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WASTE HEAT UTILIZATION FROM ELECTRIC GENERATING PLANTS

by

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SUMMARY:

A number of agricultural uses for low-grade power plant reject heat are under investigation. Summaries of the major efforts both in the U.S. and abroad are presented.

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WASTE HEAT UTILIZATION FROM ELECTRIC GENERATING PLANTS*

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INTRODUCTION

Power plants reject about 11 × 10^9 GJ (11 × 10^{15} Btu) of low-grade heat to the atmosphere annually. Typically, this heat is found in the large quantities of cooling water necessary to condense the steam in the power generating cycle. Such cooling water is generally discharged in the range of 15 to 43°C (60 to 110°F) depending on the temperature of the available inlet water, quantity circulated, plant load, and heat rejection system used.

A number of possible uses have been suggested for this low-grade heat. Because of the low available temperatures, these uses have concentrated on agricultural and aquacultural applications.

It is the purpose of this paper to describe several innovative agricultural techniques that utilize power plant reject heat. The vast majority of these projects involve greenhouse applications although undersoil heating applications are also being investigated. Schematic descriptions will be given for these techniques and a brief review of the project status will be provided.

UNITED STATES SYSTEMS

The operations described below are some of the major ongoing efforts in the U.S. using power plant reject heat for agricultural purposes. These efforts include commercial applications as well as demonstration and experimental efforts and are classed according to the type of heating system employed.

Fin-Tube Heat Coil System

Northern States Power Company (NSP) has demonstrated the technical and economic feasibility of using power plant reject heat in a fin-tube heat coil system with successful operation of the Sherco Greenhouse (1). The three-year demonstration project has led the way for commercial adaptation of the concept. Presently, three commercial greenhouse operators have put 0.7 ha (1.7 acres) of greenhouses into production using waste heat from the Sherburne County Power Plant.

The Sherco Greenhouse is an arch roof, gutter-connected house covered with a double layer of polyethelene. The greenhouse consists of 14 bays each

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5 m (17 ft) wide by 29 m (96 ft) long for a total enclosed area of about 2056 m^2 (22,848 ft^2).

The heating system, illustrated in Fig. 1, consists of an air heating system and a soil heating grid. The air heating system was designed to carry 100% of the greenhouse heat load, while the soil heating system was designed primarily for crop root zone temperature control; though it does contribute somewhat to the heat requirements of the greenhouse. The air heating system consists of commercially available packaged fan-coil air handling units. Warm water is circulated through fin-tube heat exchangers located in the fan-coil units. One fan-coil unit is located in each of the 14 bays of the greenhouse and heated air is distributed down the length of each bay in a 762 mm (30 in.) diameter perforated plastic duct. The heating system is controlled by thermostats in each bay of the greenhouse that start and stop the heating fans.

The soil heating system consists of polyethylene plastic pipes, 25 mm (1 in.) in diameter spaced 0.6 m (2 ft) on center and buried about 305 mm (12 in.) below the soil surface. The pipes were headered together in groups of 8 per bay and supplied with warm water on one end with the return taken from a header at the opposite end 27 m (90 ft) away. The system is controlled by soil temperature sensing thermostats that start and stop circulating pumps to supply water through the soil heating system.

Experience during the demonstration project proved that condenser waste heat available at approximately 29°C (85°F) was suitable to maintain a greenhouse growing environment of 13 to 16°C (55 to 60°F) when outside air temperatures fell as low as —42°C (—43°F). During the first year of operation of the pipeline system serving waste heat to commercial greenhouse customers, an overall availability of service of 97% was achieved. Backup heating capacity is supplied by propane-fired heaters.

The first crop, planted in January 1976, included rose bushes, tomatoes and green peppers. During subsequent plantings, the vegetables were replaced by floral crops so that the entire greenhouse was in floral production in the 1977—1978 growing season.

As a result of the successful experience of the Sherco Greenhouse Project, NSP was approached by commercial operators in the spring of 1977 and asked to provide a site and warm water service to a 0.4-ha (1-acre) commercial floral operation and to a 0.08-ha (0.2-acre) commercial vegetable operation. Both commercial facilities began construction in 1977 and warm water was first sold commercially to the 0.4-ha (1-acre) floral operation in November 1977. The smaller, 0.08-ha (0.2-acre), vegetable operation did not require warm water service until February 1978.

The annual savings in heating costs to commercial operators using waste heat have amounted to nearly $12,500/ha ($5000/acre) compared to conventionally heated greenhouses. The experiences of commercial operators have been sufficiently satisfactory that future expansion of waste heat service at the Sherburne County Plant site is expected.

Evaporative Pad System

In 1968, the Oak Ridge National Laboratory (ORNL) began investigations concerning the use of reject heat for greenhouse environmental control. Conceptual design studies (2,3) and a small proof-of-principle experiment at ORNL indicated that the direct-contact evaporative-pad greenhouse design was technically and economically feasible.

The Tennessee Valley Authority (TVA) decided to use the ORNL concept as the basis for experiments in vegetable culture at the National Fertilizer Development Center at Muscle Shoals, Alabama. The TVA/ORNL experimental greenhouse is a conventional aluminum-framed glass-glazed structure. Waste heat is simulated using an electric water heater.

As shown in Fig. 2, the greenhouse is heated by pumping warm water to the top of the evaporative pad and allowing it to drip through the packing. As the water flows through the packing, it interacts with the air flow being drawn through the pad by the fans located at the rear of the house. Cooling the greenhouse in summer is achieved in a similar manner using cool water in the pad.

In summer operation, the inlet and exhaust shutters are opened and ambient air is drawn into the pad where it is cooled and humidified. It is then cycled through the growing section and exhausted to the atmosphere.

In winter operation, the inlet and exhaust shutters are partially or completely closed (depending upon ambient conditions) to conserve heat. In this mode of operation, some or all of the greenhouse air exiting from the growing section is recycled through the attic back to the pad where it is heated. Because the air is continually recycled, the humidity in the growing section hovers near 100% unless significant solar flux or dry heat is added to the air. To accomplish the latter objective a fin-tube heating coil was added downstream of the pad.

Air temperature and humidity entering the growing section are thus controlled by the position of the shutters, ratio of warm water flow to the pad and fin-tube heater, and fan speed (hence, air flow).

Heating and cooling of the greenhouse was initially accomplished using an aspen fiber pad. However, subsequent experimental work at ORNL indicated that CELdek,* a cooling tower packing, was a superior pad material. As a result, the aspen pads were replaced with CELdek in 1975.

Tomatoes and cucumbers have been the primary crops produced. Annual production rates of 318 tonne/ha (140 tons/acre) and 327 tonne/ha (144 tons/acre) have been achieved for tomatoes and cucumbers (Fremfrance), respectively (4). These results have been achieved, in a large part, without using the fin-tube heating coils for humidity reduction.

Based on the positive results of the work in the Muscle Shoals pilot-scale greenhouse, a larger research and demonstration greenhouse has been constructed at the Browns Ferry Nuclear Plant (5). This 0.2 ha (0.5 acre) facility has been designed and will be operated using engineering,

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horticultural, and economic information obtained from the pilot-scale greenhouse. It will have a fin-tube heater for further evaluation of the need to reduce relative humidity. Several modifications should reduce the capital investment required for a waste heat environmental control system.

The Oak Ridge National Laboratory and the Environmental Research Laboratory (ERL) of the University of Arizona, under contract with ORNL, are cooperating with TVA in the design of the Browns Ferry greenhouse. This commercial-scale demonstration facility will be divided into three equal zones. Two of the zones will utilize waste heat from the power plant in achieving environmental control; the third zone will be conventionally heated and cooled to provide a comparison of waste heat and conventional environmental control systems.

The condenser cooling water for the 2 waste heat zones will be supplied from the discharge side of the condensers inside the turbine building at Browns Ferry. A 35.6-cm (14-in.) diameter supply line will furnish up to 0.2 m^3/s (3075 gpm) of warm water to the greenhouse site.

A schematic drawing of the Browns Ferry greenhouse system is shown in Fig. 3. One waste heat zone will be similar to the Muscle Shoals facility, except the air recirculation will be in a horizontal pattern through two adjacent sections and will eliminate the need for an attic plenum. The other waste heat zone will depend on a larger evaporative pad area and higher warm water flows to achieve environmental control without air recirculation.

Initial crop production emphasis will be placed on producing cucumbers and tomatoes using varieties, cropping systems, and management practices best suited to a waste heat environment.

Porous Concrete Floor System

Public Service Electric and Gas Company and Rutgers University have constructed a 7.3 × 12.2 m (24 × 40 ft) double-layer plastic greenhouse at the Mercer Generating Station near Trenton, New Jersey (6). The heat exchanger design is based on previous studies concerning greenhouse heat transfer performed at Rutgers University. The heat exchanger system includes a porous concrete floor, with the warm condenser effluent flowing through and underneath the floor. The greenhouse crops are grown in plastic-lined troughs in the floor. Thus, the plant growing medium is essentially surrounded by a warm water bath. In addition to providing heat for the greenhouse air, this system maintains the crop root zone at an elevated temperature.

In addition to the porous floor, a vertical plastic curtain heat exchanger will be used for additional heat input to the greenhouse. This heat exchanger uses polyethelene film draped over a PVC pipe. Warm condenser effluent water supplied to the pipe is allowed to flow onto the interior of the plastic "tent" by means of holes in the PVC header. Air in contact with the exterior of the "tent" is heated by means of natural convection. The PVC header can be raised or lowered to provide the appropriate heat transfer area.

This pilot project will also utilize CELdek evaporative pads to cool the heated discharge water to determine if the greenhouse complex can function as a horizontal cooling tower.

Thermal Envelope System

The University of Illinois has been conducting an experimental program aimed at determining the feasibility of reducing greenhouse heat losses by spraying warm condenser water over the roof of a greenhouse (7). They operated a 3.7 × 7.3 m (12 × 24 ft) plastic film covered greenhouse using condenser effluent from the Vermillion Power Station, which is located near the university. The condenser water was applied to the greenhouse roof at a flow rate of 2.5×10^{-3} m^3/s (40 gpm). At this flow rate it was possible to maintain the greenhouse at 15°C (59°F) using 30°C (86°F) water when the ambient temperature fell to 0°C (32°F).

Results from this program were promising and led to a laboratory effort using a smaller greenhouse. This study examined a number of parameters including roof slope, water flow rate, and surface type to determine the operating characteristics of the system.

Current efforts are directed at examining the applicability of this system to conventional greenhouse structures. A conventional type greenhouse is being constructed at the Baldwin Power Station near St. Louis, Missouri. The greenhouse will have 2 bays each 5.3 m wide by 14.6 m long (17.5 ft wide by 48 ft long) and will use condenser effluent from the power station.

Undersoil Heating System

The Pennsylvania State University has had an active program in undersoil heating research since 1972 (8). Their program has included analytical modeling and experimental efforts. The experimental program included development of a 15 × 60 m (50 × 200 ft) prototype soil warming field to test functions for prediction of heat transfer from buried hot-water parallel pipe networks used in their computer model. A unique feature of the prototype is the spray application of treated municipal waste water on the warmed soil to maintain efficient heat transfer and supply crop nutrients.

The pipe network consists of 26 parallel 50 mm (2 in.) diameter polyethelene plastic pipes buried at a 300 mm (12 in.) depth with a 600 mm (24 in.) spacing. Warm water is supplied continuously at 38 to 40°C (100 to 104°F) from an oil-fired hot-water furnace.

The spray irrigation system is constructed of aluminum surface irrigation pipe. Laterals running perpendicular to the long axis of the plot are spaced every 13.3 m (44 ft) with offset 450 mm (18 in.) high risers (for sprinklers) at 13.3 m (0.5 in.) intervals. Waste water is applied at the rate of 10 mm (0.4 in.) per week in biweekly applications to both the heated plot and an adjacent 15 × 30 m (50 × 100 ft) control plot.

Current research is concentrating on year-round heat dissipation capability; crop growth and development, and municipal waste water renovation questions.

EFFORTS OUTSIDE THE UNITED STATES

The operations described in this section represent some of the major efforts to utilize reject heat for agricultural purposes in foreign countries. A fundamental difference between U.S. efforts and foreign projects is that some foreign applications employ waste heat utilization systems as an integral part of the power station cooling system rather than an "add on." This results in designs that are utilized as power plant reject heat systems year-round as well as agricultural endeavors.

Canada

The Saskatchewan Power Corporation and Tri-Tec Growth Systems Inc. have developed three systems for utilizing exhaust gases for heating greenhouses (6). One system uses exhaust gas from a natural gas-fired turbine while the other two use coal-fired boiler exhaust. These experimental greenhouses are located within a few miles of Saskatoon at a power complex operated by Saskatchewan Power Corporation.

France

Agricultural uses of nuclear power plant reject heat have been studied in France since 1972 (9). These investigations have included studies of a double-wall plastic mulching technique, utilization of heat pumps, and outdoor soil heating.

An experimental greenhouse at the Grenoble Nuclear Center has been used to determine the technical feasibility of the double-wall plastic mulch technique. This greenhouse is 250 m^2 (2700 ft^2) and is covered with a polyethelene film. The greenhouse is heated (see Fig. 4) by allowing the condenser effluent to flow at a very low speed inside double-wall polyethelene mulching placed directly on the soil.

During the first year of operation, this provided a heat exchanger surface of 52% of the greenhouse floor area. In these conditions, a temperature of 9°C (48°F) was maintained in the greenhouse with an outside temperature of −11°C (12°F) and water at 33°C (91°F).

After the initial experiments a new perforated mulching led to an increase in the ratio of heat exchange area to floor area to over 80% without affecting crop density. Using this new mulch the following crops were feasible:

1. Lettuce with water at 18–20°C
2. Tomatoes with water at 25–31°C
3. Cucumbers with water at 33–35°C

The use of heat pumps to boost condenser effluent temperatures was studied on a semi-industrial scale near the Saint Laurent des Eaux Power Plant. A 3000 m^2 (32,300 ft^2) greenhouse was constructed in 1973–1974 and rented to a commercial grower. Results from this study indicate that normal crop production rates can be maintained but the heat pumps must be carefully designed and controlled to be economically viable.

A 10-ha (25-acre) agricultural-forestry site at the Cadacache Nuclear Research Center has been used to study open-circuit irrigation and undersoil heating using power plant reject heat. Open-circuit irrigation is used in the forestry section utilizing a system of sprinklers and gutters. Warm water is applied to the ground throughout the year. For conifer and poplar trees the increase in production is ∿25% by weight per year.

Results from the undersoil heating experiments have shown yields three to four times normal for strawberry plants. Adaptation of priority industrial crops (soya and late varieties of corn) has also proven successful.

West Germany

Undersoil heating experiments in greenhouses and in open fields have been performed in West Germany since 1961 (10). Large-scale experiments began in 1974 and several experimental systems have been constructed using power plant reject heat. Results from these studies have indicated yield increases for corn of up to 57%, winter wheat up to 40%, and spring potatoes up to 60%. In addition, soy beans, which do not normally grow under natural conditions can be raised due to a lengthening in growth time as a result of the heated soil.

An experimental system at Auweiler is studying 13 different pipe arrangements on a 2.2-ha (5.5-acre) plot. An adjacent 0.8-ha (2-acre) plot is used as the control plot.

The experimental system at Neurath has an area of 1.5 ha (3.8 acre) heated and 1.5 ha (3.8 acre) unheated. Experiments are being carried out to study crop rotation and crop variety questions involving grazing land and field crops. These experimental stations use oil-fired hot water heaters to simulate power plant reject heat.

The experimental plots at the Gundremmingen Plant use reject heat from a nuclear power station. This experimental station consists of 2.6 ha (6.5 acre) of heated fields and 2.1 ha (5.3 acre) of unheated area.

In addition an experimental area at Neurath uses reject heat from a lignite-fired power station. Alongside the 7 ha (17.5 acre) of heated area is a 3.5 ha (8.8 acre) unheated control section.

These large-scale experiments will probably continue until the end of 1978 at which time sufficient results are expected to answer questions concerning technical and economic feasibility of the system. If the results are positive, large-scale implementation of undersoil heating systems is being considered to provide cooling capacity for power stations in West Germany.

USSR

Two types of systems are being developed in the Soviet Union (11). The first technique distributes a layer of water 30—40 mm (1.2—1.6 in.) over the greenhouse roof while the second uses dry heat exchangers located in a room adjacent to the greenhouse. The major difference between these designs and those used in the U.S. is that they have been developed not only to supply heat to the greenhouse in winter but also to provide adequate heat rejection capability for the power station in the summer.

The water-filled roof greenhouse concept is being investigated using a 0.6 ha (1.5 acre) greenhouse located near a 300 MW power station. Condenser outlet water is distributed over the roof by specail water lines. The insulating layer of water at 18 to 20°C (65 to 68°F) reduces the heat demand from 6 to 8 MW/ha (8.2 to 10.9×10^6 Btu/hr-acre) to 0.7 to 0.9 MW/ha (1.0 to 1.2×10^6 Btu/hr-acre).

During summer operation the condenser effluent is supplied to the central zone of the greenhouse roof where it is sprayed using special nozzles. Water cooling occurs both in the spray and in the layer of water running along the roof. Thus, in addition to providing adequate cooling for the condenser, the water acts as a solar filter. Short wave radiation, necessary for photosynthesis, is transmitted to the greenhouse while a significant portion of the long-wave thermal spectrum is absorbed by the water.

The air-heated greenhouse uses a finned-tube heat exchanger located in an annex structure. The condenser cooling water is supplied to the heat exchanger where it heats air supplied from the outside, the greenhouse, or a mixture of the two. The air flow is regulated by the greenhouse fans and a series of special louvers. During summer operation, ventilating air taken from the ambient passes through the greenhouse and then to the heat exchanger. During winter operation, greenhouse air is circulated between the heat exchanger annex and the greenhouse to maintain proper growing temperatures. The warmed air is distributed in the greenhouse by means of performated polyethelene tubes.

REFERENCES

1. G. C. Ashley, "Heating Greenhouses in Northern Climates with Power Plant Reject Heat," presented at 75th Anniversary Meeting of the American Society for Horticultural Science, Boston, Massachusetts, July 15–20, 1978.
2. M. Olszewski et al., *Waste Heat vs Conventional Systems for Greenhouse Environmental Control: An Economic Assessment,* ORNL/TM-5069 (March 1976).
3. M. Olszewski, "Economic Aspects of Using Power Plant Reject Heat for Greenhouse Heating," Proceedings of the International Symposium on Controlled-Environment Agriculture, April 7–8, 1978, Tucson, Arizona.
4. C. E. Madewell, "TVA's Agricultural and Aquacultural Projects on Waste Heat Use," Workshop Proceedings: Dual Energy Use Systems, EPRI Report EM 718-W, May 1978.
5. E. R. Burns et al., *Using Power Plant Discharge Water in Controlled Environment Greenhouses,* Progress Report II, TVA Circular Z-71 (December 1976).
6. B. L. Godfriaux, "Use of Low-Temperature Waste Heat in Aquaculture and Agriculture," Workshop Proceedings: Dual Energy Use Systems, EPRI Report EM 718-W, May 1978.
7. P. N. Walker, University of Illinois, Department of Agricultural Engineering, personal communication with M. Olszewski, Oak Ridge National Laboratory, October 1978.
8. D. R. DeWalle and A. M. Chapura, Jr., "Soil Warming for Utilization and Dissipation of Waste Heat in Pennsylvania," *Nuclear Technology* 38, pp. 83–89 (April 1978).

9. P. Balligard et al., "Experience Gained in France on Heat Recovery from Nuclear Plants for Agriculture and Pisciculture," *Nuclear Technology* 38, pp. 90–96 (April 1978).
10. H. Luckow and G. Reinken, "The Agrotherm Research Project," Proceedings of Waste Heat Management and Utilization Conference, Miami Beach, Florida, May 9–11, 1977.
11. R. Minasyan et al., "A Project of a Heating and Ventilating System for Experimental-Industrial Large Greenhouses Heated with Thermoelectric Power Plant and Nuclear Power Plant Waste Heat," in F. A. Heddleson, *Compilation of Translated Russian Reports Obtained in the Fall of 1977 as Part of the US-USSR Exchange on Thermal Power Plant Heat Rejection Systems,* ORNL-NSIC-152, (April 1978).

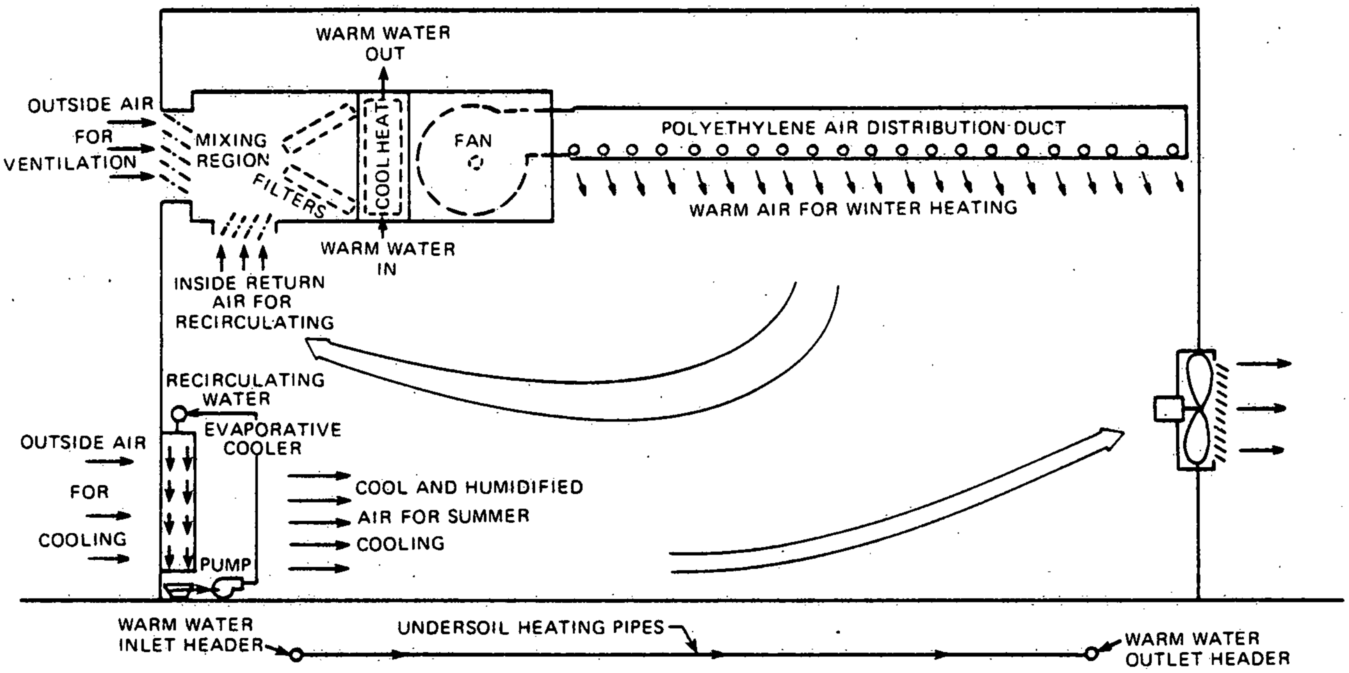

Fig. 1. Heating and cooling system schematic (from Ref. 1).

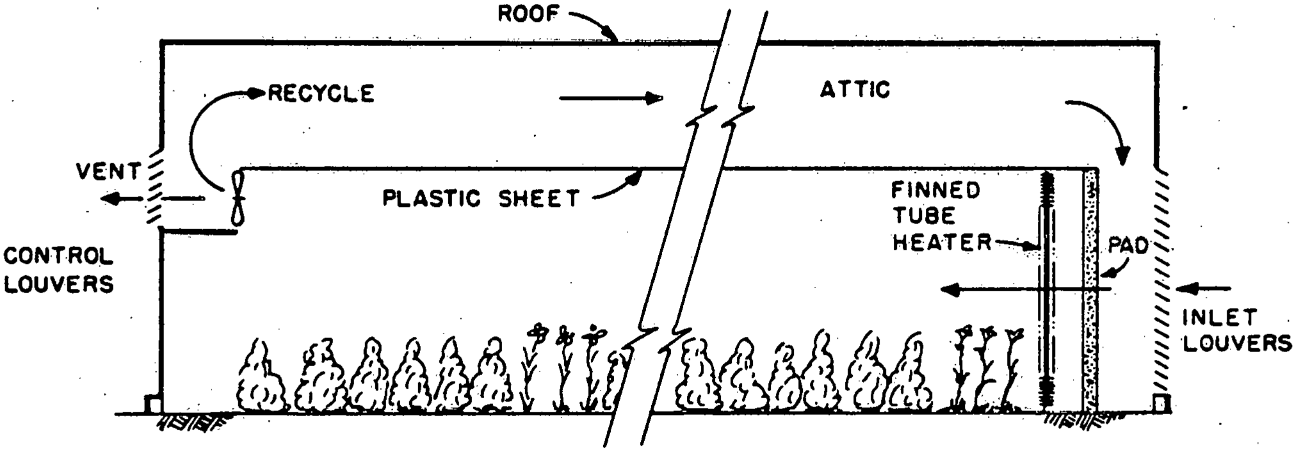

Fig. 2. Schematic of ORNL evaporative-pad greenhouse.

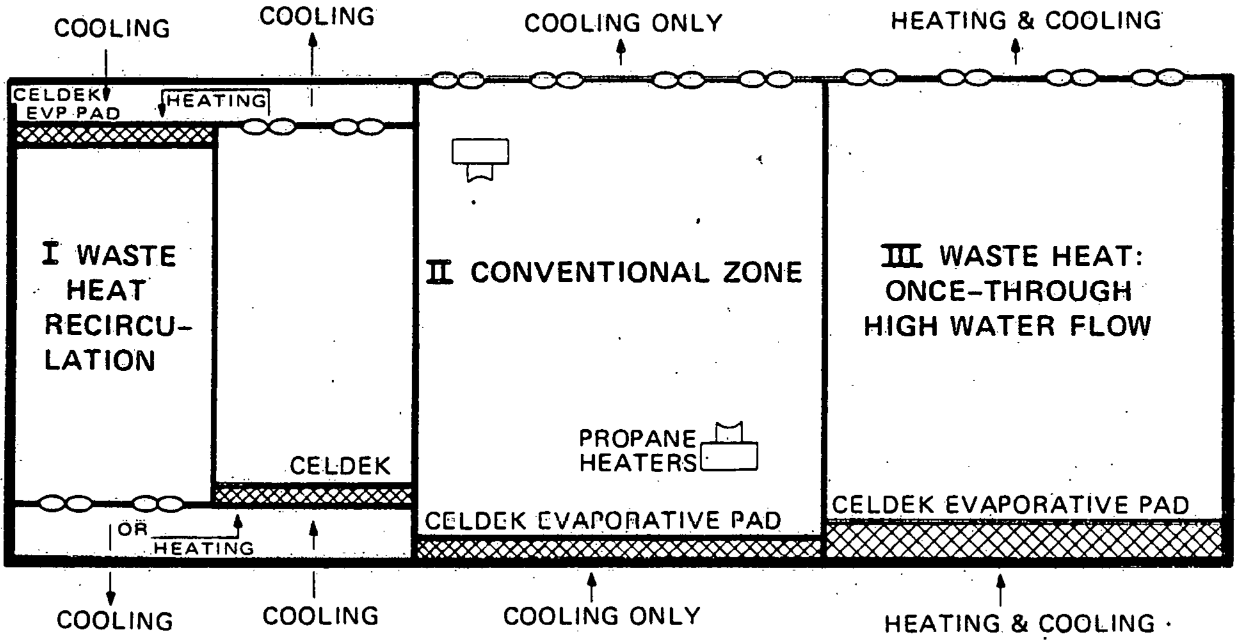

Fig. 3. Schematic drawing of the design for the waste heat greenhouse, Browns Ferry Nuclear Plant, Athens, Alabama (from Ref. 5).

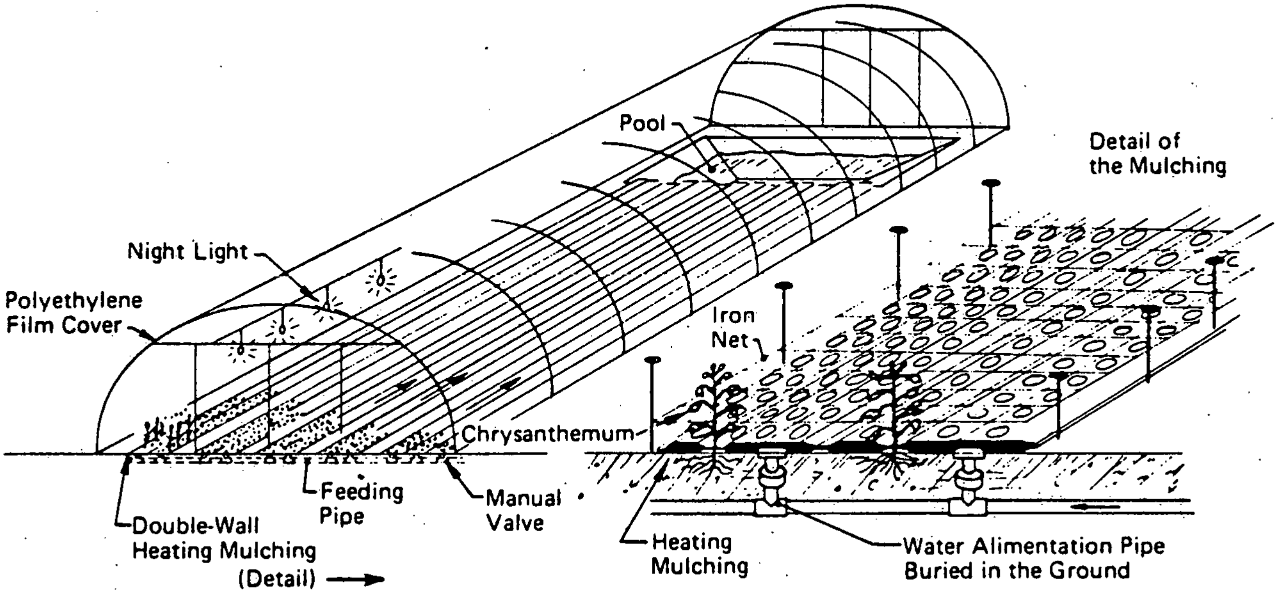

Fig. 4. Experimental greenhouse at the Grenoble Nuclear Center (from Ref. 9).