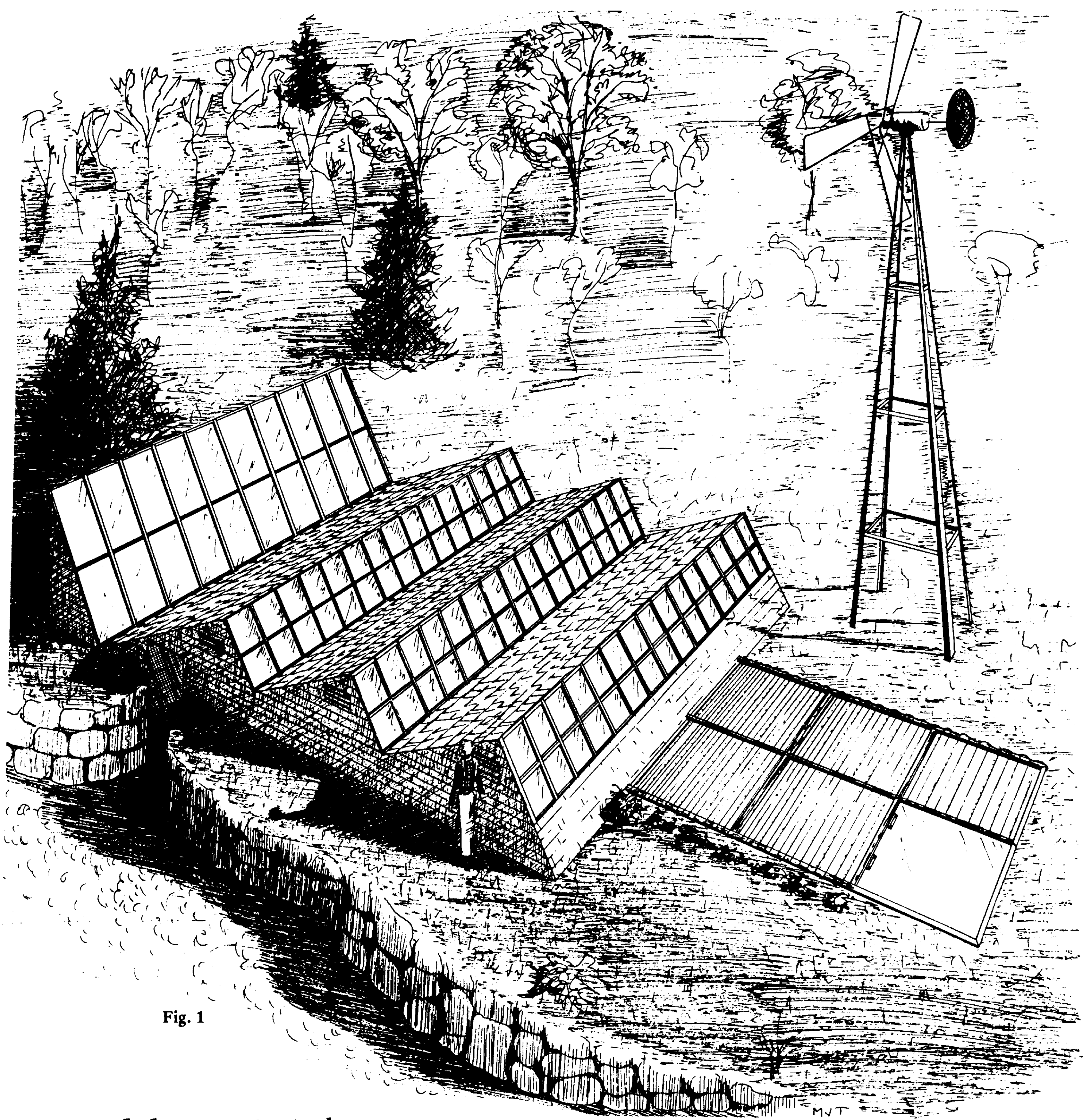

Fig. 1

New Alchemy's Ark:

*A Proposed Solar Heated and Wind Powered Greenhouse and Aquaculture Complex Adapted to Northern Climates**

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*Support for developing and researching the Ark is being sought. Contributions to this research will be very much appreciated.

INTRODUCTION

The Ark is intended to provide an alternative to a significant energy consuming component of food production in America. Greenhouses, which provide substantial quantities of vegetable and flower crops, especially during the colder seasons, utilize large amounts of fossil fuels for heating and climate regulation. To help alleviate this situation we propose to develop and evaluate a low-energy, highly productive food growing complex heated by the sun and powered by the wind. The complex will be independent of fossil fuel heating or outside electricity sources.

If food demands are to be met in the coming years, indigenous, ecologically-derived and low energy strategies for raising food are going to have to be developed. Ecologist H. T. Odum has recently suggested that energy shortages in agriculture could result in severe food shortages in the not-too-distant future (1). He bases his argument on the fact that modern agriculture is extremely energy intensive, requiring up to 20 calories of energy to produce one calorie of food on an American table. Other food producing systems borrow less heavily on the planet's finite energy sources. For example, biologically-oriented Chinese farmers in Malaysia, with few outside energy inputs, can produce annually 66,000 pounds of pork and 7,000 pounds of fish as well as vegetable crops on small 4.4 hectare farms (2), and the Tsembaga peoples in New Guinea are able to support population densities equivalent to our own, with an ecologically sound agriculture which generates 20 calories of food for 1 calorie of energy input (3). The caloric disparity between our modern, high energy agriculture and the biologically-based ones just mentioned can be as great as 40:1 in favor of the latter. Our productivity is sustained by massive inputs of energy into each of the links in the agricultural sector, and it seems likely that as fuels become scarcer, biologically-derived systems powered by the sun and the wind will become increasingly important, if not essential (4).

Each facet of modern agriculture is highly dependent upon fossil fuels as its energy base. Nitrogen fertilizers require some 15,000 TKH/ton in their manufacture and the phosphate fertilizer industry consumes extremely large amounts of energy, only being surpassed on a per unit output basis by the manufacture of aluminum. Also most modern farms are dependent upon herbicides, fungicides, pesticides and machinery, all derived from energy-intensive industries (5).

The greenhouse culture of foods and flowers is in an especially precarious position. Besides the energy inputs noted previously, there are the additional inputs for the sterilization of soils and artificial heating for up to 6-7 months of the year. The heating of these structures is a major component of their operating costs and the scarcity of fuels is of great concern to farmers using greenhouses. The impending shortage of fuels was a catalyst in The New Alchemy Institute beginning its research into solar-heated growing structures in 1970.

The present world-wide acreage of greenhouses is quite extensive. United States (5,202 acres), Britain (4,267 acres), Holland (18,242 acres), Italy (12,700 acres) and Japan (26,000 acres) are significant greenhouse producers of foods. The energy required to sustain these structures is not known, but it is believed to be extensive (6). Expansion of greenhouse production of foods is held in check by fuel scarcities and by competition from southerly regions connected to northern markets by highly developed transportation systems. As transportation costs increase, glasshouse food culture systems will come into their own, if and only if, alternative heat sources can be found for them.

We propose to construct and research a greenhouse - pond complex for the growing of vegetables and for the intensive culturing of fishes which will be heated by the sun and powered by electricity from the wind (Figure 1). The prototype will require no outside sources of heat, or chemical fertilizers, fungicides, pesticides or soil sterilization. It will be a self-regulating food ecosystem requiring the sun, waste materials and labor to sustain its productivity. The heat storage-climate regulation component of the system will be a 13,500 gallon aquaculture pond. Solar heat will be trapped directly by the covered pond and by pumping the pond water through a 300 square foot solar heater. The adjacent greenhouse will be situated below the frost line and will derive its heat from direct sunlight and from the warmed pond water passing through pipes in the interior of the structure. Many of the components have already been

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1. H. T. Odum, 1973. Energy Ecology and Economics. Paper invited by Royal Swedish Academy of Science, 26 pp.
2. K. F. Vass, 1963. Fish Culture in Freshwater and Brackish Ponds. Chapter In: J. D. Ovington, ed., *The Better Use of the World's Fauna for Food.* Symposium of the Institute of Biology, No. 11, 175 pp.
3. R. Rappaport, 1971. The Flow of Energy in an Agricultural Society. Scientific American, Vol. 224(3), 116-134.
4. H. T. Odum, 1971. Environment Power and Society. John Wiley, 336 pp.
   J. H. Todd, 1971. A Modest Proposal. Bulletin of the New Alchemy Institute No. 2, 26 pp.
   J. H. Todd, 1973. Restoration and Reconstruction in Costa Rica. The Journal of the New Alchemists (1), 32-47.
   J. H. Todd, 1974. The Dilemma Beyond Tomorrow. The Journal of the New Alchemists (2).
5. D. Pimentel, L. E. Hurd, A. C. Belloti, M. J. Forster, I. N. Oka, O. D. Sholes and R. J. Whitman, 1973. Food Production and the Energy Crisis. Science, Vol. 182(4111), 443-449.
6. Dana G. Dalrymple, 1973. Controlled Environment Agriculture: A Global Review of Greenhouse Food Production. Economic Research Service, U. S. Department of Agriculture, Foreign Agricultural Economic Report No. 89. 150 pp.

developed at New Alchemy (7). We intend to combine these various components into an integrated food production system for the year-round raising of a diversity of foods. Solar-heated greenhouse and aquaculture greenhouse complexes like the Ark, if proven successful and adapted widely, could help alleviate possible future meat and vegetable shortages in the more northerly parts of the country, particularly during the winter months or during crisis periods when transportation is disrupted.

ORIGINS OF THE ARK CONCEPT

Structures that enhance the growth of cultivated plants by extending the length of the growing season have been in use for several centuries, for practical purposes beginning with the availability of glass windows. At the beginning of the 18th century, cold frames and buildings with large south-facing windows were in general use in England. These were usually unheated due to lack of sub-zero temperatures and generally mild climate. The technology of growing structures was brought from Europe to the eastern U. S. around the mid-1800's, where substantially lower winter temperatures resulted in two lines of further development, the heated glass greenhouse and the unheated pit-greenhouse. With the discovery and availability of heating fuel, the former structure rapidly gained favor and is recognized as today's conventional greenhouse. The unheated pit-greenhouse, though evolved for northern climate winters, has been generally forgotten (8).

Pit-greenhouses are unheated structures having a glass face towards the south, an insulated face towards the north, and whose growing area is below the level of the soil. These conditions result in capture of the sun's heat to keep the growing area above freezing throughout the winter. The first pit-greenhouse in the U. S. was built about 1850 in Waltham, Massachusetts. Since then, pit-greenhouses have been used sporadically in the eastern U. S. as far north as Vermont, where it is possible to raise long-season vegetables in the summer and salad vegetables all winter with no supplemental heat (9).

Experience with pit-greenhouses indicates that small amounts of auxiliary heat, such as the heat loss through a basement wall into the pit, are sufficient to improve the operation and stability of the system (10). Several solar-heated house designs incorporate such technology that can be adapted to this purpose, specifically the Thomason and MIT solar house designs (11). In these systems, the sun's heat is captured during the sunny part of the day by water flowing through a collector and the heat is stored as hot water for later use. This technology is directly applicable to the greenhouse/aquaculture

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7. W. O. McLarney, ed. 1973. The Backyard Fish Farm Working Manual for 1973. Rodale Press, Emmaus, Pennsylvania 18049. 54 pp.
   J. H. Todd and W. O. McLarney, 1972. The Backyard Fish Farm. Organic Gardening and Farming Magazine, Jan. 72.
   W. O. McLarney and J. H. Todd, 1974. Walton Two: A Compleat Guide to Backyard Fish Farming. Journal of the New Alchemists (2).
8. K. S. Taylor and E. W. Gregg, 1969. Winter Flowers in Greenhouses and Sun-Heated Pit. Chapter 1, *Origin and Development of the Greenhouse*, 3-16. Charles Scribner's Sons, New York, 281 pp.
9. K. Kern, 1972. The Owner-Built Homestead. Chapter 9, *The Pit Greenhouse.* Sierra Route, Oakhurst, California 93644, 90 pp.
10. Ibid. Taylor, 1969. Chapter 2, *The Insulated Pit*, 17-33.
11. B. Anderson, 1973. Solar Energy and Shelter Design. Senior Thesis, Department of Architecture, M. I. T.

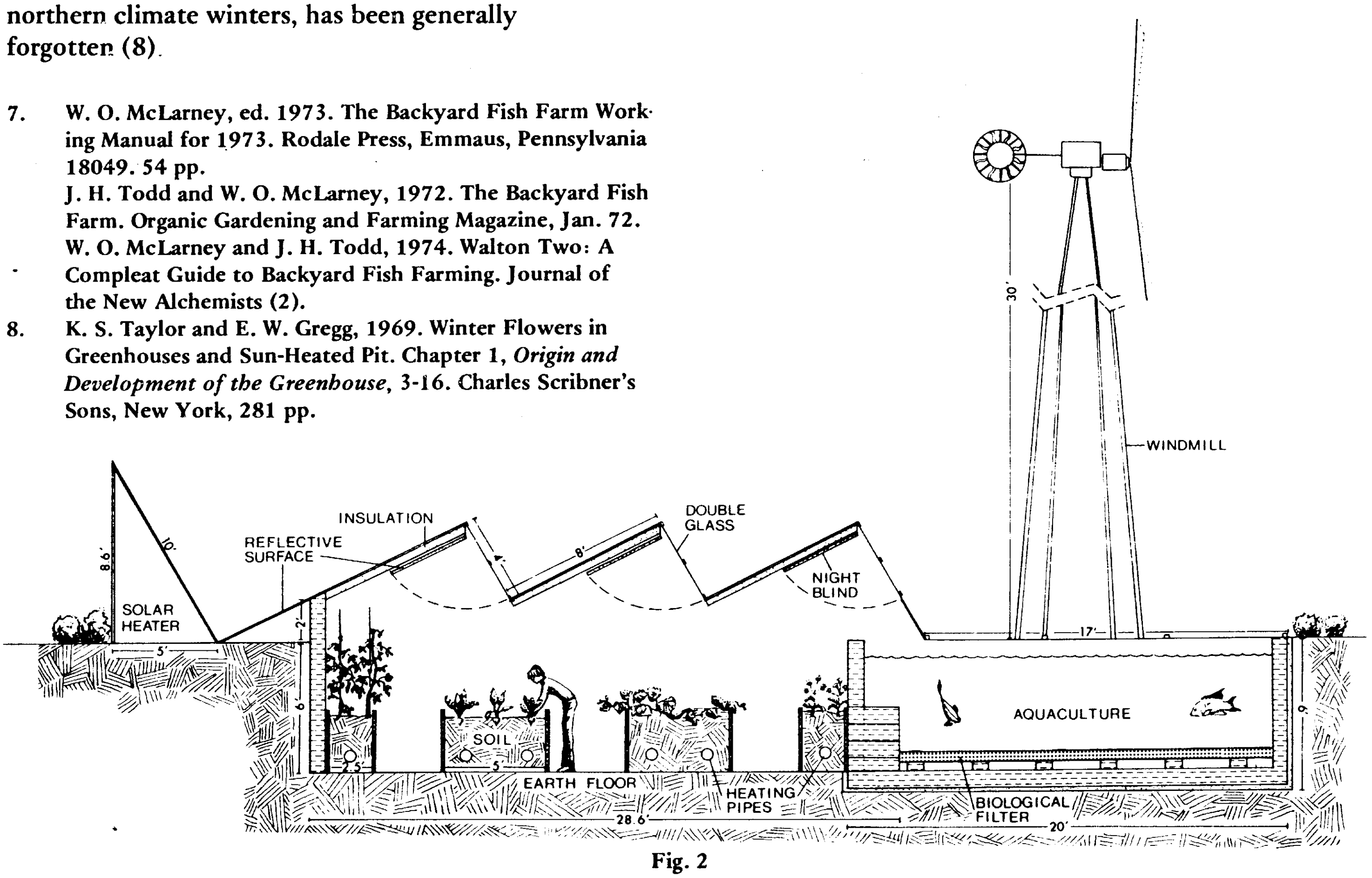
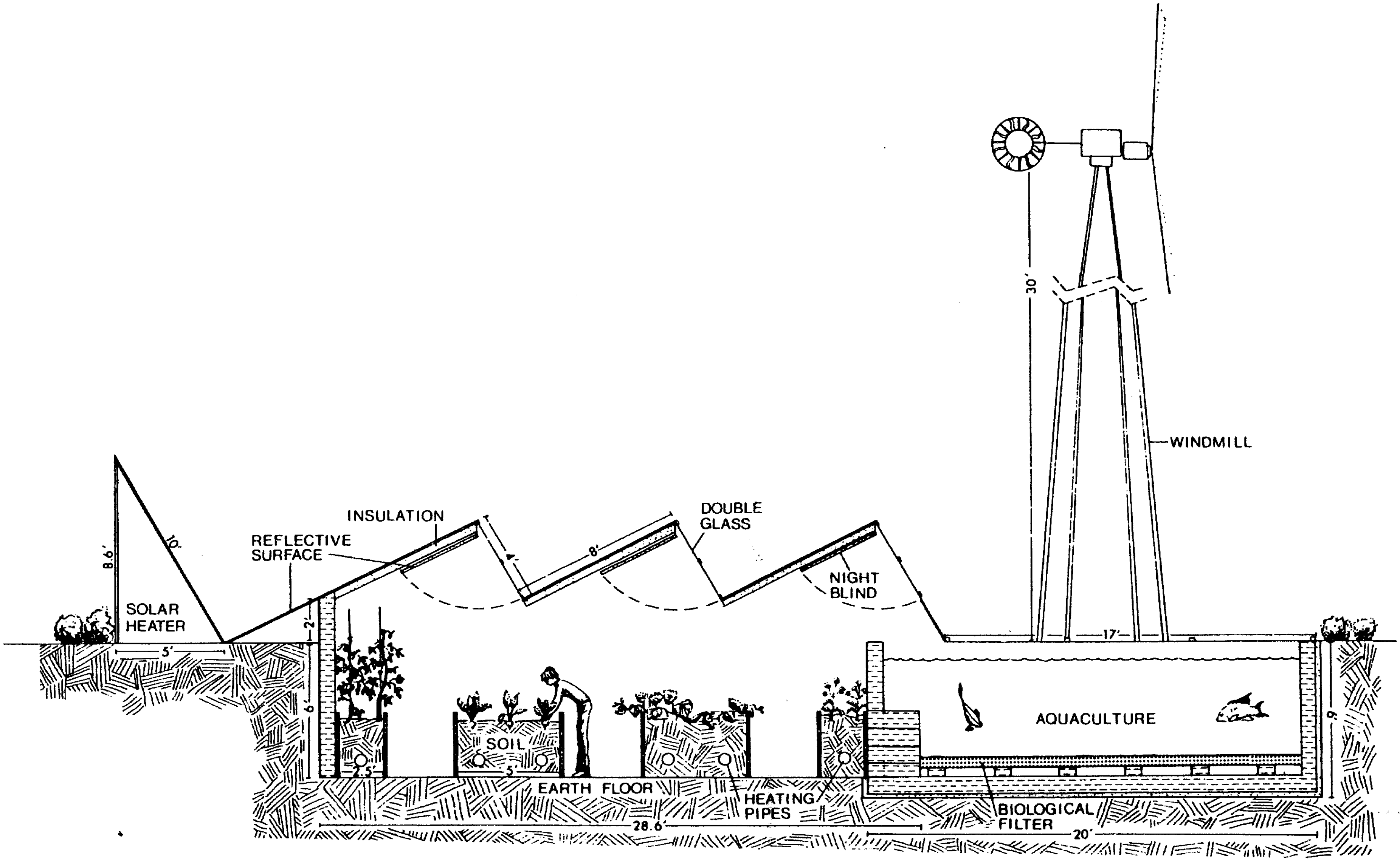


Fig. 2



WINDMILL
30'
INSULATION
REFLECTIVE SURFACE
DOUBLE GLASS
8'
4'
10'
8.6'
NIGHT BLIND
SOLAR HEATER
5'
2'
6'
17'
SOIL
2.5'
5
EARTH FLOOR
HEATING PIPES
AQUACULTURE
BIOLOGICAL FILTER
28.6'
20'
6'

complex, where a large body of water is available for heat storage. Water from the fish pond can be used to absorb direct solar energy and excess heat from the greenhouse. This heat can be released into the greenhouse at night to maintain growing temperatures.

New Alchemy Institute has investigated solar heating of growing structures and the moderating effects of large ponds of water in several experimental structures. In 1971 a transparent dome-greenhouse was built and used to grow salad vegetables during the winter using auxiliary heat from a wood stove. It was used again in the winter of 1972, this time heated only by daytime sunlight and heat radiating from the earth; hardy vegetables could be maintained throughout the winter. In 1972 two dome-greenhouses were built which contained aquaculture ponds; these ponds were maintained at approximately 80 degrees F. from May 15 to September 15 solely by passive solar heating and selective venting. The ability of the ponds to moderate the internal climate of the greenhouse was dramatically evident in late fall, when outside frosts and cold snaps had little effect on the air temperature inside the greenhouse. Thus combining aquaculture with growing plants is an ideal way for meeting the temperature stability required in a greenhouse structure.

DESIGN AND OPERATION OF THE ARK

Our experiences which led up to the Ark concept are chronicled in "Walton Two, A Compleat Guide to Backyard Fish Farming" in the aquaculture section of this Journal. Particularly pertinent is the description of the Miniature Ark, which incorporates into its design many of the concepts we wish to explore in the larger system.

PHYSICAL SYSTEMS

The proposed solar-heated greenhouse/aquaculture complex is designed to demonstrate a facility capable of producing meat and vegetables year round, employing solar and wind energy as its power base. Its major components are illustrated in Figures 1, 2, 3 and 4 and are described below; general dimensions of the structure are given in Figure 5.

i - A pit-greenhouse growing structure comparable in size to a conventional small commercial greenhouse. Partially sunken, it offers an attractive visual profile suitable for widespread aesthetic and landscaping acceptance; functionally, it utilizes the earth's heating and insulation qualities to aid in climate control.

ii - An insulated 13,500 gallon aquaculture pond with transparent cover, capable of providing fresh high-quality meat protein on a year-round basis with warm and cool season fish crops. The pond utilizes a sub-sand biological filter for continuous water purification and nutrient cycling.

iii - A solar heat collector to heat the aquaculture pond during sunny periods. The solar water heater will be of the Thomason design (12) and its pump will be powered by electricity from a wind generator. The solar collector will be controlled automatically and will act secondarily as a wind screen for the other structures.

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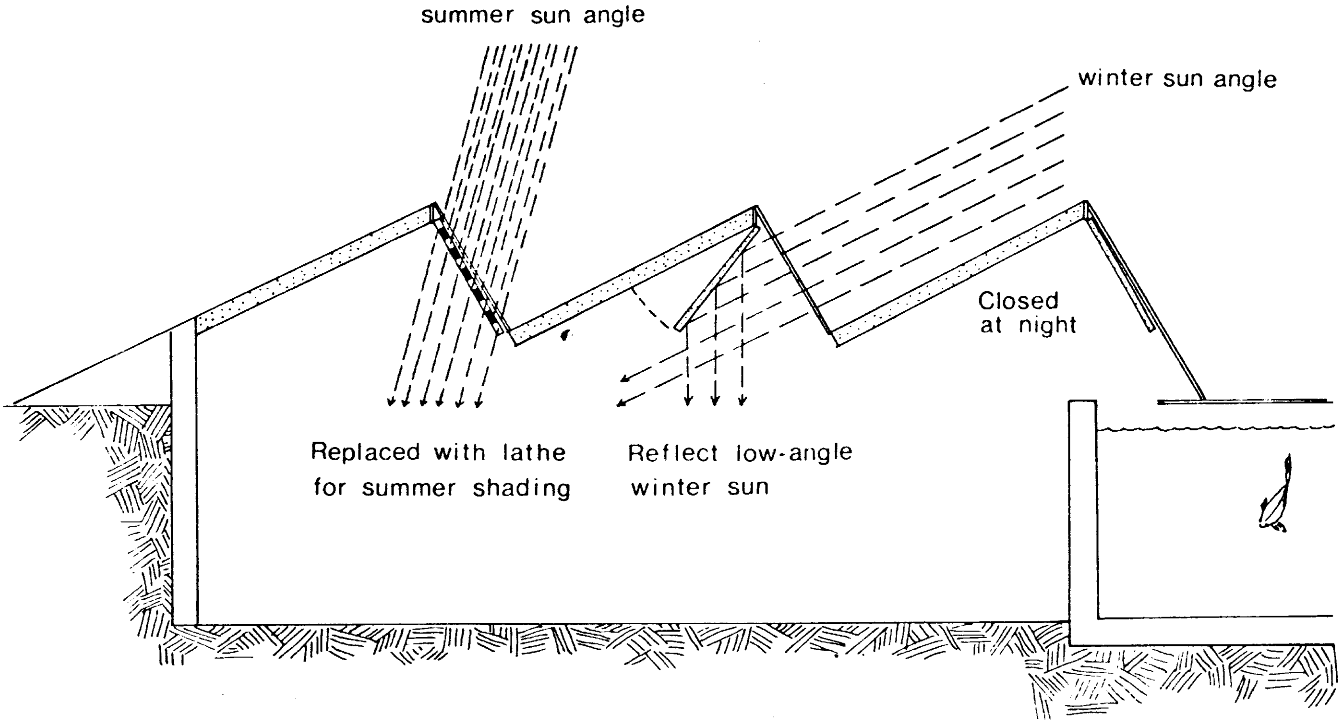
12. J. D. Thomason and J. L. Thomason, 1972. Solar Home Plans. Edmund Scientific Company.



REFLECTIVE PANELS

Fig. 3

iv. - A wind generator to produce electricity for water pumping circulation and lighting. At the present, commercial windmills do not produce enough electricity in average wind areas of the northeastern United States to meet our needs, and their costs are exorbitant, being far beyond the utilities on a kilowatt hour basis. Our plan, though, is to create an electricity system for the Ark which is independent of fossil fuels, nuclear power plants and public utilities. Towards this end, we have in the early developmental stages a 10 kw wind-driven power plant designed to produce substantial amounts of electricity at average wind speeds (13). If successful, our electricity costs within a few years may be competitive with the utilities.

It is possible that the Ark may require two windmills to function optimally. If so, an inexpensive water pumping mill, similar to the one used to power the Miniature Ark, will circulate water through the system during windy periods, and the new electricity producing mill with battery storage during spells without wind.

v. - Design and operating features related to solar energy collection, conservation and distribution are detailed in Figures 1, 2, 3 and 4. Reflective surfaces (as well as the roof angles) of the greenhouse act to direct a maximum amount of light into the greenhouse and onto the solar collector. Reflective surfaces within the greenhouse and on the north wall result in a 25-35% increase of light on the plant canopy (14). Reflective night cover panels can be positioned to direct daytime light entering the greenhouse onto various plant areas, and the same panels act as nocturnal heat retainers at night, reducing heat radiation from the structure by 15-20% (15). The aquaculture pond is insulated from the ground and covered with a double membrane skin, and all glass surfaces of the greenhouse and solar collector are double glazed. Finally, all glass surfaces will be treated with a material to prevent droplet condensation and thus

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13. Merrill Hall, 1974. A Wind Driven Power Plant for Household Use. A Research Proposal from The New Alchemy Institute. 18 pp. Not for distribution.

14. J. Maghsood, R. Alward and T. A. Lawland, 1973. A Study of Solar Energy Parameters in Plastic-covered Greenhouses. Presented at the International Solar Energy Society, U. S. Section Annual Meeting, Cleveland, Ohio, October 3-4, 1973.

15. Ibid. Maghsood *et. al.*

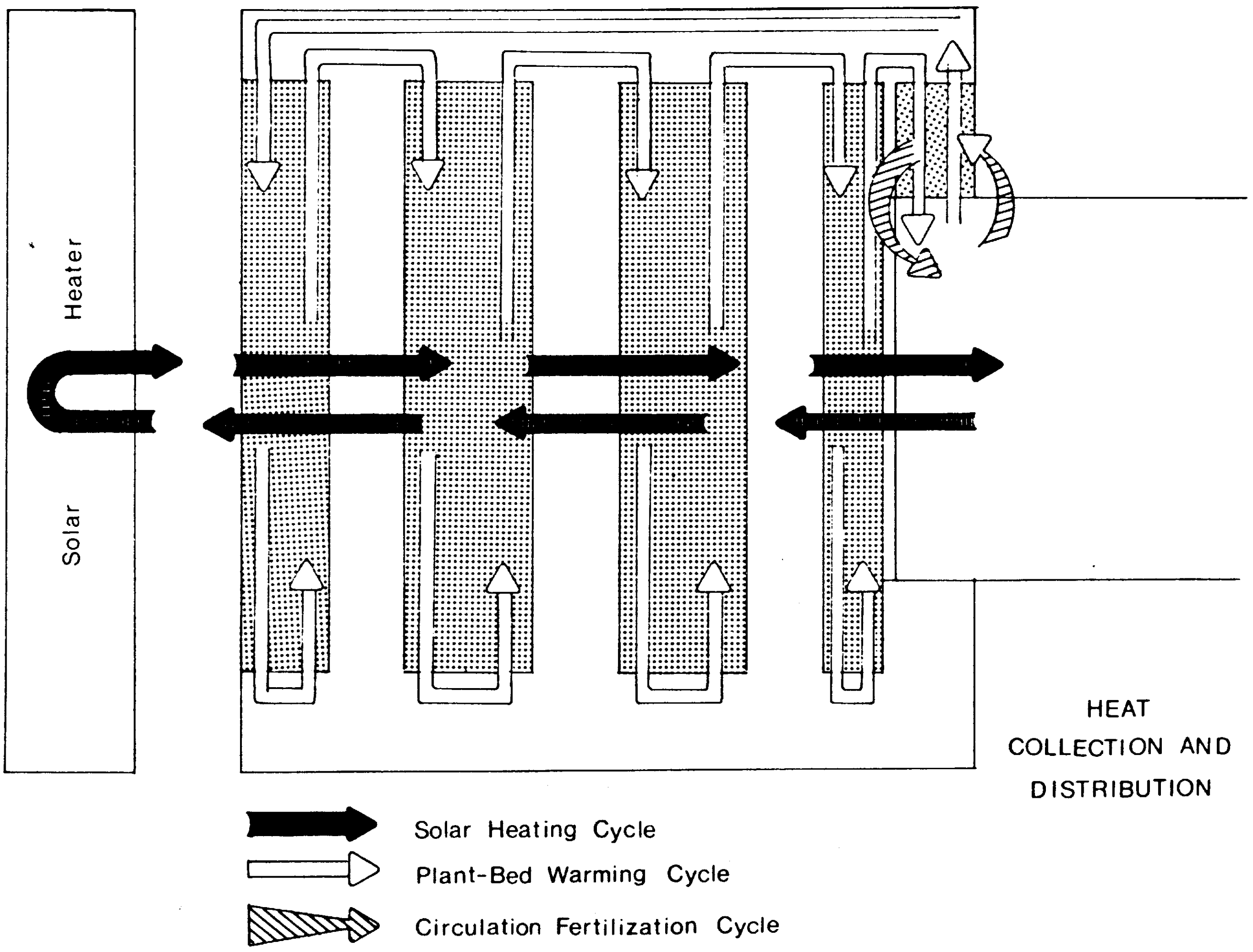

Fig. 4

allow up to 50% more light penetration than untreated glazing (16).

The greenhouse/aquaculture complex is operated in any of three modes depending on outside conditions. During daylight hours heat is stored in the aquaculture pond by circulation through the solar heater. During night hours and very cold, cloudy winter days, heat is transferred from the aquaculture pond to the soil beds in the greenhouse; warm pond water is passed through pipes in the greenhouse soil. Heat loss from the soil acts to heat the air around the growing plants. Finally, during periods when heating is not required, water can be circulated through the biological filter for aeration and purification.

BIOLOGICAL SYSTEMS

Aquaculture Components

The New Alchemy Institute has pioneered the concept of algae-based, tropical aquatic food ecosystems for northern climates and developed "backyard" fish farms which produce high quality, nutritious fishes cultured on sun-waste-algae food chains (17) (See also Walton Two - this Journal). *Tilapea aurea,* also known as St. Peter's fish, are native to Africa and are ideally suited for intensive culture. Since they are primarily algae feeders, the cost of raising fish protein is mainly in the initial construction costs of the system and a small amount of labor to maintain the ponds and crop the fish. In order for tilapia culture to work, pond temperatures of approximately 30 degrees C. are necessary. At lower temperatures growth does not take place. It was our attempting to maintain tropical temperatures that prompted us to research solar-heated ponds.

During the first year the 13,500 gallon pond, which is also the heat storage component of the whole complex, will be set up as a fish culture system and will

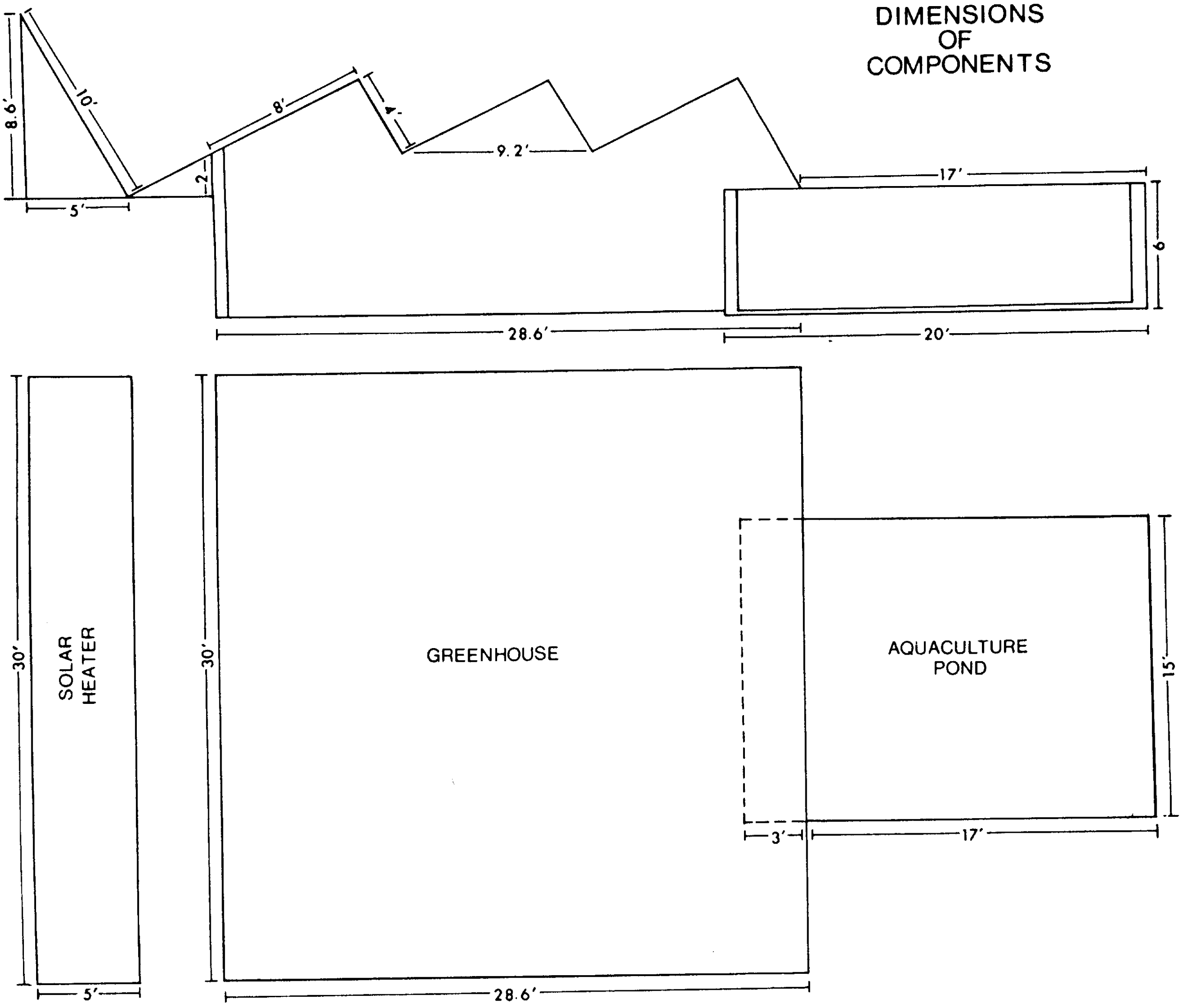

Fig. 5

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16. C. Roseman, 1973. Coatings that Control Solar Light, Heat and Condensation in Solar Stills, Greenhouses and Other Structures. International Solar Energy Society. U. S. Section Annual Meeting, 1973. Figure based on personal communication with Roseman concerning experimental glass coating.

17. The quality and taste of the *Tilapia* in our culture systems is excellent. The food editor of the *New York Times* described our fish as the best-tasting farmed fish he had experienced. *See:* Farm-Raised Fish: A Triumph of the Ecologist and the Sensualist by John Hess, N. Y. Times, Thursday, September 6, 1973.

incorporate the best of the ideas that have been developed out of our previous findings. They are:

1. *Biological Filtration*

A biological filter will encompass the whole bottom of the pond and will eliminate growth-retarding metabolites, especially ammonia. A perforated fiber glass false bottom will support a 6" layer of crushed clam, oyster and high magnesium dolomite. These materials will buffer the system and act as a substrate for the bacteria which break down the fish substances to compounds readily utilizable by the algae for their growth. The primary task of the bacteria will be to alter the ammonia to nitrates and nitrites which promote algae growth without inhibiting fish growth.

The water for the heat collection and distribution systems will be drawn out from under the filter, thereby ensuring a continuous flow of water through the filter and high filtration efficiency.

2. *Fertilization*

The pond will be fertilized with compost, rich soil, rock minerals and manures in order to sustain optimal algae production in the ponds for the fish to feed upon. This past season a breakthrough was accomplished; through the mixing of small amounts of the above compounds into the ponds, algae production was not the limiting factor in the small aquaculture systems. It would appear that we have overcome the two main stumbling blocks to intensive pond culture, namely the optimization of algae production and the breakdown of growth inhibiting waste products. The waste-algae cycle seems to have come into a productive and balanced relationship.

3. *Production of Tilapia - Summer Cycle*

Production figures are hard to estimate for the 13,500 gallon aquaculture pond. In our small 3,000 gallon solar-heated ponds we have produced 1 pound of fish per 60 gallons of water in 10 weeks *without* the critical population control, or optimal filtration. Projecting this production figure onto the proposed system would result in between 540 and 675 pounds of edible size fish being produced during the 6-7 month tilapia season. Initially 500 fish will be stocked into the system and they will be replaced with 500 young at 10-week intervals, as long as 28-30 degrees C. are maintained in the pond. There are a number of reasons to believe that these production estimates may be far too conservative. Firstly, our prior experience has been based upon culture systems in which the surface area of the filtration units was not maximized as in the present system. Secondly, the populations were too dense by a factor of five, as predators were not introduced. Thirdly, the above calculations do not take into account the fact that the production potential per unit volume increases with increasing pond size. Finally, larger ponds have more stable thermal and chemical environments which would improve fish growth.

Ultimately we believe the system will be able to produce several times the poundage of fish that have been indicated in this proposal. Intensive fish culture in Germany and Japan already has produced much higher yields, but these systems are dependent upon large amounts of additional food and energy inputs (2, 18).

4. *Cool Season Fish Culture*

During the time of year (November through April) when the water temperatures within the solar-heated aquaculture pond drop below 25 degrees C. the tilapia will be replaced with a polyculture pond including a number of native fishes and white amur or Chinese grass carp *(Ctenopharyngodon idellas)* and hybrid Israeli carp *(Carassius auratus)* in order to produce a winter crop.

The potential productivity of the cool season polyculture crop is unknown. After an optimal ecosystem has been carefully worked out, yields may come close to approximating the summer cycle.

It is hoped that when the aquaculture component of the solar-heated aquaculture/greenhouse structure is more completely worked out, the fishes in comparable systems will pay for initial costs and maintenance, particularly if costs are spread over a 10-year period. The greenhouse component would then be able to provide the income beyond expenses for its owners. This would make the concept appealing to large numbers of people throughout the country.

GREENHOUSE

The greenhouse will be established as an intensive food producing structure and vegetables and salad greens will be cultured on the growing beds as shown in Figure 2. The crops will vary from location to location within the greenhouse, depending on their light and spacial requirements and the time of year. During the fall and early winter months, a diversity of greens, peas and root crops will be grown, while during the late winter, spring and summer months heat-loving crops such as peppers, melons, eggplants and beans will predominate. Tomatoes will be grown year round. Accurate records of the yields and their market value will be kept.

GREENHOUSE MANAGEMENT

1. *Fertilization*

Initially the beds will be filled with compost and rich soils. Afterwards, the sole source of fertilization will come from the nutrient-laden pond water used

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18. J. Bardach, W. O. McLarney and J. H. Ryther, 1972. Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms. John Wiley, 868 pp. Note particularly discussion of intensive culture of carps, 29-74. This text, the definitive one on the subject in English, was primarily written by New Alchemy's W. O. McLarney.

to irrigate the plants. Our experiments linking aquaculture and the culture of terrestrial food crops have demonstrated the value of integrating the two. In experimental plots comparing aquaculture water with tap water we have obtained a large increase in yields of crops such as lettuce using aquaculture water (19). Interconnecting the aquaculture and plant crops in the solar-heated structure will reduce irrigation and eliminate fertilization costs.

2. *Pest Control*

Pests, especially whiteflies, can become a major problem in greenhouses. They are usually controlled with toxic pesticides. We have had some experience with biological controls in greenhouses, utilizing toads, salamanders and tree frogs, which prevented serious outbreaks of insect pests in an 18-foot diameter dome growing structure. The warmer, more stable climate in the proposed structure will enable us to use small lizards, especially *Anolis carolinensis*, to control insect pests. Lizards have previously been used to combat pests in a miniature tropical rain forest housed within a greenhouse (20). Pest control animals were fed a supplementary diet of fruitflies grown on a small mound of rotting fruit to sustain them during periods when no plant pests were present.

3. *Disease and Humidity Control*

Routinely, greenhouses are sprayed with fungicides to keep down diseases which can be very damaging under conditions of intensive culture and high humidity. Our strategy will be to grow disease-resistant varieties of plants where possible and to limit disease by reducing the relative humidity within the greenhouse. This will be accomplished in several ways: First, the beds have been designed to be deeper than normal and this will permit less frequent watering of the crops. Secondly, the pond section inside the greenhouse will be covered part of

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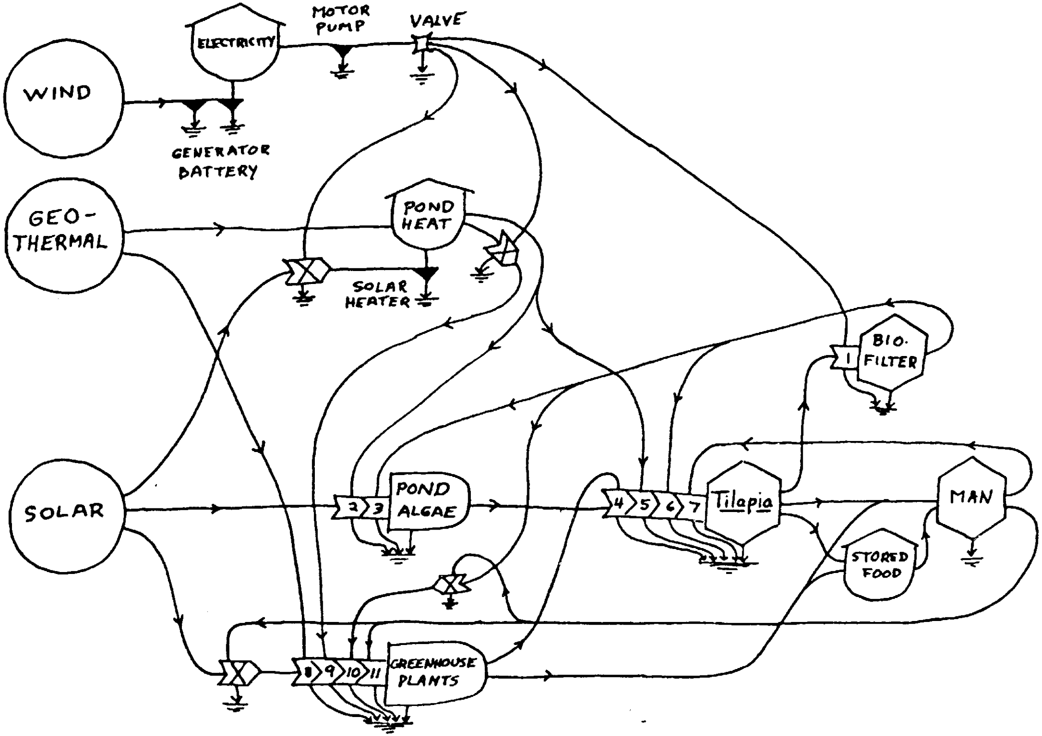
19. W. O. McLarney, 1974. Irrigation of Garden Vegetables with Fertile Fish Pond Water. The Journal of the New Alchemists (2).

20. One of us (Todd) was a doctoral student of the outstanding ecologist Marston Bates. He established in his house in Ann Arbor, Michigan, a "tropical rain forest" in order to try and understand the dynamics and interrelationships of plants, water, soils, animals including insects, birds and monkeys within a miniature ecosystem. He developed a number of sophisticated ideas on predator-prey relations in closed systems. Unfortunately, these were never published. His ideas have been an inspiration to us and we hope to extend them.



ENERGY FLOW DIAGRAM FOR SOLAR-HEATED GREENHOUSE AND AQUACULTURE COMPLEX

1) Circulation of fish pond water through biological filter. 2) Increased growing temperature for algae. 3) Nutrient cycling from fish wastes. 4) Terrestrial plants to Tilapia. 5) Increased temperature for Tilapia. 6) Removal of growth inhibitors. 7) Fish husbandry. 8) Earth heat warming the pit-greenhouse. 9) Night warming of greenhouse. 10) Irrigation by nutrient/rich water. 11) Vegetable gardening.

the time, especially during the day, to reduce humidity. Finally, when the sun is shining and the humidity outside is low, the vents will be opened fully, permitting the warm and moist air to rise out of the structure and be replaced with cool, dry air. Sporadic lowering of humidity levels should reduce the possibility of disease affecting crop production. Previously, this approach has worked for us and only two out of fourteen varieties of food crops, Black Simpson lettuce and Tiny Tim tomatoes, were damaged by disease. In these instances, the crop was only partially destroyed. In the management of the complex, we will attempt to replace chemical controls with biological ones. Biological controls will be mandatory in the greenhouse, as fishes are killed by fungicides and pesticides.

RESEARCH

After the Ark is completed, we plan an investigation of the whole system, so that our experience will be useable by others. Research will include studies of:

1. External and internal climates.
2. An energy budget for the total system.
3. Water chemistry and the chemical activity of the biological filter. This analysis will include routine measurements of oxygen, carbon dioxide cycles including free CO_2, and bound and half-bound CO_2, pH, nitrogen cycles including ammonia, nitrites and nitrates (methane if present) and phosphorous.
4. Productivity of each trophic level within the aquaculture system including the algae, algae-consuming invertebrates and fishes, and the fishes which feed primarily on animal protein. Trophic relations within the system will need to be accurately established in order to fill the available niches within the pond and optimize productivity.
5. Yields and value of all crops within the greenhouse.
6. Effectiveness of biological controls in regulating pests within the greenhouse.
7. Determination of labor required to operate the complex.
8. Economics of the solar-heated and wind-powered greenhouse and aquaculture structure in present and projected future terms.

With this information carefully collected and evaluated, it should be possible to determine if Arks will become useful tools for those trying to restore lands, protect the waters and inform the earth's stewards. We believe that the Ark will have the potential to help us restore and reconstruct during the stormy times ahead.

—Robert Angevine, Earle Barnhart and John Todd