Wednesday Morning Session, August 25, 1976

The Wednesday morning session convened at 8:35 a.m. with Mr. Allen Cook serving as moderator.

WHAT'S NEW IN POLY STRUCTURES

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Research on the engineering aspects of greenhouses at Rutgers has been primarily oriented to the development of structures which are functional, low cost and energy conserving. In the last few years energy conservation has been the highest priority goal and research has begun on alternative energy sources.

The crop requirements and the weather patterns at the greenhosue location are primary factors to be considered. The structure and its control systems must work together to provide the crop requirements under the prevailing weather conditions at a reasonable cost.

AN ENERGY-SAVING NATURALLY-VENTILATED PLASTIC GREENHOUSE

Natural ventilation obtained by openings in the ridge and side walls provides for movement of air from the greenhouse when the inside temperature is warmer than outside. One major drawback of natural ventilation is that on very warm, still days the temperatures inside and outside the greenhouses may be the same. Mechanical ventilation with controlled air flow and inlets can eliminate many problems occurring with natural ventilation but requires great investment and high operating costs.

The energy crisis has increased mechanical ventilation costs as well as heating costs. Polyethylene covered greenhouses rely almost entirely upon mechanical ventilation (6) and openings in the roof increase covering time. Removing plastic from the sides is effective only in small houses during spring and fall. In large houses located in areas of very little natural convection, little ventilation will occur through the sides.

The plastic-covered greenhouse described here is designed to overcome these problems and would be recommended for areas without severe snowfall or extremely low temperatures or for seasonal use in other areas.

Figure 1 shows a cross section of the building. Its monitor-roof design allows for natural ventilation to occur from the top of the greenhouse while still preserving the features of rapid covering required for plastic film structures. The vertical area which serves as the ventilation opening is closed by four vertically stacked inflated plastic 12″ diameter tubes. These tubes nest together to close the 40″ opening. When ventilation is required, they are deflated one at a time in sequence on temperature rise.

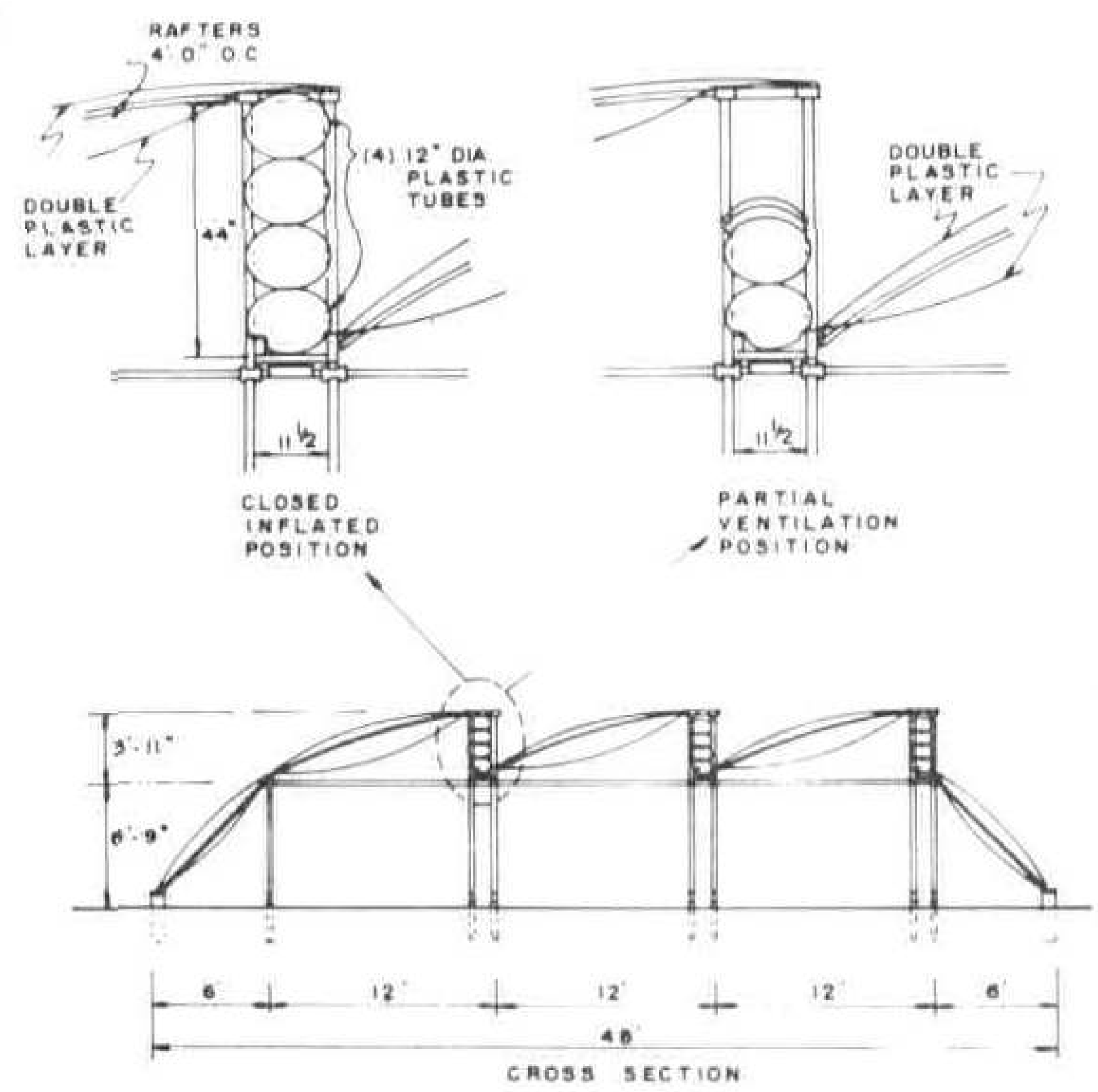

Figure 1. Monitor roof greenhouse.

The structure is designed in modules of 12 feet in both directions. Standard construction materials and standard widths of plastic film and tubing are used. It would normally be constructed 96 feet long and in widths needed by the grower. However, since fan ventilation is not needed, the length of the house can be predicated upon available lengths of plastic film or tubing, good crop management and materials handling practices, and not limitations of fan ventilation.

The entire greenhouse is covered with two layers of film which are separated by air pressure (8). Minimal wall structure is required and since there are no fans or louvers, the ends may be covered easily, quickly and inexpensively. It is structurally sound. Winds of 55 mph and gusts of up to 80 mph were recorded at a nearby weather station. The only damage occurred to the tubes which became twisted; damage by freezing could have taken place if freezing conditions had occurred during the storm. A recent modification in plastic tube selection should help eliminate this problem.

Normally the lowest of the four tubes is never deflated. This keeps the deflated plastic tubes in the gutter from obstructing the flow of water during rainstorms. As the thermostat calls for ventilation, the uppermost tube is deflated permitting natural ventilation to occur. If the temperature continues to increase, successive thermostats deflate the tubes sequentially, increasing the ventilation rate. As temperatures fall, the process is reversed, and the opening is closed in sequence. The tubes are inflated or deflated by three small fans, each fan controlled by a thermostat.

The present tubes are constructed of two layers of 12-mil vinyl film electronically sealed to form 4 individual tubes when inflated. With this technique, all tubes are connected to each other and twisting is eliminated. The tubes are heavy enough to collapse by gravity eliminating the need for weights. Another advantage is that the tubes are physically attached, greatly reducing infiltration.

Summer temperatures have ranged between 5° to 10°F warmer inside the monitor house than outside. These temperatures were recorded without shading or crops growing inside. It was observed that opening the house between the sill and the soil line improved ventilation. Figure 2 illustrates a system which could be used to control a ground level inlet for the last stage of ventilation. This is when the inlet would be most helpful.

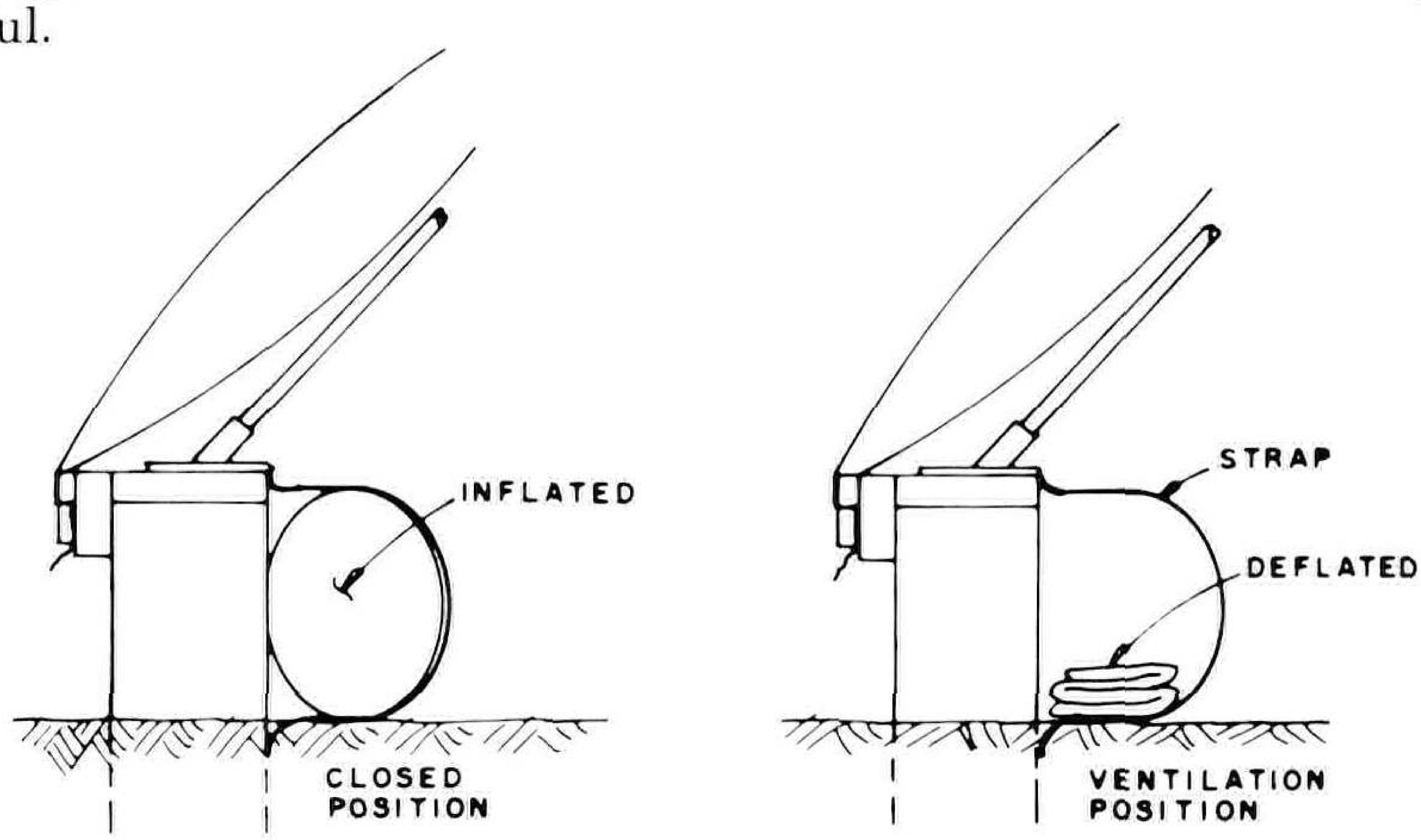

Figure 2. Ground level inlet.

No heating system has been installed in this greenhouse but probably any warm air system could be utilized. The nature of the structure causes shading from November through January. The greenhouse should be oriented with the gutter section running north-south for year-around operation so the shadow cast by the gutter and vertically stacked tubes would move from left of the gutter to the right of the gutter during the day. Locating this house in southern latitudes would alleviate this design problem.

The energy saving monitor roof plastic-covered greenhouse performed well structurally and environmentally. Although control and precision of mechanical ventilation is relinquished (10), some applications with less than critical requirements may prove successful using these techniques. Initial investment will be less and operating costs greatly reduced.

A GREENHOUSE VENT CONTROLLER

Most polyethylene greenhouses are ventilated through exhaust fans mounted in one end wall with matching intake shutters at the opposite end. It is good practice to increase ventilation rates in stages with rising temperature to a maximum of about one air change per minute. One difficulty with this system is that at lower ventilation rates it is difficult to obtain satisfactory mixing of the cool incoming air with the greenhouse environment. The air enters through the inlet shutters at a low velocity and settles to the floor causing a localized cold spot. At full ventilation the inlet velocity is high enough to induce turbulent mixing and this problem does not occur.

A ventilation controller has been developed which will open a window in stages to match the amount of air being drawn in by the fans in up to four separate steps (10). At each stage the window opening is such that the entering air velocity is between 700 and 1000 fpm which induces air mixing. The construction and operation of the controller is described in detail by Roberts and Cheney (10). Variations of this unit have been installed for several years in commercial greenhouse situations and have been found to perform satisfactorily. Excellent control of ventilation is obtained at a relatively modest cost.

A CABLE SUPPORT POLYETHYLENE GREENHOUSE

To reduce the structural components in gutter-connected double-covered greenhouses, a cable design was built and tested (5,9). A cross section of the experimental house is shown in Figure 3. Available widths of film tubing, allowable stress in the film, design conditions and lumber standards indicate an optimum module or pole spacing of 12 feet in each direction.

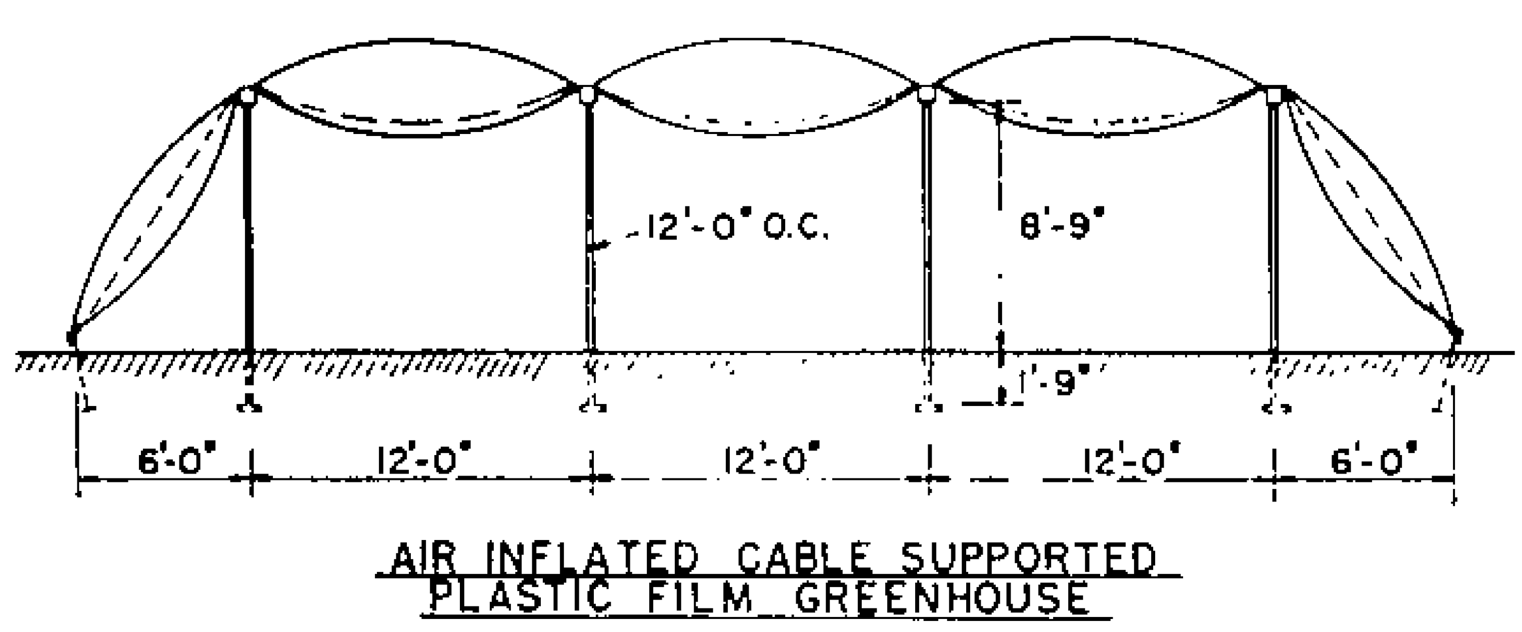

Figure 3. Cross section of 48′ × 48′ experimental greenhouse.

Various cross supports joining the gutters on 6 foot centers have been tried. These include nominal 5/16 inch nylon covered cable, nominal 3/4 inch pipe, a special pipe/cable combination truss, 2 × 6 lumber and combinations of these components. The building in all of these designs has functioned well in wind, sustaining winds of 60 mph with no damage and very little deflection. One important structural observation of this type of structure is that classic methods of calculating wind loads are not appropriate. We believe this is because air-inflated structures are able to deflect under high winds and thereby relieve themselves of the greatest wind load effects.

Difficulties with this structure have been encountered in heavy snows as there is no means to support snow. If this structure is to be used under conditions of heavy snow load it will be necessary to make provisions to melt the snow off before excessive accumulation. The apparent advantages of this structure are:

1. Few structural components to cause shade within the greenhouse.
2. Simple erection techniques, modular construction and air-inflated design all reduce building costs.
3. Structural components of the greenhouse, posts and cables can provide support to vegetable crops which require it.
4. The double plastic cover can be easily and rapidly applied or removed without disturbing the crop.

ALTERNATIVE GREENHOUSE HEATING METHODS

Several years ago a number of ideas were proposed for heating greenhouses, assuming a large supply of warm water was available such as from the waste heat of an industrial operation (4). It was proposed that large heat transfer surfaces which could be unobtrusively incorporated in the structure at low cost were a necessary prerequisite to effective utilization of waste heat. One idea consisted of essentially floating a greenhouse on a pond of warm water if only a low cost floor could be found that would enable us to "walk on the water".

One practical solution to this problem has been developed using a porous concrete floor made with aggregate, cement and water but no sand. By adding an impermeable plastic layer and a gravel mass under the porous concrete a floor capable of storing warm water with a dry surface is created. A substantial amount of heat can be transferred from the warm floor to the greenhouse, but not enough to heat a polyethylene greenhouse in New Jersey in the coldest weather.

Double film polyethylene greenhouses require 30% less energy to heat than single glazed greenhouses of similar size. Additional heat savings can be achieved by using horizontal and vertical curtains inside the greenhouse to reduce convection and radiation losses. Work at Rutgers in a glass greenhouse indicated a savings of over 50% when a black plastic curtain system, normally used for day length control, was used as a blanketing system. Simpkins et al (11) reported on various materials used for heat loss reduction in an environmental chamber and a prototype double-filmed greenhouse. Horizontal and vertical insulation curtains can significantly reduce energy losses in double-filmed greenhouses. Tests in a small greenhouse using a black polyethylene curtain indicate heat savings of 30% with an inside to outside temperature difference of 40°F and a 65% savings with a 10°F temperature difference. Reflective materials installed with the reflective side facing outward further increase the potential for savings.

Mechanical systems of all types are used to position or close the curtains during the night. The curtains, of course, must be stored in the daytime to minimize shading of the growing crops. Roberts (7) described a system which hangs the curtain from cables.

With the porous floor filled with warm water and the insulation curtain pulled, most of the heat is provided but on the coldest night more heat exchange capacity between the warm floor and the greenhouse air is required. A heat exchanger consisting of a sheet of plastic draped over a perforated pipe was developed. The pipe is attached to the insulation curtain-pulling cables so that it is elevated at night and drops to the floor in the daytime. At night, when extra heat is needed, warm water is pumped from storage under the floor through the perforated pipe. As it flows down in a sheet between the two layers of plastic, heat is given off to the greenhouse. At the bottom it runs through the porous concrete back to storage. The entire system is shown in cross section in Figure 4.

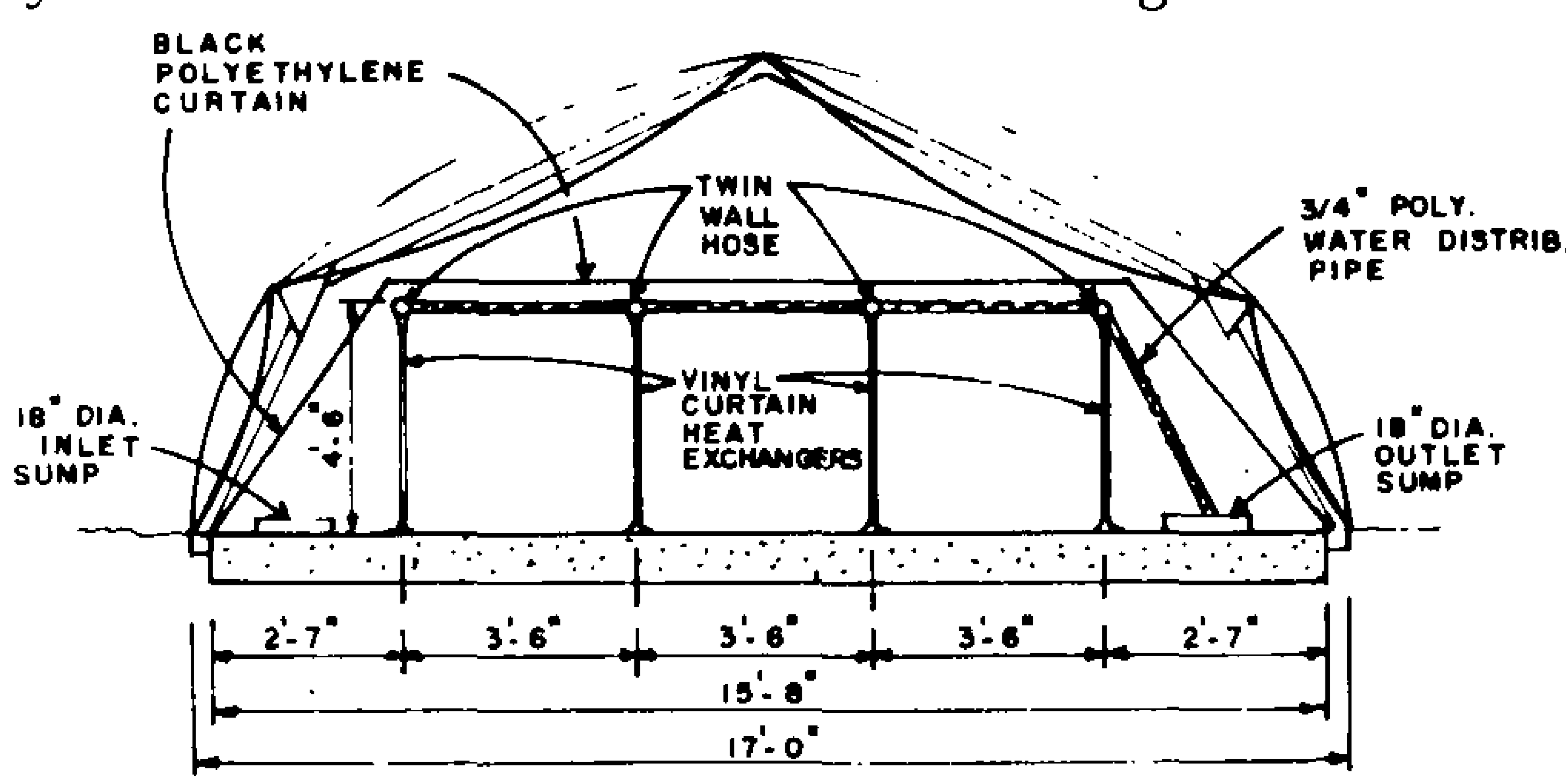

Figure 4. Double-layer air-inflated 17′ × 24′ polyethylene greenhouse with porous concrete floor, black polyethylene curtain and vinyl curtain heat exchangers.

One attractive source of warm water for the above system could be solar collectors. A simple solar collector is almost as efficient as more expensive units designed to deliver hot water (3). One style of collector that has been developed is shown in cross section in Figure 5.

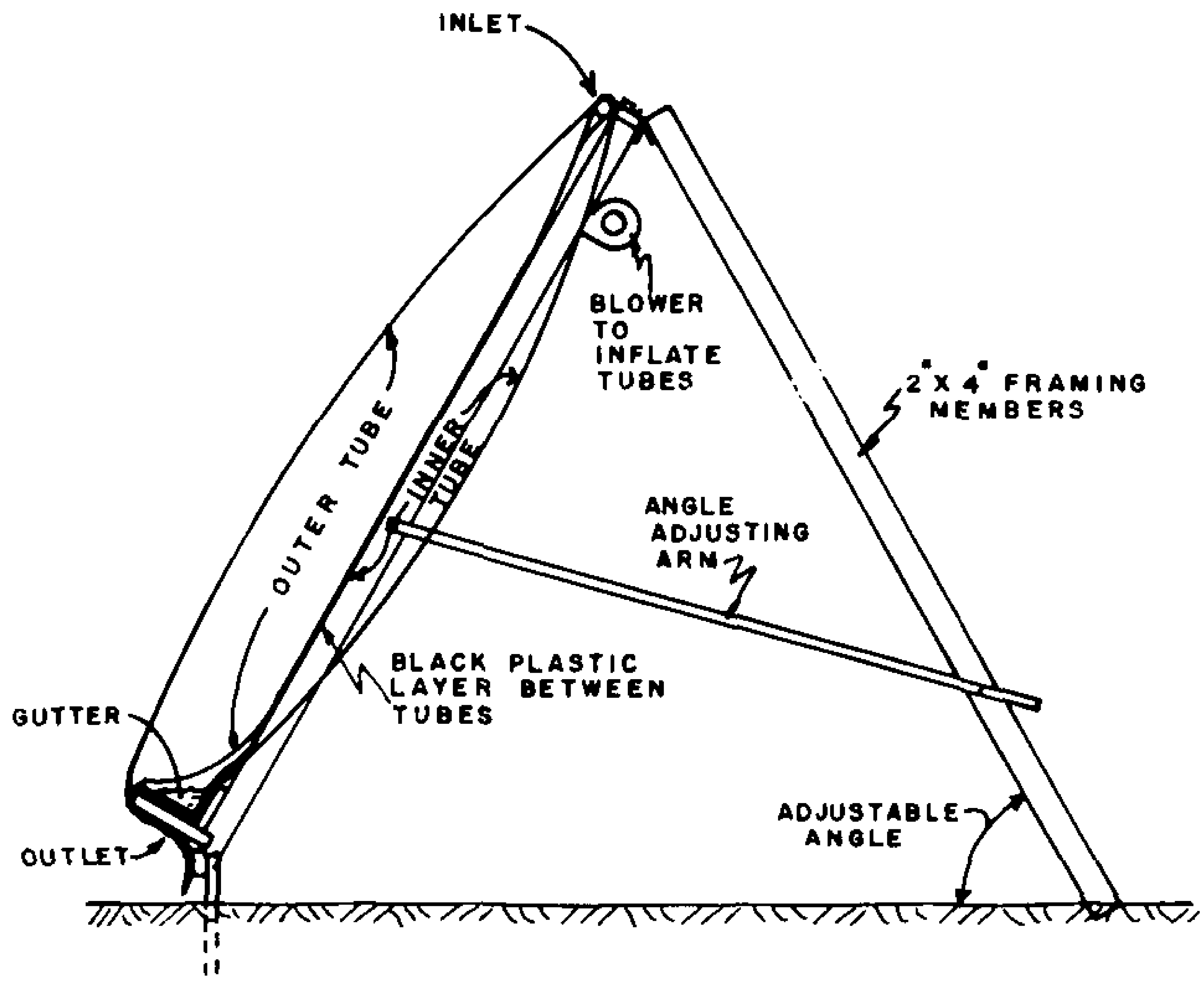

Figure 5. Cross section of sloped solar collector.

This collector is designed with a simple wooden frame that can have its angle from the horizontal adjusted. A single layer of black polyethylene film is sandwiched between two double layers of clear UV stabilized polyethylene. The two spaces between the clear pairs are inflated to provide structural stability and some insulation. Water is pumped through holes in a header pipe along the length of the unit at the top. The water trickles over the black plastic in sheet flow picking up heat from the sun and is collected in a gutter at the bottom from which it flows back to storage under the porous concrete by gravity. The sheeting action of the water at lower flow rates can be improved by adding detergent to the water or a scrim such as polypropylene shade netting over the black plastic layer.

Another idea developed for use where a completely paved floor is not wanted involves a heat exchanger/storage system. The heat exchanger should be part of the storage structure to minimize costs and equipment. The entire system must fit under the greenhouse benches and not interfere with normal operations. Most important, the materials must be low in cost. Long life and freedom from any maintenance are also desirable.

The basic components of this system are a plastic bag, which runs underneath the bench for its entire length, and an insulated arch over this bag to provide an air plenum. A fan with thermostat control blows greenhouse air to be heated into the space between the arch and the water bag where it picks up heat, then leaves under a slot the length of the bottom of the arch. This system is shown in the drawing in Figure 6. The vertical posts would provide support for the benchtop. This unit has a large capacity for both heat storage and heat transfer when the fan is running. With the fan off there is relatively little heat transfer from the stored warm water.

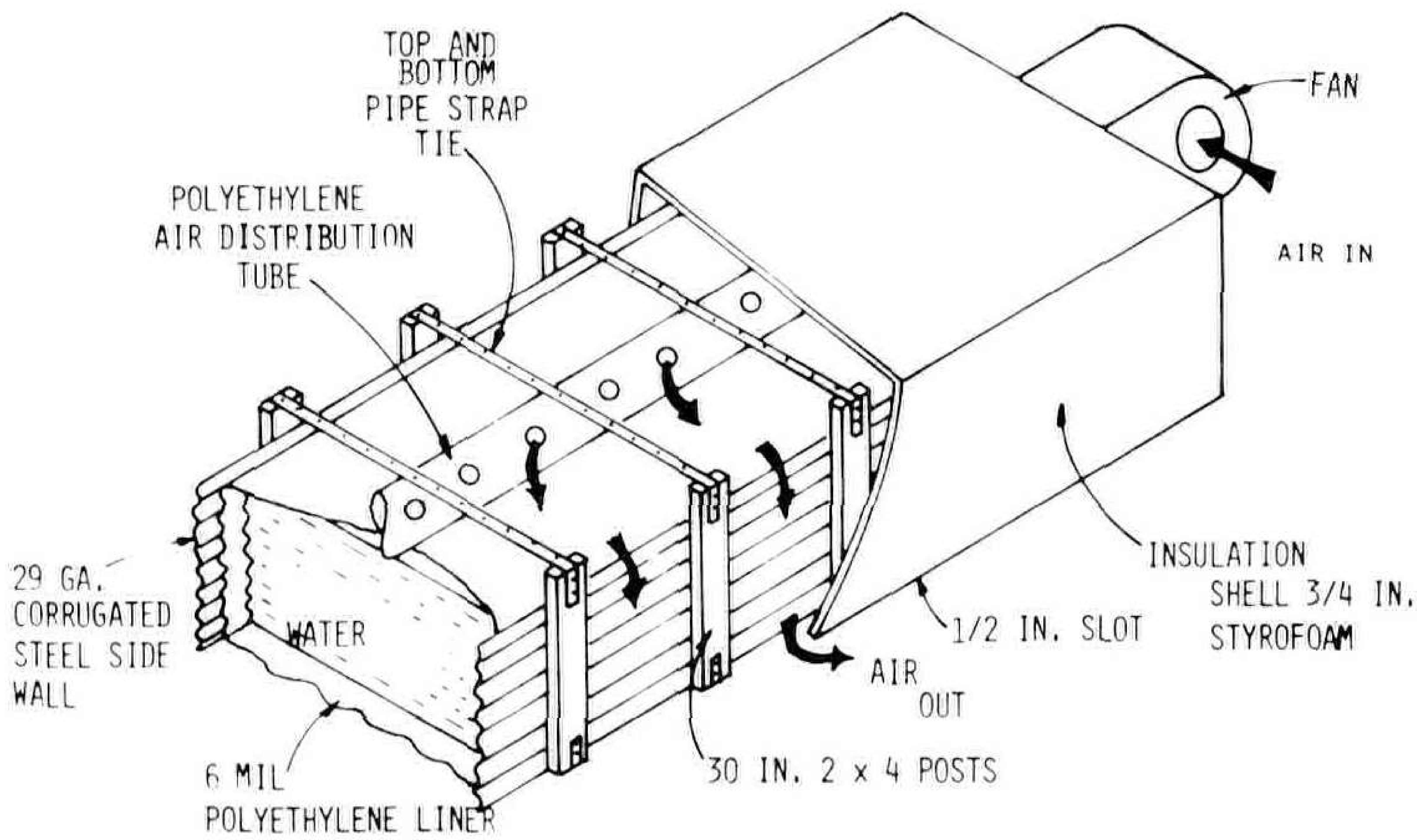

Figure 6. Cutaway view of underbench water storage/heat exchanger.

SUMMARY

Reduction of greenhouse heating and ventilating costs will continue to be important problems and imaginative solutions are needed. The most practical steps are in the area of heat conservation. Movable insulation curtains show great promise for heat conservation for any heat source.

Solar systems for greenhouse heating is dependent upon the development of equipment with much lower initial costs than the units now available and the use of energy conservation measures. The units discussed in this paper are by no means the only hope for effective, low-cost units, but do show promise. It is our feeling that if efficient heat exchangers that are capable of heating greenhouses with low-quality heat (warm water) can be developed, substantial reductions in heating costs will be possible. Also, it is important to get complete systems into operating greenhouses to begin to collect the experience that will let the "art" of solar design begin to develop.

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