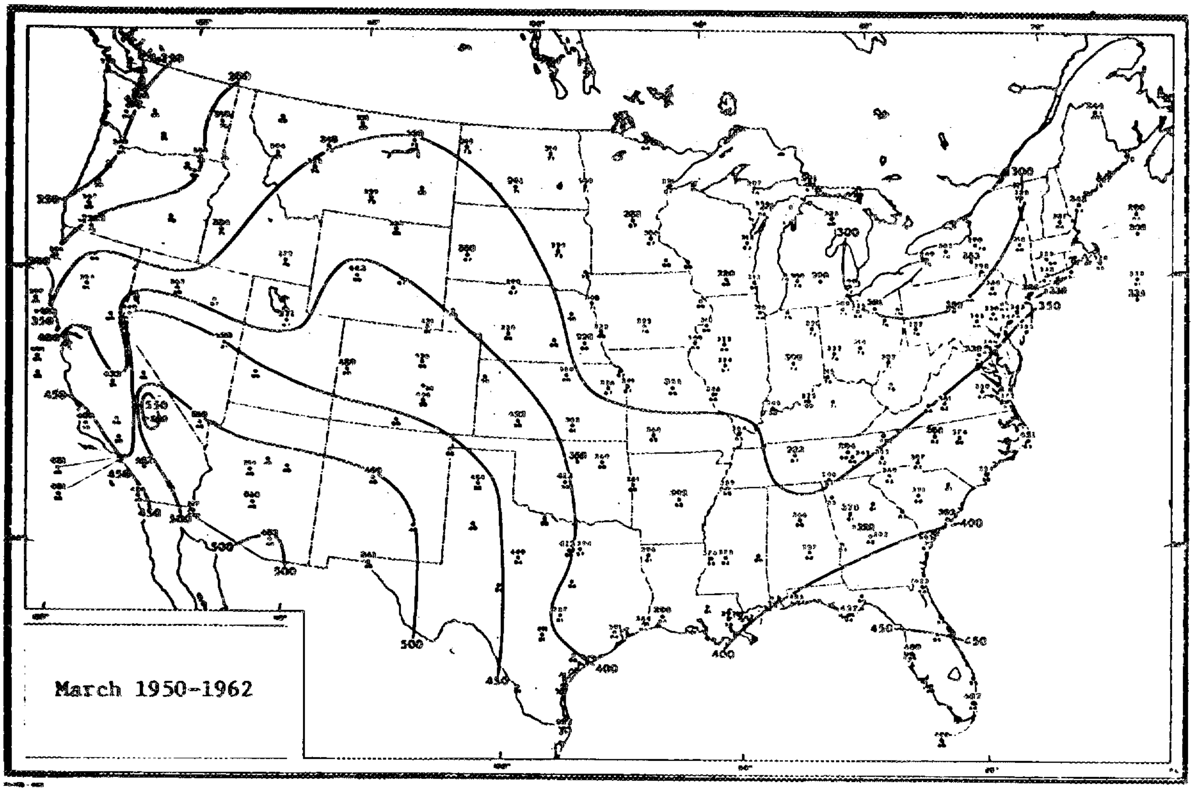
APPENDIX H

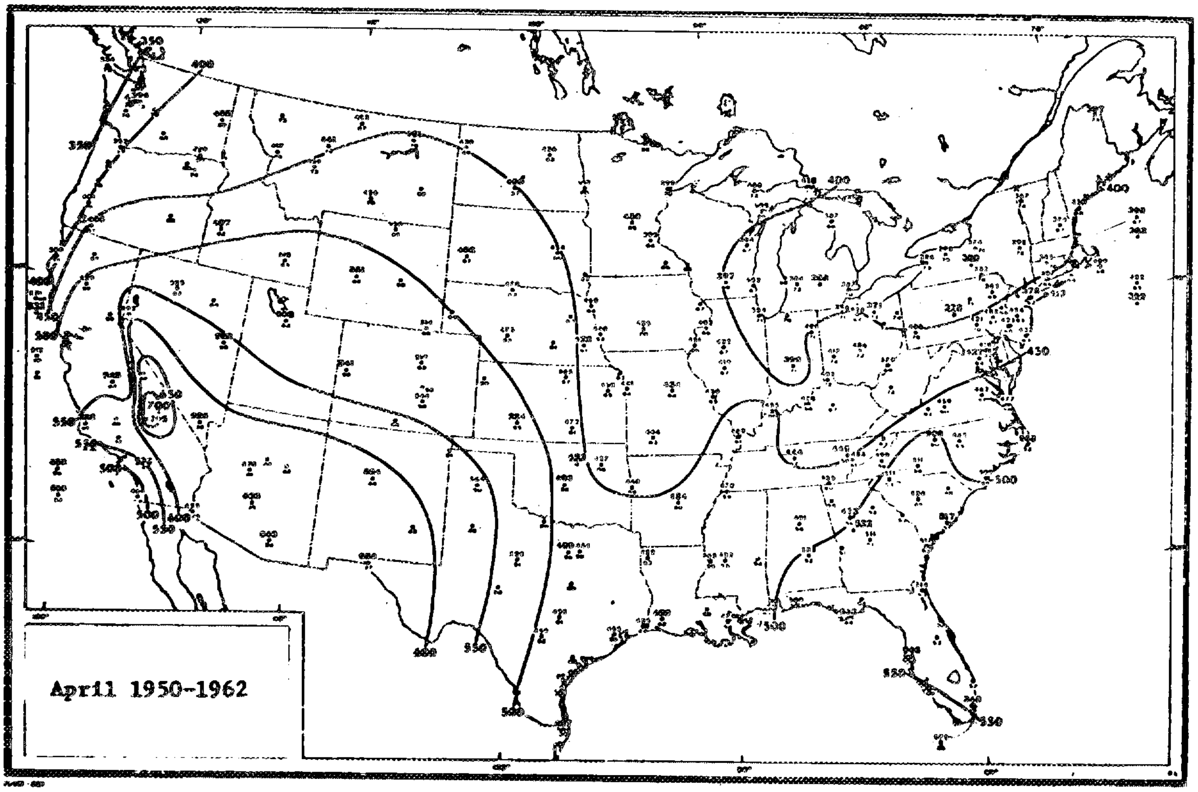




Daily total solar radiation (average days) (Langleys/day).
(1 Langley = 3.68 Btu/ft^2)

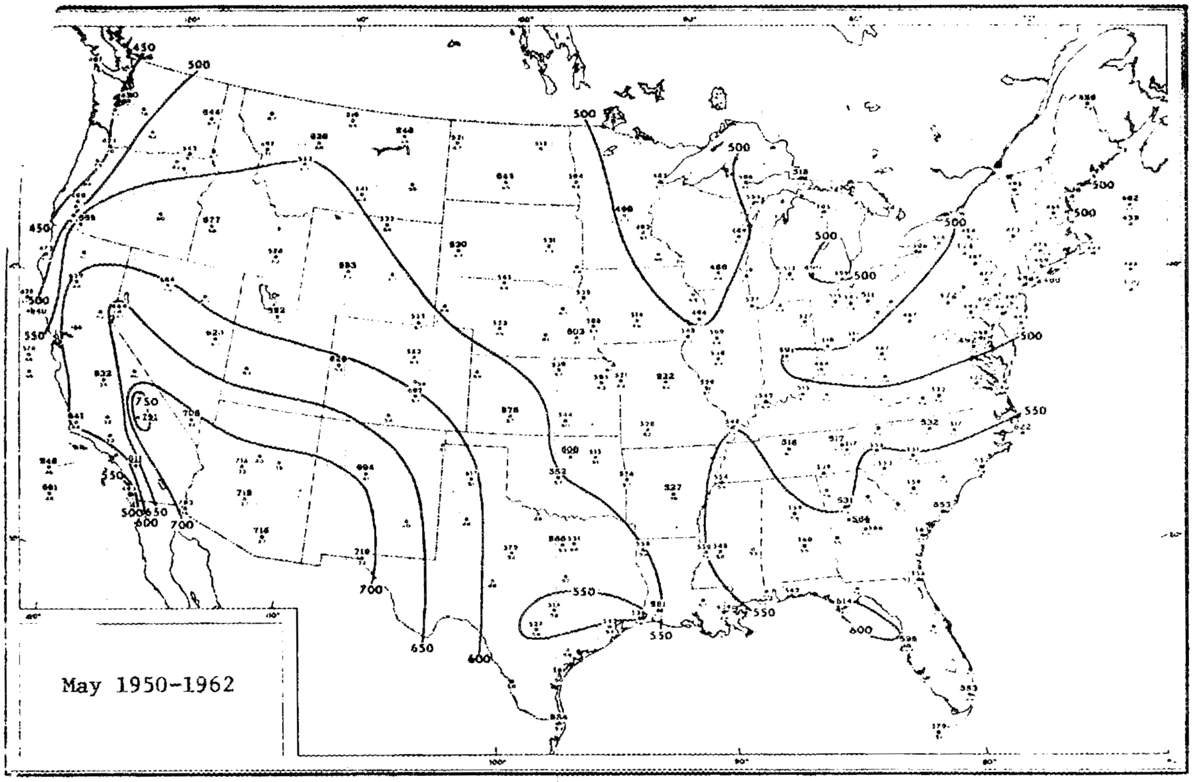
APPENDIX H (continued)

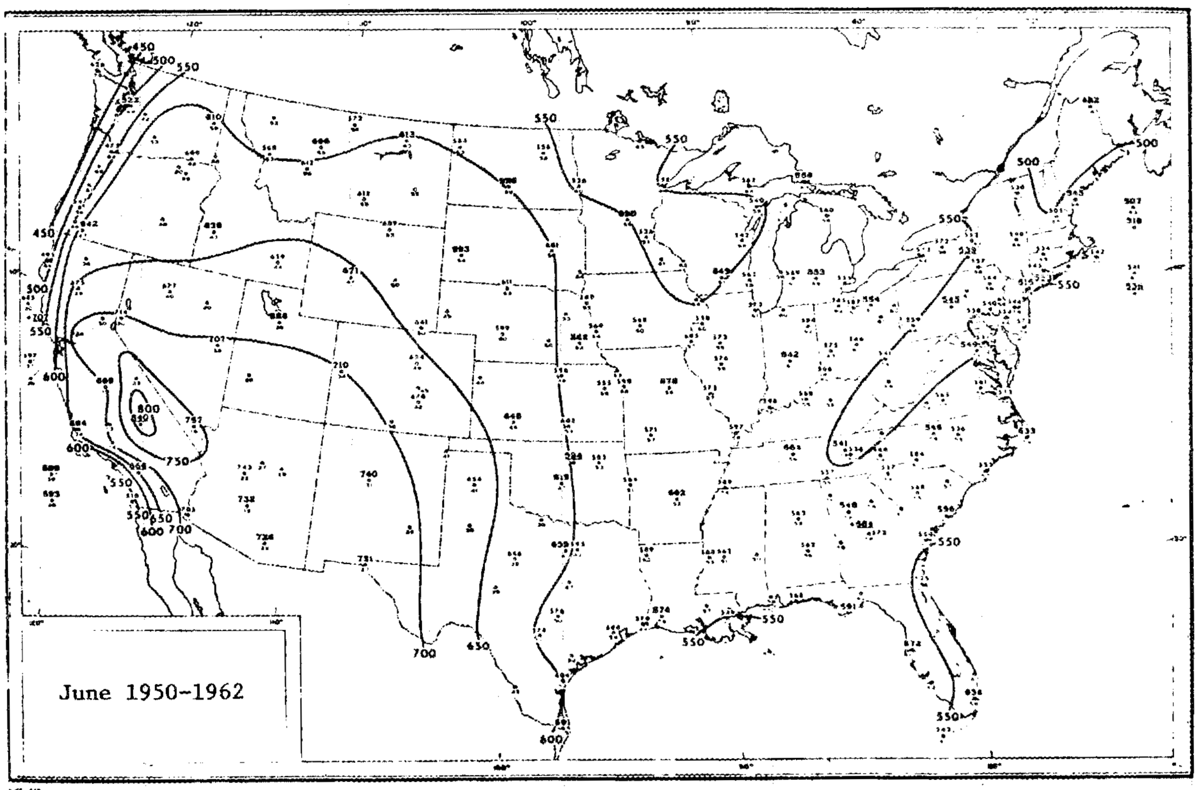




Daily total solar radiation (average days) (Langleys/day).
(1 Langley = 3.68 Btu/ft^2)

APPENDIX H (continued)





Daily total solar radiation (average days) (Langleys/day).
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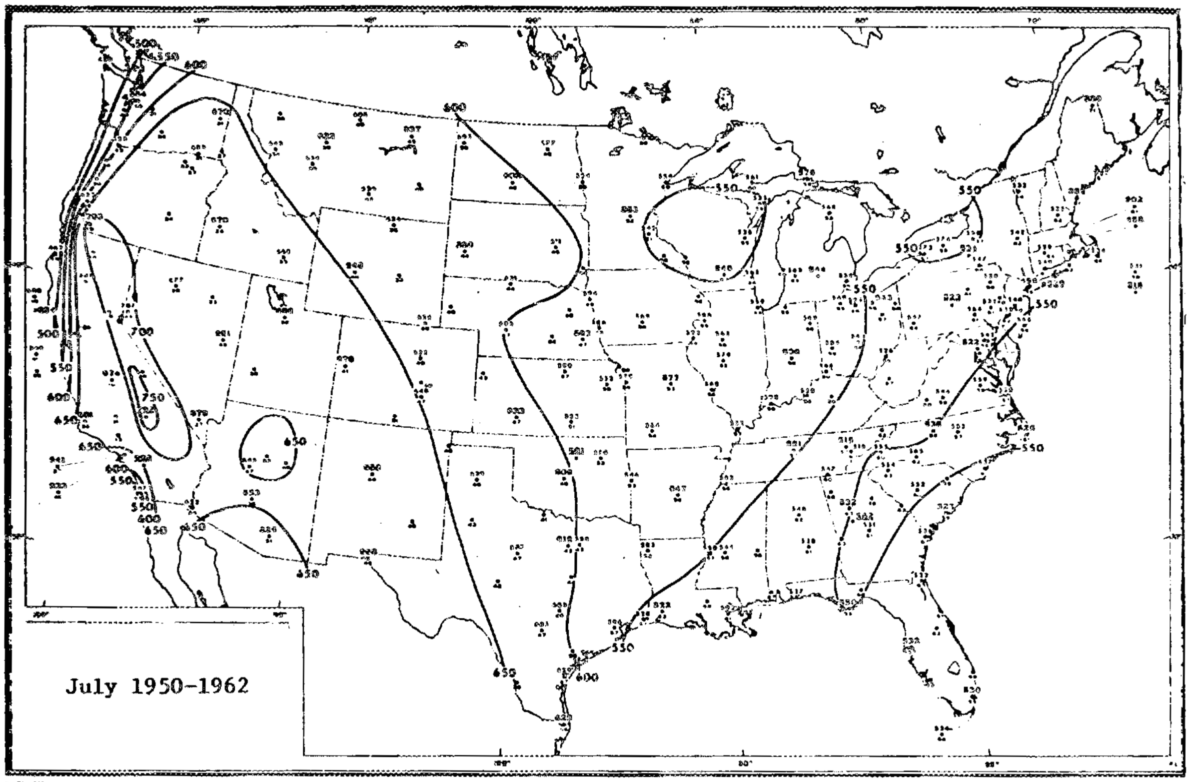
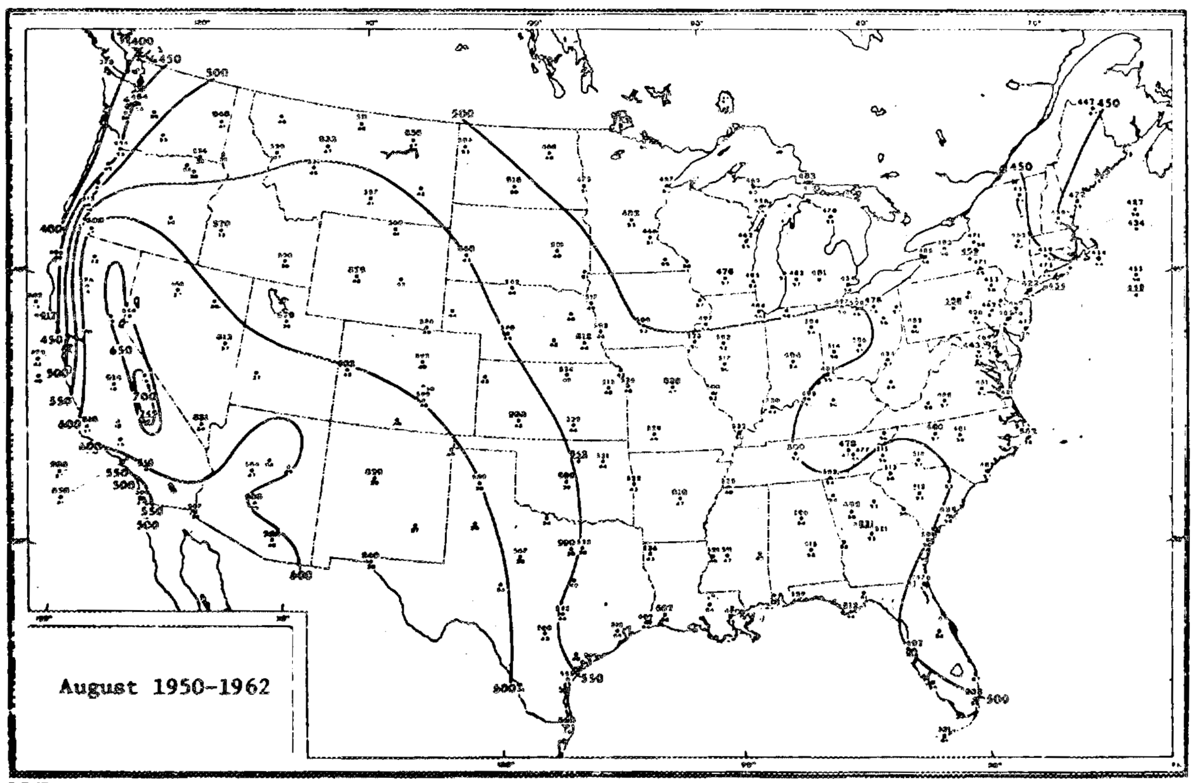
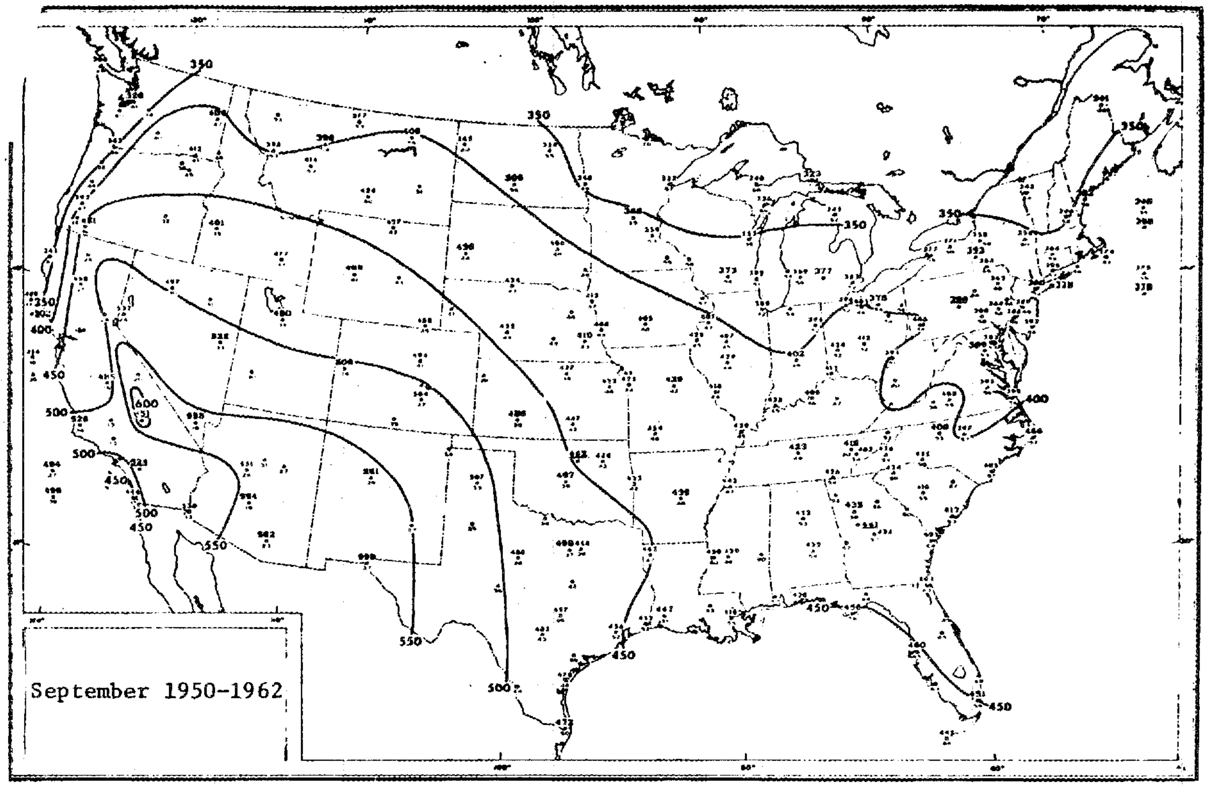
APPENDIX H (continued)

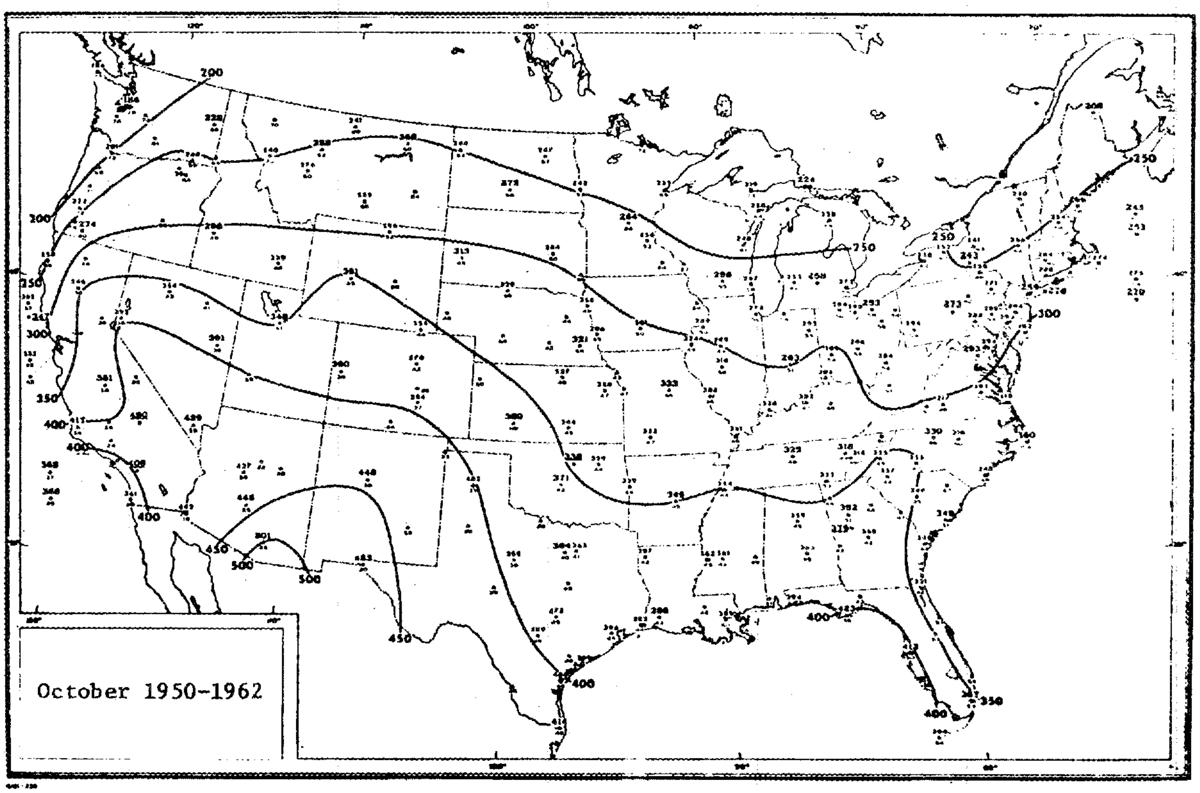




Daily total solar radiation (average days) (Langleys/day).
(1 Langley = 3.68 Btu/ft^2)

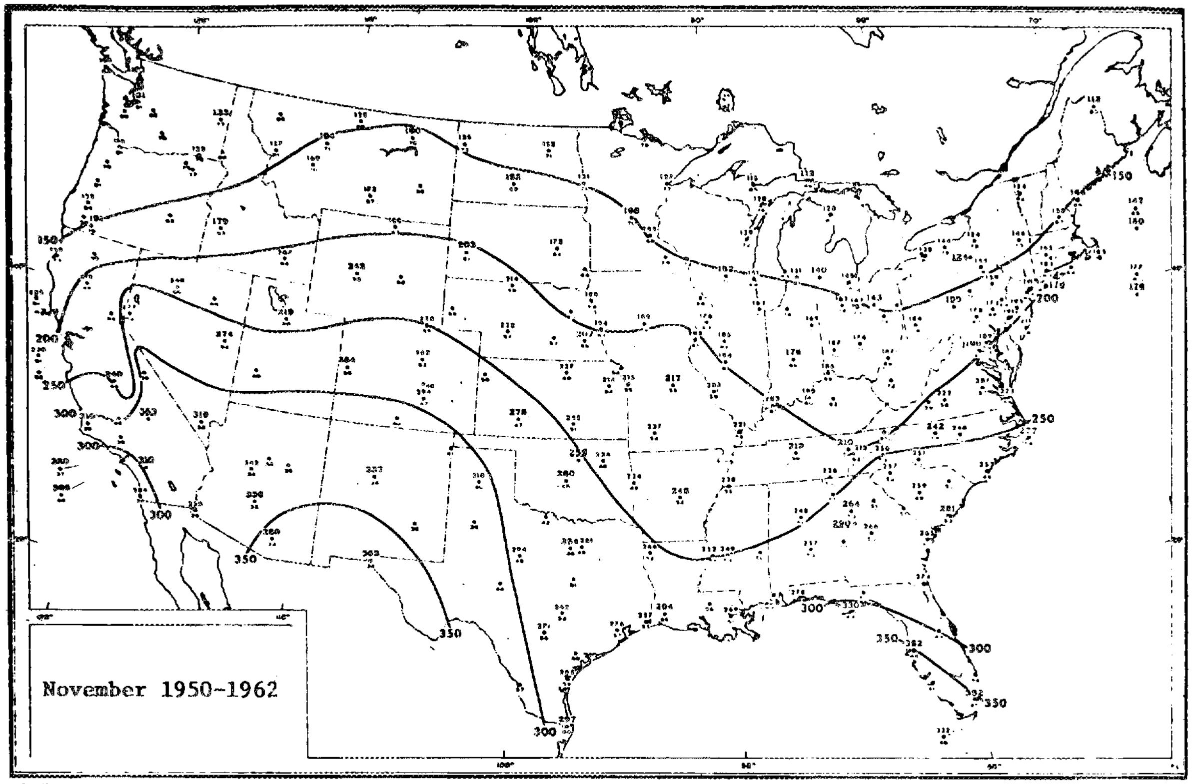
APPENDIX H (continued)

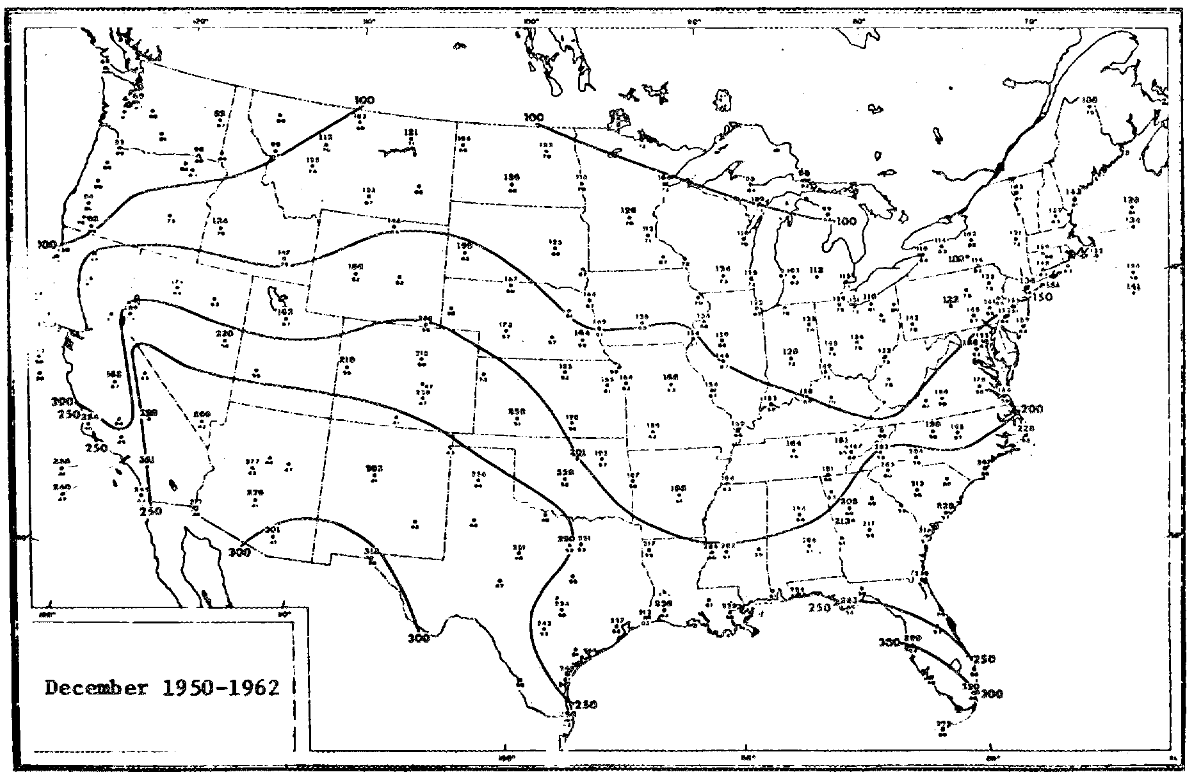




Daily total solar radiation (average days) (Langleys/day).
(1 Langley = 3.68 Btu/ft^2)

APPENDIX H (continued)





Daily total solar radiation (average days) (Langleys/day).
(1 Langley = 3.68 Btu/ft^2)

APPENDIX I

SUPPLIERS OF ACES COMPONENTS AND SYSTEMS

Chiller Evaporators

Heatron Inc., 333 Eberts Lane, York, Pennsylvania 17405

Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832

ITT Bell & Gossett, 8200 N. Austin Avenue, Morton Grove, Illinois 60053

Dunham-Bush, Inc., 175 South Street, Hartford Connecticut 06110

Refrigeration Research, 525 N. Fifth Street, Brighton, Michigan 48116

Ice Bank Coils

Chester-Jenson Co., Fifth and Tilghman Streets, Chester Park, Pennsylvania 19013 (steel)

Peerless of America, 5800 N. Pulaski Road, Chicago, Illinois 60646 (aluminum)

Dole Refrigerating Co., 5910 N. Pulaski Road, Chicago, Illinois 60646 (steel)

Aluminum Solar Panel Extrusions

Brazeway, Inc., 2711 E. Maumee Street, Adrian, Michigan 49221

Bohn Aluminum & Brass Corp., Plant 16, Holland, Michigan

Refrigeration Research, 525 N. Fifth Street, Brighton, Michigan 48116 (resale aluminum and manufactured steel panels)

Heat Pump/Ice Makers

Turbo Refrigerating Co., 1515 Shady Oak Drive, Denton, Texas 76201

Desuperheaters and Water Cooled Condensers

Refrigeration Research, 525 N. Fifth Street, Brighton, Michigan 48116 (copper)

Edwards Engineering Corp., 101-A Alexander Avenue, Pompton Plains, New Jersey 07444 (copper)

Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832 (copper, steel, and aluminum)

Ice Bin Materials and Systems

Foam-Form Midwest, 2924 Country Club Drive, Colorado Springs, Colorado 80909

Refrigeration Research, 525 N. Fifth Street, Brighton, Michigan 48116 (resale only)

Packaged Heat Pump (ACES)

Friedrich Group, 4200 N. Pan Am, San Antonio, Texas 78295 (up to 10 tons)

Bohn Aluminum & Brass Corp., Heat Transfer Division, 1625 E. Voorhees Street, Danville, Illinois 61832 (10 tons and up)

Refrigeration Systems Co., 611 State Street, Newburgh, Indiana 47630

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