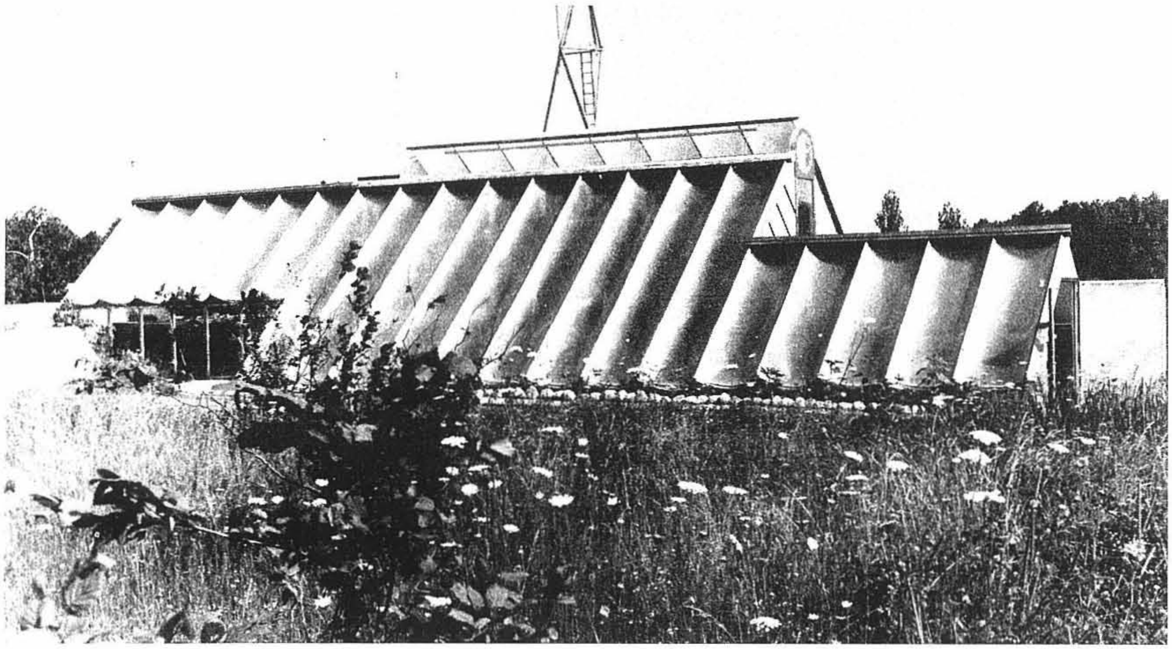
Bioshelters

This section on bioshelters is divided into two distinct parts, the one scientific and the other more or less domestic. The first, "Logging the Course of the Ark," reflects the range of our investigatory research in the Cape Cod Ark, which, at the age of five, has earned a venerable standing among solar greenhouses. Horticulture, pest control, modeling, toxic materials, and designing future bioshelters are discussed in the light of our current knowledge.

The second part, if less scholarly, is more broadly experiential. It is written by an assortment of people who having been exposed to the Ark have incorporated a bioshelter in some form or another into their lives. Any readers contemplating doing so themselves will be interested in the variety of approaches and costs represented.

N.J.T.



Hilde Maingay

LOGGING the COURSE of the ARK

Indoor Gardening

Colleen Armstrong

One of the goals underlying the design of the Ark was to point the way toward a solar-based, year-round, employment-creating agriculture for northern climates. Our goal was to devise a food-raising ecosystem that would require one-fifth to one-tenth the capital of an orthodox farm but use far less space. Our original target was for a bio-shelter-based microfarm costing $50,000, land included. The experimental prototype described on the following pages cost less.

Our strategy was to avoid mimicking and scaling down single-crop commercial farms. We adopted rather an ecological perspective, integrating into the design a blend of soft technologies, mixed crops (including greens, vegetables, flowers, fish, and other aquatic foods), and the mass propagation of trees. The microfarm was encapsulated in a solar building in which internal climate and the control of disease and pests were carried out by ecological, structural, and data-processing subcomponents. This contained ecosystem with its interrelated and interdependent components of plants, earth, insects, fish, and people is a bioshelter, which we called the Cape Cod Ark.

Sterile soils and the use of toxic chemicals for intensive management are common elements of orthodox greenhouse food culture. We opted for deep, biologically diverse soils that we "seeded" from fields, meadow, and forest environments in alluvial, limestone, and glacial areas in southern New England. The process has become a continuing one. To the soils we added compost, seaweeds for trace elements and structure, and composted leaf litter. We wanted to create soils with the following characteristics:

1. High fertility.
2. High organic matter and water-holding ability.
3. Multiple nutrient-exchange pathways and storage capabilities.
4. Optimizes carbon dioxide production through dense bacterial activities.
5. Provides shelter for diverse animal population, including earthworms and pest predators.


Hilde Maingay

For agricultural purposes the most relevant indicator of soil fertility is the amount of produce a plant yields. In the Ark there are two important facts that should be considered when discussing soil fertility. First, the soil is the basic, essential source of plant nutrients; second, unlike the situation when seasonal cropping is practiced, the soil's nutrients are tapped 12 months of the year. We use crop rotation to balance nutrient demand. Two laboratories (Woods End Laboratory in Temple, Maine, and University of Massachusetts Suburban Experimental Station in Waltham, Massachusetts) have assisted us in evaluating our soil conditions by auditing Ark soil samples. Table 1 summarizes the basic composition and development of the Ark's soil over a two year period. A steady accumulation of organic matter and improved carbon: nitrogen ratio is attributed to cyclic introduction of properly composted material. Mineral levels fluctuate upon various demands of specific crops. Such reports are vital when selected crops are heavy feeders and possible nutrient deficiencies may arise.

Soil fertility is maintained through a process of annual innoculation. In September, after the summer season has come to a close, each bed is turned with well-decomposed organic matter. This rein-

Table 1. SUMMARY OF ORGANIC MATTER AND MINERAL CONTENT OF CAPE COD BIOSHELTER'S SOIL, 1977–1979.[a]

		Date		
		11/77	*11/78*	*6/79*
Planned use		*Leaf vegetables*	*Leaf vegetables*	*Tomatoes*
Texture		*Sandy loam*	*Sandy loam*	*Sandy loam*
Organic matter		*5.5%*	*8.1%*	*8.7%*
Humus		*3.8%*	*4.9%*	*5.7%*
CEC (Meg/100 g)[b]		*18.8*	*20.7*	*17.6*
Soil pH		*7.0*	*6.4*	*7.0*
C:N balance		*Good*	*Very good*	*Excellent*
Available Nutrients		*11/77*	*11/78*	*6/79*
Nutrient Anions (1b/A)[c]				
Nitrogen (NO_3) annual releases	Desired level	100	100	200
	Level found	90–139 M	130–170 M	240 M
P_2O_5 reserve phosphorus	Desired level	350	250	130
	Level found	700 H	760 MH	660 MH
Exchangeable Cations (1b/A)				
Calcium	Desired level	4,900	5,800	4,900
	Level found	6,200	6,100	5,300
	Saturation	82% H	73% M	76% MH
Magnesium	Desired level	670	600	570
	Level found	580	1,000	830
	Saturation	13% M	20% H	20% MH
Potassium	Desired level	370	320	280
	Level found	570	590	590
	Saturation	4% M	4% MH	4% M

[a]Private circulation of Woods End Laboratory, RFD Box 65, Temple, Maine.

[b]Cation exchange capacity: a measure of the soil's capacity for holding available cations in reserve. Meg/100 g means milli-equivalent weights per 100 grams of soil; a milli-equivalent weight is the weight of a cation which exchanges with one equivalent weight or one gram of hydrogen.

[c]1b/A = pounds per Acre
H = High
M = Medium
MH = Medium-High

states many microorganisms that break down organic matter with steady nutrient and mineral release. In addition, an irrigation program using the warm fish-pond water continually provides soluble nitrate-nitrogen, ammonium-nitrogen, and phosphate compounds.

Winter Crop Varieties

Over the past four winter seasons, from November through April, we have been evaluating many vegetable and flower varieties for their performance in the Ark. The Ark shares a number of characteristics with other passive solar greenhouses, but it it a bioshelter—a solar greenhouse with a difference. There are several qualities that distinguish it from other greenhouse environments. The primary difference lies in the concept of the Ark as an enclosed ecosystem, rich in diverse organisms. The practices of agriculture, aquaculture, and soil and insect ecology are all interdependent. When regulating the climate of the Ark, we must consider the living components. Fish can be more sensitive to thermal change than plants, and seasonal plants may require specific soil and air temperatures. The Ark may not provide optimal growing conditions for certain vegetable and flowers. Consequently, varieties must be chosen with these factors in mind.

In the Ark the average soil temperature at a 2 inch depth during the coldest months is as follows: November, 60° F; December, 59.5° F; January, 55° F; February, 59° F; March, 62° F. Average soil temperatures for two periods of November through April in 1977, 1978 and 1979 were 59° F at a depth of 2 inches, 54.1° F at 6 inches, and 53.2° F at 12 inches.

Although the soil beds provide more than sufficient temperatures for bountiful winter vegetable production, they are also considered a portion of the total thermal mass. The air temperatures fluctuate. Clear, sunny days will raise the daytime air temperature to 77° F, whereas on cloudy days it tends to drop to 55°–60° F. With an average minimum air temperature of 49.2° F and an average maximum air temperature of 70.8° F, the Ark's climate is similar to that of spring in a temperate zone. At this time, many foliage and root crops can be cultivated. The Ark provides an average of 25 portions of salad greens per day during the winter season. What better time to have access to fresh vegetables, rich in good nutrition?

Before we select which vegetables to grow, we give careful thought to each garden bed. These are a few of the questions we ask to make the most reasonable selections.

What is the size of the garden bed?

In the Ark, all of the beds are 5 feet or less in width and can be planted intensively. However, each bed borders a pathway and in our case must be able to take the abuse of reckless visitors and gardeners. Many dwarf flowering plants such as marigolds, alyssum, and lobelia make excellent borders, and we make use of them as such. A few hardy plants like beets, celery, parsley, and thyme can be employed as fences. Smaller areas should be planted with compact foliage crops that can be harvested by leaf. Loose-leaf lettuce, endive, celery, and chard can be planted close to one another and picked continuously for weeks. Larger beds offer freedom for all kinds of intercropping with broccoli, cauliflower, chard, kale, head lettuce, and herbs.

What is the quality of light striking the garden bed?

This is the most important question. Light can range from full through partly shaded, lightly shaded to deeply shaded. Full light exists when direct sunlight is present throughout the day. Moving down the scale, a partly shaded area has direct light for only a portion of the day. Light shade prevails when no direct sunlight reaches the bed, but a high light intensity is maintained. Deep shade is an extreme case in which there is low light intensity at all times.

Throughout the winter season, most vegetables require full light. Real sunworshippers are celery, head lettuce, leeks, broccoli, cauliflower, beets, dill, and thyme. Vegetables that will produce in partly or lightly shaded areas are endive, chard, parsley, kale, and Chinese greens. A few exceptional foliage crops continue to produce throught he dead of winter. They are endive, parsely, New Zealand spinach, beet greens, and both Swiss and red chard.

What is the condition of the soil?

A steady program to build and maintain soil fertility is an inherent part of our gardening practice. However, it's important to recognize that some crops are heavy feeders, and crop rotation should be employed.

Some vegetables may need additional compost dressing. If light conditions are stressing, a balanced rich soil and good air circulation will assist the plant to retain strength and will minimize pest problems.

Table 2. SUITABLE WINTER VEGETABLE VARIETIES FOR BIOSHELTERS IN NEW ENGLAND.

Vegetable	*Name of Variety*	*Seed Co.*	*Transplant/ Seed*	*Fall/ Spring*
Beet	Early Wonder Tall Top	Johnny's	Transplant	F
	Green Top Bunching	Stokes	Transplant	F
Broccoli	Cleopatra	Stokes	Transplant	F
	Ce Cicco	Johnny's	Transplant	S
Celery	Utah 52–70R Improved	Johnny's	Transplant	F & S
Chard, red	Burpee's Rhubarb®	Burpee	Transplant	F & S
Chard, Swiss	Fordhook Giant	Stokes	Transplant	F & S
Cauliflower	Opaal®	Rijk Zwaan	Transplant	F
Cabbage	Matsusitima	Johnny's	Transplant	F
Chinese	Chinese Pac Choi	Johnny's	Transplant	F & S
Endive	Full Heart Batavian	Johnny's	Transplant	F
	Green Curled	Stokes	Transplant	F
Kale	Harvester LD	Johnny's	Transplant	F & S
	Green Curled Scotch	Stokes	Transplant	F & S
Lettuce, Bibb type	Ravel RZ®	Rijk Zwaan	Transplant	F & S
	Rossini®	Rijk Zwaan	Transplant	F & S
	Ostinata	Stokes	Transplant	F & S
				F & S
Lettuce, head	Reskia RZ®	Rijk Zwaan	Transplant	S
	Zwaareese®	Rijk Zwaan	Transplant	F & S
Lettuce, loose-leaf	Grand Rapids Tip-burn Resistant	Stokes	Transplant	S
Parsley	Champion Moss Curled	Stokes	Transplant	F & S
	Plain Dark Green Italian	Stokes	Transplant	F & S
Spinach	New Zealand (perennial)	Stokes	Seed	F
	Malabar	Burpee	Seed Transplant	S

What vegetables should be given priority?

Criteria for choosing vegetables are that they please the intended consumer and are nutritionally complementary. A short story might be pertinent. A few years ago, we grew lots of New Zealand spinach. It was fabulous for re-enforcing the rock walls and was a nonstop producer. Unfortunately, only the most reckless of greens aficionados would chew it, sometimes with reluctance. Rumors developed that most of it was going to chickens and goats. Graffiti such as "Yuck" began to appear in the tally book. It seems sturdiness and nutritional value cannot stand alone. At least not with us.[1]

We have experimented with varieties of lettuce, endive, celery, chard, beet, brassicas, spinach, and parsley to ascertain which vegetables are most adapted to the thermal and light regimes inside the Ark. While a few crop varieties demand a specific season, most of the foliage crops can be cultivated throughout this cool period. See Table 2. Lettuce varieties from Holland have proved superior to domestic varieties. It is possible that Dutch greenhouse crop-breeding conditions may more closely approximate conditions in bioshelter environments in northeastern United States. We set the following criteria for our varietal tests. Each variety of lettuce was rated for number of days until maturity, average ounces per plant, ounces per square foot, color, aphid resistance, disease and heat resistance, tip-burn and taste (see Table 3).

Undoubtedly, Ravel R2®, a bibb lettuce with outstanding qualities, is our favorite, most productive variety in the Ark. Grand Rapids Tip-Burn Tolerant is the preferred loose-leaf lettuce however; most of the bibb lettuces give higher yields per square foot.

Our vetetable production can be divided into two categories: overall production from the 517 square foot (ft^2) growing area, and optimal production from testing areas (Tables 3 and 4). Over a three-year period, we have brought about several changes in the growing area. In fall 1978, we placed three solar-algae ponds in areas of low light, providing additional heat storage, accessible pond water, and warmer temperatures in the soil surrounding the ponds. At the same time, we designated a 35 ft^2 plot as a permanent area for tropical plants; this serves as an animal and insect sanctuary.

Figure 1 shows the six-month winter vegetable production from the 517 ft^2 area over a three-year period. The vegetables included lettuce, endive, tomatoes, celery, brassicas, chards, beets, and herbs.

[1]For readers uninitiated to New Zealand spinach, ruminating briefly on a rusty nail will provide a fair analogue of the taste, if not the texture, of sampling the real thing. *Ed.*

Valuable Crops

Celery

After a successful pretrial season, we cultivated celery as the main crop in the fall of 1979. Celery has a long maturing process from seed to harvest. Seed germination is approximately 21 days, an additional 45 days is required for developing as a transplant, and it is 76 more days until harvest. The advantages of growing celery in bioshelters include the long developing process, and the fact that it is a compact, verticle-axis crop. The crop occupies bedding space for 72–76 days, only about half of the total maturation time. Celery has the added advantage of being a relatively high priced, popular vegetable in American markets.

There are a few characteristics of celery that should be taken into consideration, however. It is one of the more difficult crops to grow. It is a rich feeder of nitrogen and requires an abundance of moisture from the soil. Blanching (preventing the development of color) and binding are required for a marketable crop. Offsetting such demands, celery can be spaced at one plant per square foot and weigh 1–2 pounds per plant. As of this writing it brings a retail price of 89 cents per bunch. Celery is a good storage vegetable and has a flexible harvest period. The first-year results have been encouraging, and crop evaluation will continue both in early spring and fall.

Tomatoes

During seasons that tomatoes are imported, retail prices on Cape Cod approach and often exceed $1 per pound. A review of the tomato culture literature indicates that greenhouse tomatoes have two seasons: spring and fall. Predictably, the spring season—with longer photoperiod and higher luminosity—is more profitable. With the rising cost

Figure 1. Average Winter Vegetable Production in Cape Cod Bio-shelter over Six-Month Period.

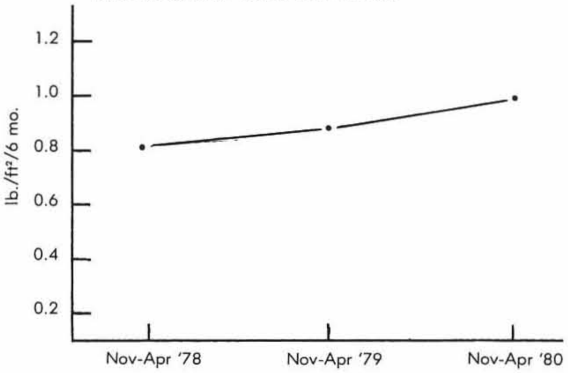


Table 3. VARIETAL TEST SHEET FOR LETTUCE IN CAPE COD BIOSHELTER.

Name of Variety	*Time to Maturity (days)*	*Average weight (oz/plant)*	*Density (oz/ft²)*	*Equivalent 1b/ 1,000 ft²*	*Aphid Resistance*	*Bacterial Soft-Rot Resistance*	*Heat Resistance*	*Tip-Burn Resistance*	*Color*	*Taste*
Deci-Minor (Holland)	75	5.4	10	625	Medium	Medium–high	High	High	Dark green	Very good
Grand Rapids[a] loose-leaf (US)	45	5.0	8.7	544	Medium	High	Medium–low	High	Light green	Very good
Ostinata (US)	60	4.9	9.3	581	Medium–high	Medium	Medium–high	High	Medium green	Good
Prizehead loose-leaf (US)	48	Failed	—	—	Low	High	Low	Low	Green/red	Failed
Ravel RZ® (Holland)	66	5.5	11	688	High	High	High	High	Dark green	Excellent
Reskia® (Holland)	74	8.0	8.2	512	Medium–high	Medium	Medium	High	Light green	Very good
Rossini® (Holland)	70	5.5	11	688	Medium	Medium	High	High	Dark green	Very good
Zwaareese (Holland)	74	8.0	8.2	512	Medium–high	Medium	Low	High	Light green	Good

[a]Grand Rapids Tip-Burn Tolerant Variety

Table 4. VARIETAL TEST SHEET FOR TOMATOES IN CAPE COD BIOSHELTER.

Name of Variety	Days Until Maturity (from Transplant)	Average Weight per Fruit (oz)	Yield (lb/ft²)	Equivalent lb/ 1,000 ft²	New England Production (lb/ft²)	Insect Resistance	Disease[a] Resistance
SPRING:							
Small Fry (US)	68	0.75	1.2	1,200	—	Medium–high	Medium
Lito® (Holland)	78	2.5	4.0 (double-pruned)	4,000	2.5	Medium	Medium–high
Tropic (US)	82	2.8	1.8	1,800	2.5	Medium–high	High
Type 127 (Holland)	72	2.3	3.6 (double-pruned)	3,600	2.5	Medium	Medium–high
FALL:							
Lito® (Holland)	78	2.5	1.2	1,200	—	Medium	Medium–high
Tiny Tim (US)	45	0.4	0.6	600	—	Low	Medium

[a]Diseases include verticillum wilt, fusarium wilt, leaf blight and anthracnose.

of fuel, many conventional tomato growers in New England have decreased production.

An evaluation of the first year of summer tomato production in the Ark showed an average of 2 lb/ft² for the 1978 season. This yield is probably low as we know part of the crop was snitched by visitors.

The following spring we evolved a more sophisticated program incorporating a valuable pruning technique. Double-pruning as it is called is a European method that incorporates a selected axial sucker or vegetative outgrowth into a second indeterminant stem. This pruning technique can double fruit yields while not affecting fruit size. It is an excellent method for maximum space utilization. We began our preliminary trials with Dutch seeds. To date, the favorite variety has been Lito® from the Rijk Zwaan Co. in Holland. This variety is slightly smaller than the average garden tomato although it tastes as sweet. Mid-March planting gave us fruit by early June and a production figure in July of an average of 5.5 lb/plant! Fruit production lasted 14 weeks with a final figure of 13 lb/plant, or 4 lb/ft², twice the yield of the first year. If the tomato area in the Ark were equivalent to 1,000 ft², Lito® could produce 4,000 lb of fruit in the spring season.

Fall tomato production also has merit in bioshelters. Again, timing is most important. Seeding begins on the first of June. Healthy plants are set in beds by the first week in August and the first tomatoes begin to ripen in mid-October. Fall fruit production is considerably less than spring production, measuring 1.2 lb/ft² compared to 4 lb/ft². However, top prices are paid at this time of year and further on into December. In the future, many additional factors such as light-reflection material, thermal curtains, and better glazing may contribute to boosting fall tomato production.

The results of our tests of several tomatoes are shown in Table 4.

Seedling Production

Besides the deep-dug, intensive beds in the Ark, there is approximately 75 ft² of bench space that we alot to young seedlings. The area is regarded as a nursery. A germination box provides the environment for optimal seed sprouting. Young plants are transplanted into containers that hold 3–10 of a particular variety. Although small, the bench space is essential to us and is most productive in late winter and in spring. In 1979 we produced over 6,000 transplants in the Ark for New Alchemy's gardens and experimental plots. A seedling schedule indicates what vegetable and flower seedlings to grow at the proper time of year. A cycle envolves; as mature transplants are moved to the cold frame, a second set of younger seedlings assumes their space. After a few weeks, the second set is taken out to be hardened off, and a third moves into the same space. Many growers find spring the most profitable season. On Cape Cod, three tomato plants can retail at $1. With adequate timing, spring transplant profits could exceed those of any other time of year.

Planting Regimes

Figure 2 displays three alternate vegetable-planting schedules. All can be made profitable ventures. Schedule A was the regime for the 1979/1980 season in the Ark. Table 5 lists the retail revenue per square foot using the three schedules. Schedule A

Table 5. REVENUE FROM ALTERNATE ANNUAL PLANTING REGIMES.

	Retail Price	Produce/ft²	Revenue ($/ft²/yr)
SCHEDULE A:			
Celery	89¢/bunch	1 bunch	$0.89
Tomato	avg. 69¢/lb	4 lb	2.76
Lettuce	69¢/head	(two) 1.9 head[a]	2.62
TOTAL			$6.27
SCHEDULE B:			
Celery	89¢/bunch	1 bunch	$0.89
Tomato[a]	99¢/lb	1.2 lb	1.18
Lettuce	69¢/head	1.9 head	1.31
Cauliflower	$1.89/head	0.4 head	0.76
TOTAL			$4.14
SCHEDULE C:			
Lettuce	69¢/head	(two) 1.9 head[a]	$2.62
Tomato	avg. 69¢/lb	4 lb	2.76
Cauliflower	$1.89/head	0.4 head	0.76
TOTAL			$6.14

[a]Two reasons
[b]Off-season price

offers the highest income at $6.27/per square foot per year; another plan may be selected to facilitate crop rotation and balance the nutrient requirements drawn from the soil. Comparing the three schedules, flexibility in crop selection is often narrowed by the premium price available at a particular season. We remind readers that with prices soaring, these prices shortly may be regarded as too conservative!

Biological Islands

Because crops are planted, removed, and altered from season to season, most agricultural environments are intrinsically unstable. Such instability can lead to pest outbreaks, since biological regulatory mechanisms are not usually well established. An example is the introduction of ladybird beetles (*Hippodamia convergens*) to control aphids. Once the crop is harvested, the number of aphids, which provide nourishment for the predator, is reduced. The ladybird beetle population will consequently drop or become nonexistent. In the Ark we increased ecological diversity and biological stability by creating aquatic and terrestrial microcontrol "islands" throughout the interior. These "islands" include such stable perennial plants as ginger, flowers, herbs, and grasses like bamboo that are not cropped. These in turn provide continuing habitats for pollinators, predators, and parasites of insect pests. The parasites include parasitic wasps, larvae of flies, predatory mites, spiders, frogs, and lizards. The entire island network, located in slightly suboptimal growing areas, also creates a pleasant surrounding.

Figure 2. Alternate Annual Planting Regimes.

°Lettuce grown under mature tomatoes.

Hilde Maingay

Controlling the Whitefly

Colleen Armstrong

At the time of my last chronicling of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), I felt secure that this harmful herbivore's existence would be relatively insignificant to the Ark's insect community.[1] Previous success stories of the use of *Encarsia formosa* (Gahan) in controlling greenhouse whitefly encouraged me to continue my investigation and I planned to devote more time to observing and monitoring interactions between host and parasite. Winter 1978/1979 was mild and cloudy, and the Ark was cool enough to limit the number of active whiteflies. The parasitic wasp *E. formosa* was undoubtedly present, though even quieter than its host. With a fall crop of tomatoes that lasted until mid-February, both insects were assured of one of their favorite food sources. The whitefly probed the tomato tissue, preferring apical leaves, while the *Encarsia* searched for immature whitefly in which to deposit their eggs. It was a tranquil time of year for this particular host-parasite relationship.

When the tomatoes became diseased with a fungal growth, *Cladosporium* sp., we uprooted and composted the 12 ft plants. Realizing that the majority of the Ark's *E. formosa* population lived on the tomatoes, we scavenged each plant for black-coated, parasitized whitefly scales (sessile larval stages) and distributed leaves throughout the bioshelter. We pinned many leaves to the underside of young tomato plants above the rock storage bed. Little did I know we were about to enter a tumultuous season of whitefly.

You might say I've progressed to the trial-and-error stage of science, but my mistakes have taught me a great deal about insect control in bioshelter environments. The Ark is far from the conventional laboratory. Such variables as percise temperature and exact insect members are not controlled. Although we are practicing biological control in a contained environment, it can follow patterns of nature so closely that you often forget the feeling of walls.

Successful insect control can be a complicated process. To quote the *Source Book of Integrated Pest Management*, "A managed resource ecosystem is a component of the functioning ecosystem . . . actions are taken to restore, preserve or augment checks and balances in the system."[2] Over the growing season under discussion, various factors such as temperature, timing, and ratios of host to parasite contributed to the lack of stability in the Ark's gardens.

The average daily winter temperature in the Ark for the three coldest months, December, January, and February, was approximately 21° C (70° F). Its climate can be described as cool and moist. When the old tomato leaves were removed from the diseased mother plant and pinned to new plants, many of the leaves disintegrated in the dampness of the bioshelter.[3] Consequently, the parasitized scales were lost, and the *E. formosa* population took a drastic dip. At relatively low temperatures, 18–21° C (64–70° F), the whitefly's life span is longer and the female can lay many more eggs than the parasitic wasp can.[4] (See Figures 2 and 3.) In the spring, as the whitefly population began to gain momentum, the lack of *Encarsia* was most felt. I began to search for an outside source of *E. formosa*.

As routine practice, we made weekly counts of whitefly adults and scales, and took parasitized

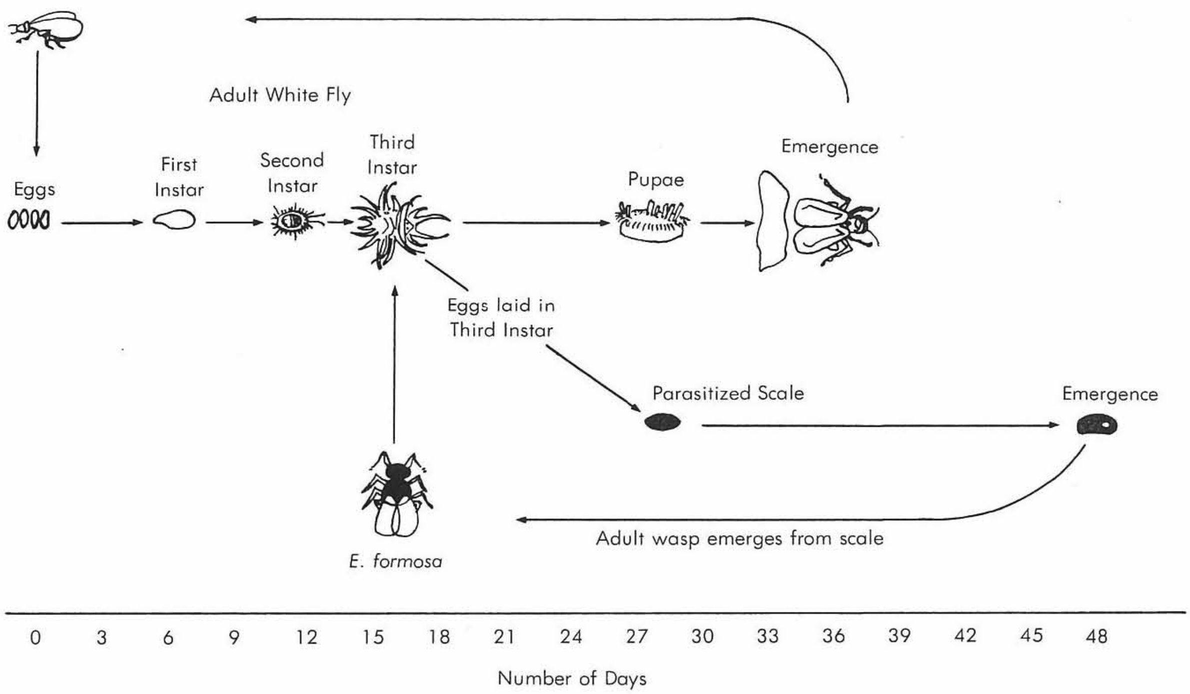
[1]Armstrong, 1980. Reference 12.

[2]Reference 2.

[3]In summer, parasitized scales can be pinned to the underside of a fresh leaf surface with little disruption to *E. formosa's* life cycle.

[4]Helgesen and Tauber, 1974. Reference 4.

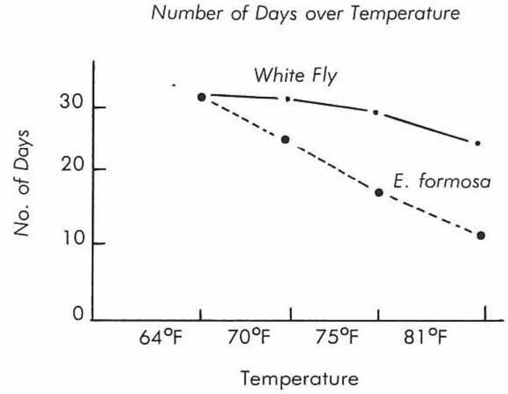
Figure 1. White Fly's and *E. formosa's* Life Cycles at 75°F (24°C).



scales from the spring tomato crop. We tallied a random count from other plants in the Ark. In mid-May, I began to find parasitized scales on the oldest leaves of the tomatoes. The crop by then stood 6 ft tall, and was laden with clusters of fruit. By June, the plants approached 8 ft in height and the youngest leaves were well out of sight. Average daily temperatures reached 25° C (75.5° F), but the large whitefly scales outnumbered parasitized scales many times over. (See Figure 4.) At the end of the month, sooty mold began to grow on the tops of the leaves and the plants began to wilt.[5] This could only be attributed to an extreme infestation, with the whitefly multiplying to a high density. Then in the next two weeks, the number of parasitized scales skyrocketed, but too late. The tomato plants had sustained sufficient damage to curtail vigor and growth. Physically, they appeared beaten. We pulled the crop and I concluded that my management practices had failed.

[5]Black, sooty mold feeds on the whitefly's excretion, a sticky substance often called honeydew.

Figure 2. Lifetime Development for White Fly/*E. formosa*.*



*Data based on Burnett, T., reference 2.

Figure 3. White Fly/*E. formosa* Fecundity

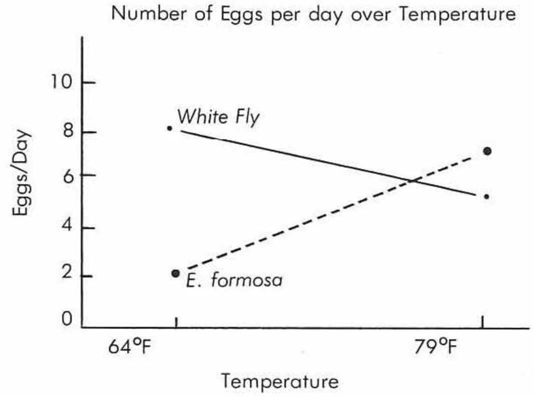
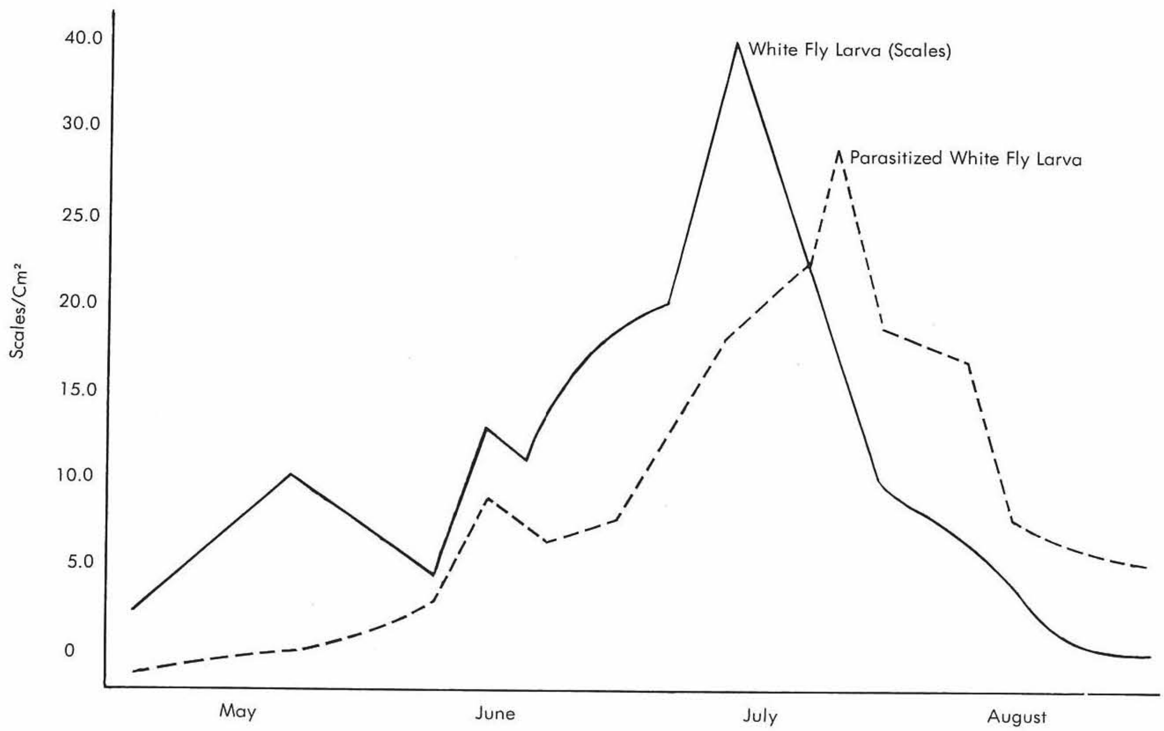


Figure 4. White Fly and *E. formosa* Population Densities on Tomato Crop, Spring-Summer, 1979.



What were the mistakes? What was so different about that year compared to previous ones? The grower bows her head and sorrowfully states, "Optimism and ignorance; but for both our sakes let's recount them just the same."

Predictably, when the diseased tomato leaves decomposed, the mainstay in the diet of *E. formosa* was forfeited. We should have begun the search for a source of new parasites at that time. Waiting until the abundance of whiteflies became apparent made for too long a delay. Presently, only one commercial insectary on the North American continent, the Canadian firm Better Yields Insects, located in Tecumseh, Ontario, breeds *E. formosa*. A purchase from the United States requires an importation permit from the USDA Animal and Plant Protection Health Inspection Service. Permits take time, sometimes up to eight weeks.

The loss could have been otherwise prevented had more than one type of host plant been predominant in the Ark's breeding scheme. The whitefly is attracted to more than 200 vegetable and ornamental plants,[6] but *E. formosa* is not as extensive in the search for immature whitefly larvae. Tomato and tobacco cultivars are favored by both, though other cool-season plants can be utilized as breeding stations. Nasturtiums and scented geraniums are vigorous flowering plants that thrive in the winter season of the bioshelter. Long-lived or perennial host plants like these allow the *Encarsia* to develop without disturbing their life cycle. Yet another obstacle was a lack of information. It is hard to know when exactly the whitefly population density reaches a level injurious to fruit production.

When biological agents are depended on for insect control, it is necessary to have precise biological control recommendations for specific crops. One should know, for example, that vegetables can often take a higher pest population density than ornamental plants. Without this type of information, the grower cannot know when his/her crop is endangered. Luckmann and Metcalf state this in terms of a population density reaching an economic threshold level, or beyond, to an economic injury level.[7] (See Figure 5.) If the population density of the pest exceeds the economic threshold level for a particular crop, artificial controls are justified to prevent loss.

Tomatoes can tolerate a moderate number of

[6]Russell, 1963. Reference 10.

[7]Reference 8.

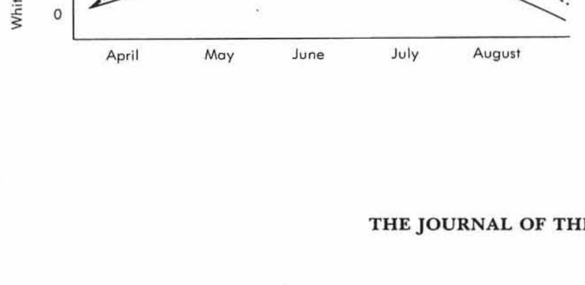
whiteflies, to 20 scales per square centimeter, until the pest adversely affects crop yields.[8] The survival of a certain age-class of whitefly such as eggs, first, second, third, and fourth instar, is variable, specifically with regard to temperature.[9] The ideal ratio of *E. formosa* to its host is 1:30; the wasp lays approximately 30 eggs in a lifetime.[10] The most effective control is reached when the parasite is introduced at a low whitefly population density, certainly below a level causing economic injury. For further coverage on how to establish *E. formosa* successfully, read R. G. Helgesen and Maurice J. Tauber's article on the biological control of the greenhouse whitefly.[11]

Are there other control methods compatible with *E. formosa* in checking whitefly populations? In the context of the bioshelter environment, it's an important question to ask. We hope other beneficial insects help control this pest. We have observed adult whitefly predation by damsel flies and spiders. Most likely, our quick-drawing frogs have lashed out at a naive few. Other interactions may have passed unnoticed. But evidently, the Ark's combination of food, temperature, and a lack of natural enemies favors the augmentation of a whitefly population, especially in the spring. If the managed resource ecosystem is to succeed, an integrated pest control scheme is necessary.

Trap plants like nasturtiums serve well. Repellent plants such as white geranium can be useful. Also helpful is learning what attracts both predators and prey. Many plant feeders are attracted

[8]Hussey et al, 1969. Reference 5.
[9]Helgesen and Tauber, 1974. Reference 4.
[10]Burnett, 1949. Reference 1.
[11]Reference 4.

Figure 5. Hypothetical Graph of a White Fly Population on Tomato Crop. Three Separate Cases Stating: (A) Low Population Density, No Additional Control Needed; (B) Population Density Approaching Economic Threshold Level; (C) Population Density Requires Additional Control Intervention to Prevent Crop Yield Damage.



to yellow and yellow-green colors.[12] A trapping scheme that uses boards painted yellow and coated with a sticky substance with a texture on the order of flypaper has snagged the adult whitefly successfully.[13] Among various trials, this method has proven effective in collaboration with *Encarsia formosa* for integrated control with established whitefly infestations.

Although biological control is the most desirable method for controlling pest populations in a bioshelter environment, effective mechanical controls may fill the void when beneficial insect activity is low. Overall the objective remains to minimize the existence of the pest by employing control strategies that will not disrupt the resource ecosystem. Source for *Encarsia formosa*:

Better Yields Insects
13310 Riverside Dr. E.
Tecumseh, Ontario N8N 1B2
Canada

Minimum Order: 2,000
Importation permit is required for U.S.

Address for Importation Permit:

Importation Permits
Technical Service Staff
Plant Protection and Quarantine, APHIS USDA
Federal Center Bldg.
Rm. 670
Hyattsville, Maryland 20782

Form 526

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[12]Lloyd, 1921. Reference 7.
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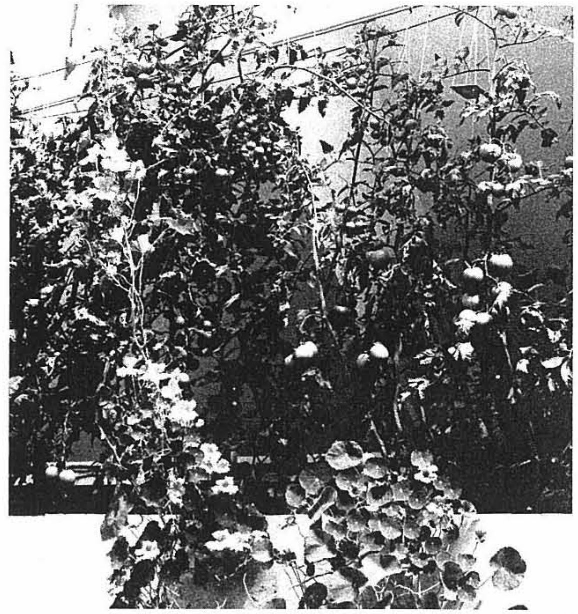
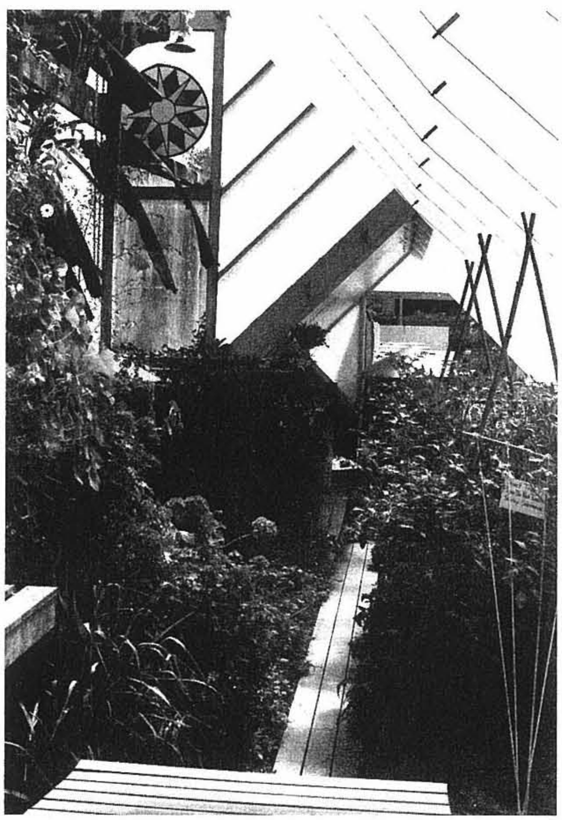


Hilde Maingay



Hilde Maingay

Toxic Materials in the Bioshelter Food Chains and Surrounding Ecosystems[1]

Dr. Han Tai,[2] Colleen Armstrong and John Todd

The following tables show the results of a preliminary screening of potentially toxic materials that might be found at the institute. DDT and chlordane, used some time before our tenancy on the New Alchemy farm, still persist in the soils—an unfortunate legacy from past farmers. The other toxin, heptachlor epoxide, is a pesticide used before World War II. Its occurrence in soil is a mystery.

The chlorinated hydrocarbons seemed to be locked into the soils, reaching their greatest concentrations in the field in front of the bioshelter, then diminishing in the Ark, and ultimately disappearing in the woods that ring the farm. A report on heavy metals is not yet complete. Perhaps the best news is that newer pesticides were not found in the samples.

[1]The toxic substances study was financed jointly by Rockefeller Brothers Fund (sampling, shipping, and evaluation) and the Environmental Protection Agency.

[2]Toxicant Analysis Center NSTL/NASA Bay Saint Louis, MS 39529

Table 1. A COMPARISON: LEVELS OF TOXIC MATERIAL IN ASSORTED VEGETATION SURROUNDING NEW ALCHEMY INSTITUTE, OCTOBER 1979. RESULTS IN PARTS PER BILLION.

Sites	*Technical Chlordane*	*pp DDE*	*op DDT*	*pp DDT*	*Heptachlor Epoxide*	*Dieldrin*	*Organo-Phosphates*	*Organo-Nitrogens*	*PCB's*	*Pathalates*
Bioshelter I Kale (leaves)	ND[a]	ND	ND	ND	ND	ND	ND	ND	ND	ND
New Alchemy Inst. Garden plot Kale (leaves)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Non-organic Garden plot Kale (leaves)	ND	–[b]	–	–	–	–	–	–	–	–
Bioshelter I Tomato (fruit)	ND	–	–	–	–	–	–	–	–	–
New Alchemy Inst. Garden plots Tomato (fruit)	ND	–	–	–	–	–	–	–	–	–
Non-organic Garden plot Asparagus (leaves)	ND	–	–	–	–	–	–	–	–	–
New Alchemy Inst. Garden Plot Asparagus (leaves)	ND	–	–	–	–	–	–	–	–	–
New Alchemy Inst. Garden plot Carrot (root)	ND	–	–	–	–	–	–	–	–	–
N.A.I. Garden plot Adjacent road Carrot (root)	ND	–	–	–	–	–	–	–	–	–
Bioshelter I Celery (leaves)	ND	–	–	–	–	–	–	–	–	–
New Alchemy Inst. Garden Plot Celery (leaves)	ND	–	–	–	–	–	–	–	–	–
Woodlands adjacent New Alchemy Inst. Bishops laurel (leaves)	ND	–	–	–	–	–	–	–	–	–

[a]ND: Nondetectable, below detection limits.

[b]Dash means test failed, no data available.

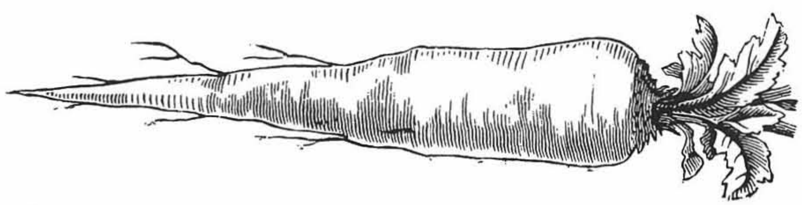


Table 2. A COMPARISON: LEVELS OF TOXIC MATERIAL IN WATER SOURES SURROUNDING NEW ALCHEMY INSTITUTE, DECEMBER 1979. RESULTS IN PARTS PER BILLION.

Sites	*Technical Chlordane*	*pp DDE*	*op DDT*	*pp DDT*	*Heptachlor Epoxide*	*Dieldrin*	*Organo-Phosphates*	*Organo-Nitrogens*	*PCB's*	*Pathalates*
Bioshelter I Solar-Algae Ponds	ND[a]	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bioshelter I Cement Pond	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
New Alchemy Inst. Original water source	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Natural Pond Adjacent New Alchemy Inst.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Spring Water Source	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a]ND: Nondetectable, below detection limits.

Table 3. LEVELS OF TOXIC MATERIAL IN SOILS SURROUNDING NEW ALCHEMY INSTITUTE, NOVEMBER 1979. RESULTS IN PARTS PER BILLION.

Sites	Technical Chlordane	pp DDE	op DDT	pp DDT	Heptachlor Epoxide	Dieldrin	Organo-Phosphates	Organo-Nitrogens	PCBs	Pathalates
Original farmer field	313.9	976.4	500.3	2794.7	8.8	8.5	ND[a]	ND	ND	ND
Field adjacent Bioshelter I	–[b]	320.6	80.2	506.2	ND	ND	ND	ND	ND	ND
Bioshelter I	249.7	160.0	64.8	300.8	9.8	ND	ND	ND	ND	ND
Nonorganic garden	67.2	51.8	29.8	120.8	ND	ND	ND	ND	ND	ND
NAI garden adjacent road	35.4	82.2	17.3	114.3	ND	ND	ND	ND	ND	ND
Household greenhouse	193.0	52.7	19.6	60.3	ND	ND	ND	ND	ND	ND
Experimental plot (bean field)	39.4	36.2	10.0	45.2	ND	ND	ND	ND	ND	ND
Leaf storage area	45.8	20.5	9.4	35.7	–	ND	ND	ND	ND	ND
Woodland adjacent to NAI	–	52.1	–	86.1	ND	ND	ND	ND	ND	ND

[a]ND: Nondetectable, below detection limits.

[b]Dash means test failed, no data available.

Table 4. EPA DETECTION LIMITS OF TOXIC MATERIAL ANALYSIS FOR SOIL AND VEGETATION SAMPLES.

Toxic Material	Detection Limits (ppb[a])
1. Early eluters: heptachlor epoxide	0.01
2. Late eluters: all DDTs, dieldrin	0.02
3. All multicomponent pesticides: technical chlordane, PCBs	0.05

[a]ppb: parts per billion.

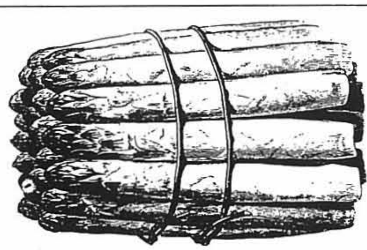
Table 5. EPA DETECTION LIMITS OF TOXIC MATERIAL ANALYSIS FOR WATER SAMPLES.

Toxic Material	Detection Limits (ppb[a])
1. Early eluters: heptachlor epoxide	0.10
2. Late eluters: all DDTs, dieldrin	0.50
3. All multicomponent compounds: technical chlordane, PCBs	1.50
4. Organophosphates	
Early eluters	1.00
Mid eluters	2.50
Late eluters	5.00

[a]ppb: parts per billion.

Table 6. TIME COMPARISON OF TOXIC MATERIAL IN BIOSHELTER I SOILS 1979. RESULTS IN PARTS PER MILLION.

Toxic Material	January 1979	November 1979
Technical chlordane	0.51	0.25
p, p = DDE	0.14	0.16
o, p = DDT	0.09	0.06
P, P = DDT	0.34	0.30
Heptachlor epoxide	0.01	0.01



Reglazing

John Wolfe

The winter of 1978–1979 seemed unusually hard on Cape Cod Ark: plants grew slowly, the night air temperatures chilled almost to freezing, and the solar-algae ponds chilled to nearly the lethal limit for our tropical fish. Meanwhile, returning friends who last saw the Ark just after its completion kept commenting on how much whiter the fiberglass glazing appeared.

In late winter we made a computer prediction of light transmission through the fiberglass-reinforced plastic cover and into the Ark. We also measured light levels outside and in the Ark. Measured light transmission through the glazing into the Ark was only one-half to two-thirds of predicted levels. "Either a mistake in our computer program or the unpredicted effects of water condensation on the fiberglass," we surmised.

By midsummer we had second thoughts and contacted the manufacturer. Yes, they told us, it was possible for their oldest version of solar glazing to deteriorate in the Ark's three-year lifetime. No, painting new resin over the old probably wouldn't recover the original light transmissivity. According to the manufacturer, the old material degraded because glass fibers extended through the resin to the interior surface of the glazing. Moisture wicked through these fibers into the core of the glazing and under hot, sunny conditions turned into steam. This burst the fiberglass along a myriad of tiny cracks, crazing and whitening the glazing. Their new glazing, they assured us, had a protective coating on the interior side, and they donated enough new fiberglass to cover the south face of the Ark.

When the fiberglass arrived in September the work began. The old panels had been secured with hundreds of galvanized screws and sealed with an impressively durable and tenacious bead of silicone caulk. All the old work had to be undone, and new panels had to be assembled in the barn by pop-riveting the new fiberglass to both sides of aluminum channels that acted as spacers. The fiberglass sheets flex easily when not in place, and the most difficult task was moving the flexible panels without accidentially creasing or cracking the sheets. As a side project, we upgraded the Ark's weatherstripping and wall insulation.

Nearly every Alchemist and apprentice, skilled or inexperienced, helped in the mammoth undertaking, as well as volunteers from as near as Falmouth and as far away as Costa Rica. Proficiencies were cultivated in pop-riveting, caulking, drill-screwing, and teetering on ladders.

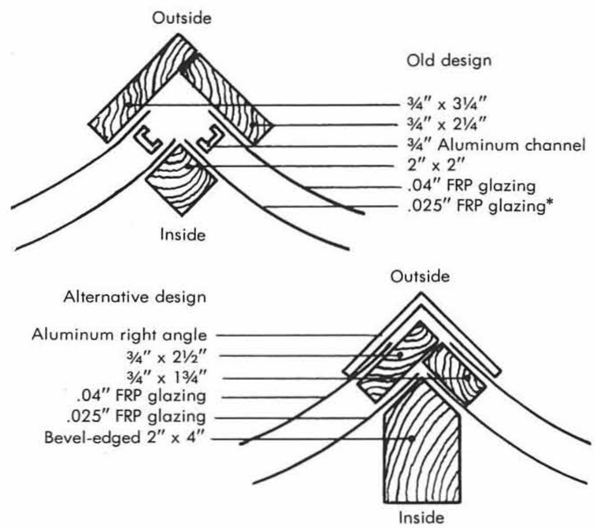
Would we repeat the same design next time? The panels, curving inward in the center to form concave troughs, have their advantages. The curve transmits light more evenly through the day than a flat surface, avoiding the sharp peak of heat input at noon characteristic of flat glazing surfaces. Comparing the curved surface with the flat, less light enters at noon, but more light enters near sunrise and sunset. New Alchemy computer simulations of light transmission suggest that over a day almost exactly the same total amount of light gets through the curved surface as a flat one. The more evenly distributed light of the curved panels probably increases plant photosynthesis by avoiding both leave overheating around noon and underlighting in the early morning and late afternoon. More constant light entry also prevents excessive air temperatures and allows storage components more time to soak up the heat.

The curves also give strength, allowing much less structural support. The bellies of the fiberglass draw water condensation away from the structural wood rafters and down to a drip edge that spills the condensation droplets into the gutter. Each panel collects as much as a gallon of condensate over a winter night.

On the negative side, the curves add 12 percent more surface area than a flat expanse on the south side, and the heat loss through the glazing is correspondingly higher. Curving the panels, hanging them in place, and sealing the edges consume enormous amounts of time.

If we did choose to keep the same shape, we might assemble the panels differently next time. Rather than a sandwich of wood two-by-two inside, fiberglass sheet, aluinum channel, fiberglass sheet, wood 1x batten outside, we might use a sandwich of bevel-edged two-by-six support inside, fiberglass (0.025 in.), 1x wood spacer, fiberglass (0.04 in.), outside aluminum angle batten (see accompanying diagram).

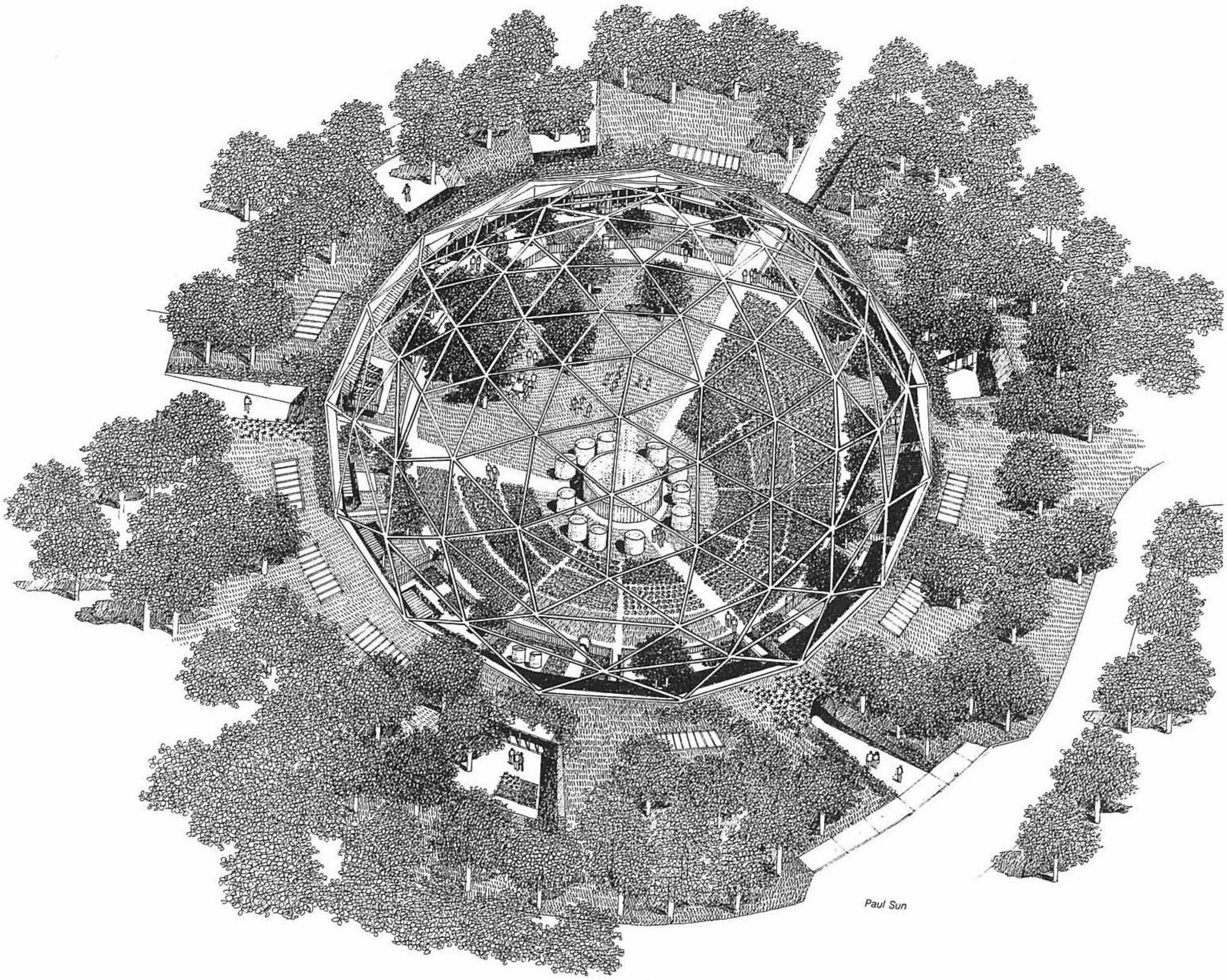
The wooden spacers avoid the time-consuming procedure of pop-riveting the fiberglass to the aluminum channel. Wood spacers should also allow the fiberglass to be nailed directly to the support rafter. The thin outside aluminum batten avoids the early morning and late afternoon shading that occurs with thicker wooden battens that protrude above the glazing surfaces.



*The original inner skin was 0.04 in. fiberglass reinforced polyester. The 0.025 in. skin was installed upon reglazing for better light transmission.

Time constraints limited the reglazing project to reassembling the old design. The project was completed in November 1979 and cost the institute $1,083 in professional carpentry help and $946 in materials beyond those contributed. In addition, the project required several person-months of New Alchemy staff labor. We trust that we will not have to repeat such a massive undertaking in the near future, that the manufacturer's claim of a 20 year lifetime for the new glazing is true. The longevity of solar glazings remains a critical question for materials science.

The initial results of installing the new glazing are encouraging. The panels appear more transparent than the old ones ever were. The vegetable crop in December 1979 outweighed production in December 1978 by 2.7 times. Though crops and weather differed slightly, the predominant change was the new glazing. The Ark once again sails through winter blizzards with a tropical climate within.



Modeling and Design of Future Biosheltera

Joe Seale and John Wolfe

There are myriad design possibilities for the next generation of bioshelters. Questions that need to be answered concern such difficult design trade-offs as light vs. warmth and such elegant design synergies as aquaculture units doubling as heat storage. Building shape, glazing, thickness of insulation, insulated area, and internal components influence the interior solar climate. Creating computer models to test such design variables is considerably more economical than putting up separate buildings to do so. The computer model, called SUNAI1, explores domes with different types and numbers of solar membranes, with different aspects (height-to-diameter ratio) and with various interior configurations of soil, plants, and water.

Description of the Program

DOME 1 dynamically simulates solar dome temperatures based on hourly weather data measured at Boston's Logan Airport. The weather data consists of wind speed, temperature, total incidence of solar radiation, and a computed breakdown into direct and diffuse sunlight components. In comparison to Logan, New Alchemy on Cape Cod experiences lower wind speeds, slightly higher temperatures, and more sunlight.

The shape of the dome is approximated by 50 facets. Light penetration of each facet is based on the solar incidence angle with respect to the facet and a transmission function based on the glazing materials (five glazing configurations are tested). Structural framing reduces the effective glazing area. Light penetrating the dome and hitting the opposite glazing is partially transmitted and partially reflected back into the dome.

The absorption of entering light is divided three ways according to the solar elevation. The three absorptive surfaces are

1. Translucent aquaculture silos.
2. Soil.
3. Plant surfaces in thermal equilibrium with the air.

The heat storage elements are: air (includes plant mass), the water of the aquaculture units, and soil subdivided into three layers (0–3, 3–12, and 12–36 in. in depth).

Heat flow driven by temperature differences occurs between

1. The adjacent layers of soil.
2. The topsoil layer and interior air.
3. Water and interior air.
4. Interior air and exterior air.

Interior-to-exterior heat exchange includes a combined conduction/convection/radiation coefficient for the dome glazing and a comparable term for the structural members. Air infiltration comprises additional heat loss and depends on air humidity and wind speed.

Easily varied input parameters include the following:

1. Dome radius and height.
2. Shading from structural framing.
3. Thermal conductivity of structural framing.
4. Glazing configuration (number of layers and types of glazing, including Southwall Corporation's HEAT MIRROR.
5. Reference air infiltration rate and wind speed dependence.
6. Average dome humidity.
7. Plant cover as a fraction of total ground area.
8. Ground corrugation factor (corrects air/soil heat transfer area for raised growing beds).
9. Soil thermal conductivity and heat storage capacity.
10. Number of standard-size solar ponds (5 ft diameter and 5 ft high water-filled silos).
11. Overheating temperature above which heat is vented to the outside.
12. Time interval of the simulation.

The computer, directed by DOME 1, takes TMY weather data, combines it with the hypothetical building's characteristics, and predicts the resulting light and temperature levels within. The computer makes its predictions by moving through imaginary time in small increments (or steps), calculating temperatures within the building at each step. This is the process of computer simulation. For all simulation runs that follow, the interval was six minutes. For each time interval the program computes rates of heat flow according to present temperature differences and insulation rate (sunlight intensity) as thus rates of temperature change. These rates determine temperatures at the next time point and ultimately the temperature fluctuations through time.

The simulated temperatures may be slightly underestimated because

1. Air film thermal resistances on the inside and outside of the dome skin may be considerably higher than the standard ASHRAE (American Society of Heating, Refrigration, and Air Conditioning Engineers) coefficients used. The dome's shape may foster low turbulence air flow along its inner and outer surfaces, creating a thick insulating air film.
2. Reflection of light into the dome off the ground surrounding the dome is not considered.
3. Heat production from compost is not considered.

On the other hand, the simulated temperatures may be slightly overestimated because

1. Ground perimeter heat loss is not considered.
2. Reflection of light off interior surfaces and back out the dome is not considered.

Results

The results of the DOME1 simulation are summarized in Tables 1, 2, and 3. The program's weather data covers the period from January 15 to February 14, and encompasses the harshest combination of cold weather, cloudiness, and low sun angles. In all runs the dome diameter is set at 80 ft. The model assumes the dome contains no active fan-driven heat storage components, but does include 36 solar ponds (5ft diameter and 5ft high water-filled silos).

Table 1. CONDITIONS IN HYPOTHETICAL DOME BIOSHELTERS—JAN. 15 TO FEB. 14.

Glazings	Aspect[a]	Interior Light Level[b]	Temperatures (°F)		
			Avg. Midpoint	Avg. Daily Swings	Monthly Extremes
Three (heat mirror)	¼	277	55.3	13.9	42.4–74.3
	⅜	323	55.0	15.1	39.7–74.8
	½	378	53.0	16.4	36.3–73.6
Three (reg. film)	¼	345	53.6	16.5	37.8–74.7
	⅜	394	51.7	17.5	34.8–73.6
	½	453	49.6	18.5	31.7–72.3
Two reg. layers	¼	358	48.4	16.4	32.3–69.5
	⅜	408	46.7	17.4	29.7–68.5
	½	469	46.1	18.2	27.1–67.8

[a]Height/diameter; diameter is always 80 ft.
[b]Light has the units BTU ft^{-2} day^{-1} on the plant beds.

Although the computer calculates new light intensities every hour, and new heat flow rates and temperatures every six minutes, the information from a monthlong simulation can be summarized by the following five numbers.

1. Light intensity inside the dome striking the plant beds, averaged over the month (BTU ft^{-2} day^{-1}). Compare these figures to 550 BTU ft^{-2} day^{-1} day for average light levels striking the ground outside.

2. Average midpoint temperature of dome air: the *midpoint* between daily minimum and maximum temperatures, averaged for the month. This is near, and probably slightly higher than, the average temperature. The outside average midpoint temperature was 28.8° F for the simulation month.

3. Average daily temperature swing of dome air: the *difference* between daily minimum and maximum temperatures, averaged for the month. The average daily temperature swing for outside air was 12.4° F for the simulation.

4. & 5. Monthly temperature extremes for dome air: the coldest and hottest temperatures found inside the dome over the entire simulation month. The outside air temperature extremes were 6° and 55° F. The inside overheating temperature, at which venting occurs, is 80° F for all the following simulations.

All five variables affect plant productivity within the dome. Higher light levels enhance plant growth. All crop varieties have an optimum average temperature and an optimum day/night temperature swing (cool night temperatures reduce plant respiration, encouraging more efficient growth). Extremely low and high temperatures can permanently damage crops. Temperatures that persist below freezing can destroy even cool-weather crops, and temperatures above 80°–85° F often cause bolting and bitter flavor.

Table 2. INTERIOR LIGHT LEVELS AND MINIMUM TEMPERATURES FOR VARIOUS DOME GLAZINGS AND ASPECTS, INDEXED TO THE HEAT MIRROR SANDWICH AND TO THE SHALLOW ¼ DOME. BASED ON DATA FROM TABLE 1.

Glazing Comparison		Aspect Comparison	
Light Index (Ratio):			
3 w/H.M.	= 1.0	¼	= 1.0
3 w/Film	= 1.20 to 1.25	⅜	= 1.14 to 11.17
2 Layers	= 1.24 to 1.29	½	= 1.31 to 1.36
Minimum Temperature Index (Degrees Fahrenheit):			
3 w/H.M.	= 0.0	¼	= 0.0
3 w/Film	= −4.6 to − 4.9	⅜	= −2.6 to −3.0
2 Layers	= −9.2 to −10.1	½	= −5.2 to −6.1

Table 1 compares solar domes with different numbers and kinds of glazings, and with different height-to-diameter ratios (aspects). The glazings considered are the following:

1. Three layers of solar covers. The interior and exterior glazings are made of low-iron glass. Between them lies Suntek's Heat Mirror, a film that transmits some sunlight but reflects back into the dome most of the infrared radiation that would othewise represent a heat loss. Heat Mirror must be placed in a dessicated space between layers of vapor-impervious material (e.g., glass).
Maximum Light Transmission: 60%
Heat Loss Coefficient: 0.23 BTU ft^{-2} hr^{-1} $°F^{-1}$

2. Three layers of standard solar covers. Low-iron glass or a plastic equivalent make up the inner and outer skins. Between them lies a highly transparent solar film (e.g., one mil Teflon FEP film).
Maximum Light Transmission: 74%
Heat Loss Coefficient: 0.40 BTU ft^{-2} hr^{-1} $°F^{-1}$

3. Two layers of standard solar covers, consisting of low-iron glass or a plastic equivalent.
Maximum Light Transmission: 78%
Heat Loss Coefficient: 0.60 BTU ft^{-2} hr^{-1} $°F^{-1}$

These glazing alternatives represent a very important trade-off between light transmission and insulating value.

The height-to-diameter ratios, or aspects, considered are:

1. A shallow ¼ dome with a maximum height of 20 ft and a diameter of 80 ft.
2. A moderate ⅜ dome with a height of 30 ft.
3. A full hemisphere (½) dome with a height of 40 ft.

Table 3. AIR AND WATER TEMPERATURE DATA FOR VARIOUS DESIGN CONFIGURATIONS AND MODEL COEFFICIENTS—JAN. 15 TO FEB. 14.[a]

	Temperatures (°F)					
	Inside Air			Solar Ponds		
	Midpoint Avg.	Avg. Daily Swing	Monthly Extremes	Midpoint Avg.	Avg. Daily Swing	Monthly Extremes
STANDARD RUN						
3 w/H.M.	55.0	15.1	39.7–74.8	55.8	3.1	45.4–65.0
3 w/Film	51.7	17.5	34.8–73.6	52.7	3.6	42.2–62.9
2 Layers	46.7	17.4	29.,7–68.5	47.8	3.6	38.2–58.0
ALUMINUM STRUCTURE AS THERMAL BRIDGE						
3 w/H.M.	50.6	14.8	35.0–69.6	51.5	3.0	41.4–63.3
3 w/Film	48.8	17.2	31.9–70.0	49.9	3.5	39.7–61.7
2 Layers	44.9	17.1	27.9–66.7	46.1	3.5	36.9–57.1
LOWER AIR INFILTRATION RATE						
3 w/H.M.	57.5	15.5	43.1–78.9	57.7	3.2	48.7–67.8
3 w/Film	53.3	18.0	36.9–78.1	53.8	3.7	44.0–65.2
2 Layers	47.7	17.8	31.1–72.2	48.4	3.7	39.1–59.8
NO SOLAR PONDS						
3 w/H.M.	54.5	24.6	31.9–80.0	54.8	4.5	41.9–67.1
3 w/Film	51.6	27.8	27.3–80.0	51.8	5.0	39.1–65.0
2 Layers	47.4	27.6	23.4–80.0	47.3	4.8	35.0–60.5
NO PLANT COVER						
3 w/H.M.	53.9	11.3	40.1–70.4	55.9	2.7	45.9–64.4
3 w/Film	50.3	13.1	34.9–69.4	52.7	3.2	42.6–62.5
2 Layers	45.3	13.2	29.9–64.8	47.8	3.1	38.6–57.7
FLAT GROUND, NO RAISED BEDS						
3 w/H.M.	55.3	16.9	38.8–76.8	55.7	3.3	45.2–65.1
3 w/Film	52.0	19.5	33.8–75.7	52.6	3.7	42.0–62.6
2 Layers	47.0	19.2	28.9–70.5	47.7	3.7	38.1–58.2
WET, HEAVY SOIL						
3 w/H.M.	55.4	14.3	40.3–74.8	56.3	3.1	45.6–66.8
3 w/Film	51.8	16.7	35.2–72.8	52.8	3.6	42.3–64.3
2 Layers	46.7	16.6	30.1–67.6	47.9	3.6	38.3–59.5
DRY, LIGHT SOIL						
3 w/H.M.	55.0	15.9	39.1–75.5	55.5	3.2	45.3–64.5
3 w/Film	51.7	18.5	34.2–74.4	52.4	3.7	42.1–62.5
2 Layers	46.7	18.3	29.2–69.5	47.6	3.7	38.1–58.1
LOWER RELATIVE HUMIDITY (50%)						
3 w/H.M.	56.3	15.2	40.0–76.7	57.1	3.2	46.3–67.4
3 w/Film	52.4	17.7	35.3–74.6	53.3	3.7	42.7–64.5
2 Layers	47.2	17.5	30.1–69.5	48.1	3.6	38.5–58.8

[a]Height is always 30 ft, diameter 80 ft. Aspect is therefore 3/8.

Table 1 shows that during even the harshest month, the triple-glazed domes create an acceptable greenhouse environment. The table also reveals three very important trends:

1. The higher the aspect of the dome, the more light strikes the plant beds.
2. The higher the aspect of the dome, the wider the temperature swings and the lower the minimum monthly temperatures.
3. The heat mirror glazing sandwich creates the warmest temperatures but the lowest light levels, while the two layers of glazing create the highest light levels and the coolest temperatures.

The 3/8 aspect heat mirror dome and the 1/4 aspect regular triple glazed dome represent the best compromise between light and warmth. Temperatures are a bit lower than the Cape Cod Ark, while light levels are slightly higher.

Table 3 evaluates the thermal impact of various design options (design testing), and examines changes in assumed model coefficients (sensitivity testing). In all cases a 3/8 aspect 80 ft diameter dome is tested with the three glazing configurations listed above. All the results are compared to the "standard run," which matches the results listed in Table 1. Table 3 lists solar pond water temperatures as well as interior air temperatures.

In the standard run, the model assumes the aluminum framing for the geodesic structure has a thermal R-value of one (plus air film resistance). This insulating value could be provided by 1/4 in. foam covering the inner or outer surface of the aluminum framing, or by a 1 in. wood spacer between inner and outer aluminum ribs.

The first design test in Table 3 looks at what happens if the aluminum structure is continuous from interior to exterior, creating a thermal "bridge" or "short circuit" for escaping heat. The change lowers minimum temperatures in all cases. It most drastically affects the best-insulated dome glazed with heat mirror (causing a 4.7° F drop in minimum temperature) and least affects the worst-insulated double glazed dome (causing only a 1.8°

F drop). Insulating the structural members is more critical in the well-insulated design because heat loss from uninsulated members is great relative to the small total heat loss.

The second design test, reducing the air infiltration rate, demonstrates the inverse of the same principle. Lowering the air infiltration rate makes a significant improvement in the well-insulated heat mirror dome (a 3.4° F gain) and a lesser improvement in the double glazed dome (a 1.4° F gain).

The third design test removes the aquaculture component from the building. With the removal of this major thermal mass, all the domes exhibit 10° F wider average daily temperature swings, and 6–8° F lower monthly minimum temperatures. This computer run demonstrates the critical role solar ponds play in storing heat.

The drop in minimum temperature is greatest in the heat mirror dome. Successive degradations in dome insulation or heat storage cause lessening decrements in temperature. In the extreme cases of no insulation or no storage, nighttime dome temperatures could drop no lower than ambient temperatures. Hence we find that the more poorly insulated dome configurations have less to lose by reductions in heat storage.

The inverse of the heat storage principle is demonstrated in the next case. Here the plant cover is removed (in the standard run, plants cover 70 percent of the available surface area). This allows sunlight to strike the soil directly, rather than striking plant leaves that in turn heat the air. Thus removing the plant cover increases the effectiveness of soil heat storage. As the heat-retention principle suggests, this leads to a 0.4° F improvement in minimum temperatures for the heat mirror dome, but only a 0.2° F increase for the double glazed dome. In absolute terms, plant cover is not a critical factor in either case.

In the standard run, soil surface exchange area is enhanced by taking into account the sides of walk-way trenches between raised plant beds (a 1.4 times greater surface area than flat was assumed). As shown in Table 3, a flat growing surface yields slightly wider temperature swings and slightly lower minimum temperatures. The drop is small, but perhaps significant (0.9° F for heat mirror, 0.8° F for double glazing).

The last three runs change assumed coefficients in the model, and provide what is known as a sensitivity test. The first two of these runs examine the assumed properties of the dome's soil. In the first run, a wetter and heavier soil than that in the standard run is assumed. In the second run, a drier and lighter (e.g., higher humus content) soil is assumed. The wetter and heavier the soil, the better it holds and conducts heat. The extremes between wet and dry soil properties account for only a 0.9° to 1.2° F change in minimum temperatures of the simulation runs. The model is therefore not very sensitive to the unknown properties of the particular soil in the dome.

The last run alters the assumed average relative humidity of the air. At typical indoor temperatures, small changes in relative humidity represent large changes in air heat content because of the heat content of the water vapor. Losing humid interior air means a much greater heat loss than losing dry air of the same temperature. The standard run assumes a relative humidity of 70% whereas the last run assumes 50 percent. A 0.4° to 1.1° F increase in minimum temperature results. The average relative humidity is a large unknown in the model; in the Cape Cod Ark relative humidity cycles as low as 30 percent during the day and as high as 100 percent at night. The relative humidity has more impact during the day, when temperatures are elevated, since warmer air holds more water vapor at a given relative humidity. In future models it may be worthwhile to model the humidity cycles directly, although the present model does not seem unduly sensitive to different assumed humidities.

In summary then, four conclusions can be drawn:

1. An acceptable winter greenhouse environment is created by a triple glazed dome (with or without the special heat mirror film) containing solar ponds and situated in coastal New England.
2. The shallower the dome, the darker and warmer the interior becomes.
3. Better insulation, more heat storage, and more heat-storage exchange surface all reduce temperature swings and raise temperatures.
4. Insulation and heat-storage improvements have a greater temperature effect on already well insulated domes.

The next step in modeling solar domes is to examine them with opaque, insulated walls having reflective inner surfaces. Examining light entry through separate facets of clear domes can suggest the best glazing/insulation boundary for domes partially clad with opaque insulation. The facets transmitting the least amount of light should be insulated first.

Figure 1 shows the average daily incoming light transmitted through 300 facets of a double-glazed hemispherical dome. Figure 2 depicts light entering each facet, *minus* light that enters from the opposite side, shoots through the dome, and exits out that facet. Negative numbers occur along the steep northern facets in Figure 2, indicating that more sunlight leaves through these facets than

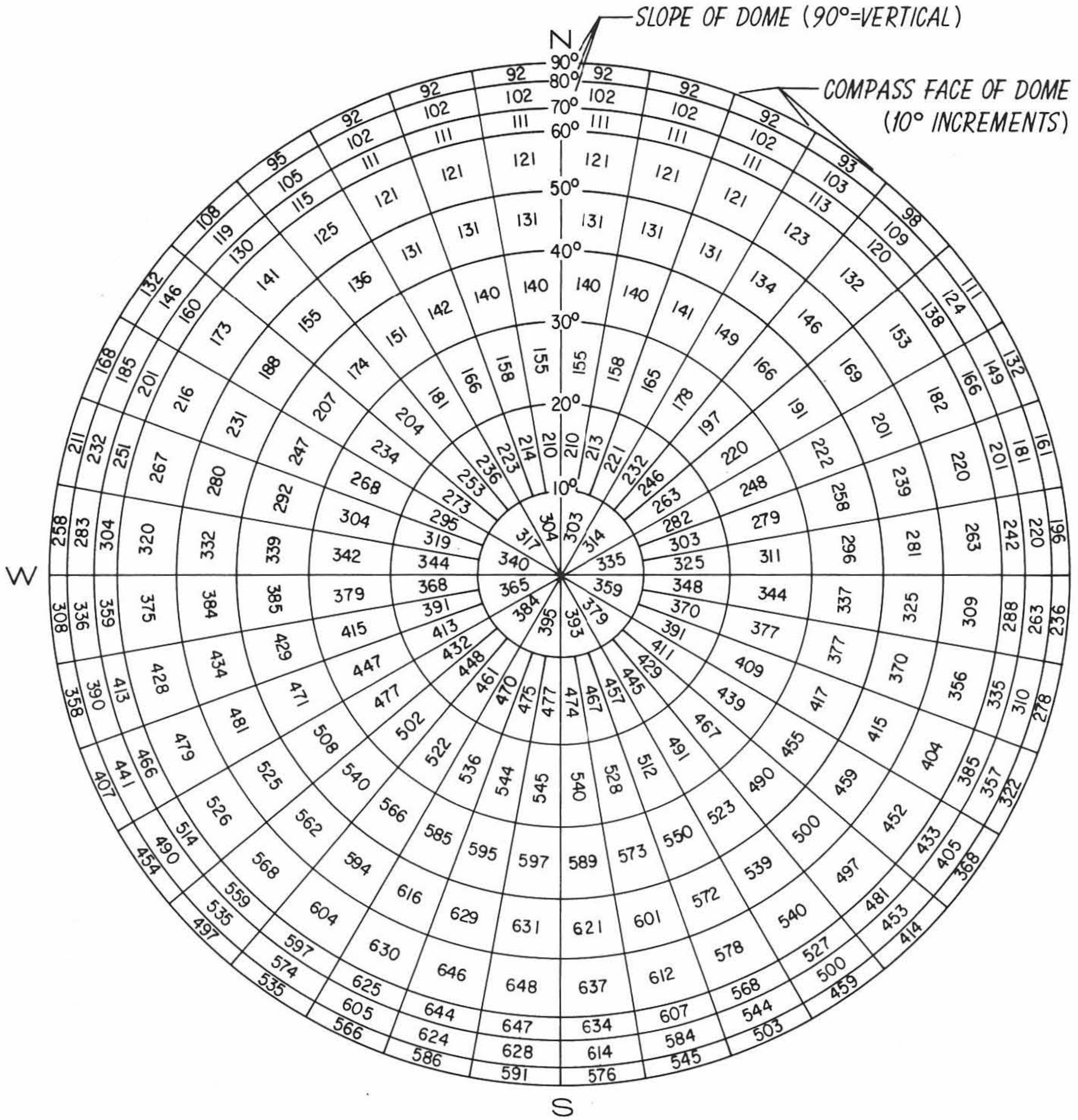


Figure 1. Incoming light gain transmitted through 300 facets of a double-glazed dome. Logan Airport, Boston, Massachusetts for a statistically typical January 15 to February 14 period.

enters. To maximize winter light levels on the growing beds, it is actually desirable to cover these facets with reflective foil to bounce outgoing light back into the building.

When using Figures 1 and 2, two caveats about the assumptions behind the model are in order:

1. No ground reflection is included in the model. This assumption underestimates light entry for steeper southerly surfaces.

2. Diffuse radiation is assumed evenly distributed across the sky. In fact, diffuse radiation clusters around the sun's position (see sky distribution patterns of dif-

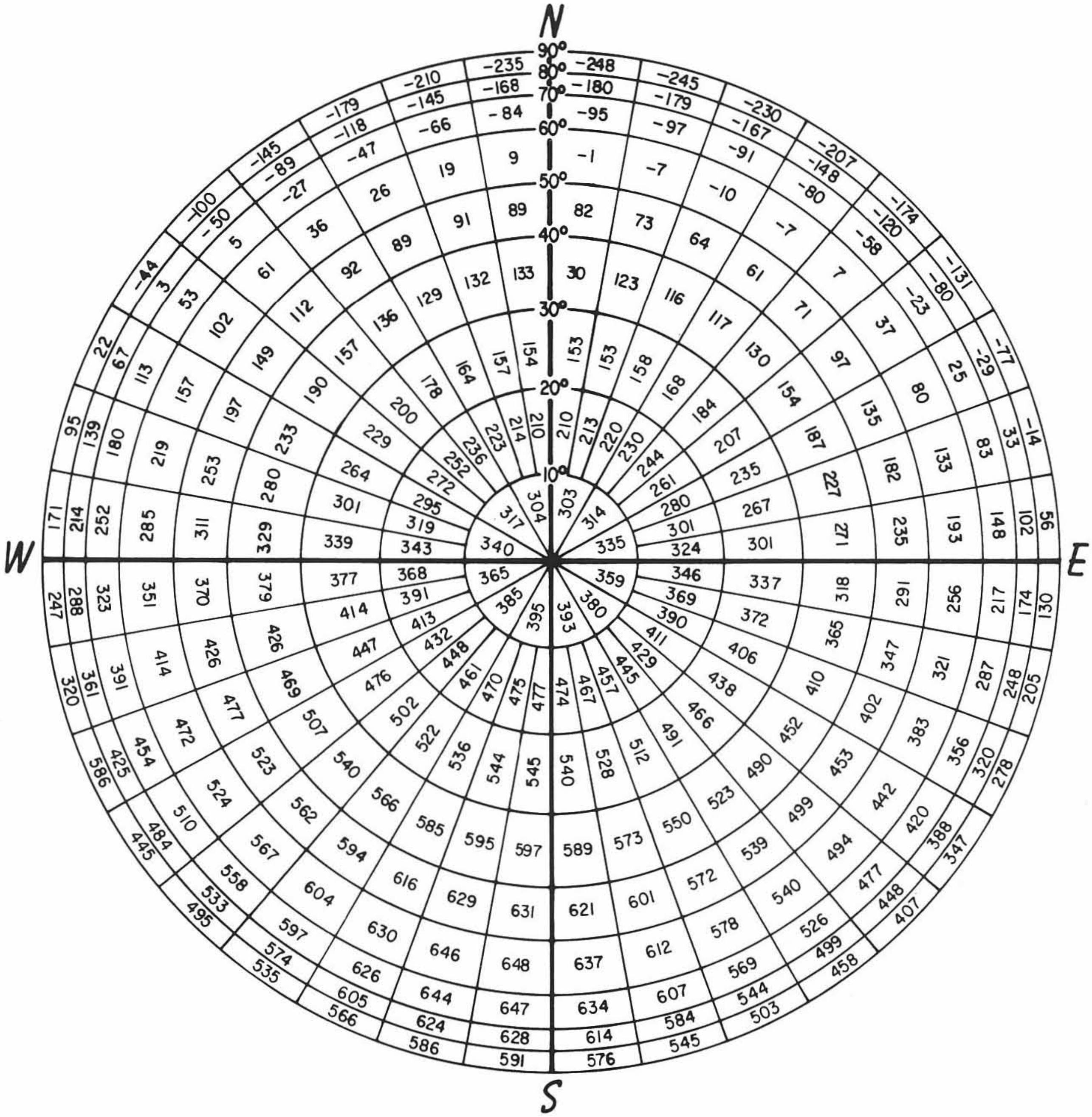


Figure 2. Net light gain (entering minus exiting light) through 300 facets of a double-glazed dome. Logan Airport, Boston, Massachusetts for a statistically typical January 15 to February 14 period.

fuse radiation diagrammed on p. 82 of Duffie and Beckman's *Solar Engineering of Thermal Processes*. The assumption tends to underestimate light entry on steeper south sides, overestimate it on the north.

Future versions of the computer model will examine north wall insulation, movable night insulation, and other shapes (such as Quonset and A-frame). With the climates of all these design options quantified by the computer model, we can then predict the crop productivity and capital cost of each design option. We will then know which design gives the maximum yield of organically grown off-season vegetables per dollar invested.

Ron Zweig

PUTTING OURSELVES on the LINE

They say that there is often a certain simultaneity to new ideas. The experience of Alfred Wallace and Charles Darwin—who independently came up with similar theories of evolution—comes at once to mind. In a modest way, in early 1979 the same sort of thing occurred at New Alchemy. For years we had been shifting a bit uneasily when enthusiastic visitors to the farm would say something like, "It's wonderful! And I suppose you live like this at home too?"

Awkward. Because at the time, we didn't. But in the early winter of 1979, Denise—stationed in the main office, which functions rather like the central nervous system of the place—was the first to get wind of what was coming. She began to pick up scraps from various conversations, direct or overheard. Piecing them together she came up with the news that six different New Alchemy households had decided to go solar. Predictably and characteristically, we were all intending to do so in six very different, highly individual ways. Just what the dynamics were that made this blossoming of solar structures close to simultaneous, we're still not sure. Perhaps sometimes ideas are contagious, like colds.

A year and more later our respective efforts at solarizing are complete. I asked the various people involved to tell their stories in their own ways. The pieces that follow are just that: why and how six different households incorporated solar greenhouses into their lives and how it feels to have done so.

N.J.T.

The BAM[1] Greenhouse: Homemade Tapestry

Hilde Maingay

It is winter vacation 1980. Flowering geraniums, impatiens, and nasturtiums. A summer bouquet in the winter. Sitting at the table, I can stretch my arm to pick a big salad for dinner. I clip the lawn of the floor under the table—no sweeping here! The kids play a game of cards in T-shirts. Laughter and red, warm faces. A cool drink of grape juice,

[1]BAM = Barnhart–Atema–Maingay greenhouse.

just taken from the icehouse, in their hands. Not too much later and the grapevine just outside the greenhouse door wil be "watered" by the boys. Ate walks by the honey pot in the kitchen, sticks his finger in the pot and licks, then goes outside to get some logs of firewood.

The smells from the oven mix with those from the scented geraniums. A kale and chard soufflé is cooking. Sven takes the container with kitchen scraps and empty eggshells outside to the chickens, returns with a handful of beautiful eggs. Jurgen is in charge of making dinner. He loves custard pudding—the fresh eggs never make it to the cold storage in the icehouse. Layers of homemade applesauce alternate with layers of custard pudding and are topped with raspberry sauce! The raspberries last year were picked from the bushes in the chicken yard near by. The bushes give shade to the chickens and pollen to the bees, the chickens in turn keep the berry patch weeded and fertilized while the bees pollinate the berry flowers and give us honey to make the sauce.

While dinner is getting ready, I mix up some potting soil. As is the soil for the vegetable beds in the greenhouse, the potting soil is mainly made up from the soil and manure in the chicken yard (a bag of laying mash can go a long way—eggs, meat, compost), then mixed with the some peat moss and vermiculite. I seed a flat with birdhouse gourds, special seeds grown by a member of the American Gourd Society. The gourds last for several years and will attract many birds to the gardens where they will act as a natural pest control.

It is eighty degrees in the greenhouse, bright and light. The house is comfortable at seventy degrees, but the lights are already on. The kids' rooms in the basement are pretty constant at a cool sixty to sixty-five degrees. Little excess heat comes from the oil furnace—next to their rooms—these days, as it no longer needs to run except for domestic hot water. Ate starts the fire in the wood stove, puts the insulated shutters in the windows. The sun is low behind our neighbor's house. It will soon get chilly in the greenhouse. The kettles are filled with water and put on the stove. Drips of water sizzle as the stove is heating up—there will be hot water for dishes, coffee, and tea after dinner.

In the greenhouse the chameleon moves slowly behind the Spanish moss hanging in the bamboo. A spider drops down from the wooden beam. Ants crawl into their hideouts behind the stone walls, and O. J., our big white daddy goose, knocks on the glass door of the greenhouse asking for company and some fresh kale, chard, and grass shoots. Tomorrow I will sprinkle the wood stove ashes on the lawn so the grass will get rich and green in the spring when the goslings will hatch. Tomorrow I also will do some bench grafting onto the hardy apple rootstocks and pot the new bee plants that just arrived today through the mail. Let's see . . . and then I should also seed the tomatoes, eggplants, peppers, chard, marigolds, rosemary, thyme, parsley, and sage—and a few cucumbers to replace the winter greens in the greenhouse and provide shade in the summer—and I shouldn't forget to check on the nuts that are being stratified in the cold storage, and . . .

"Dinner is ready, Mom."

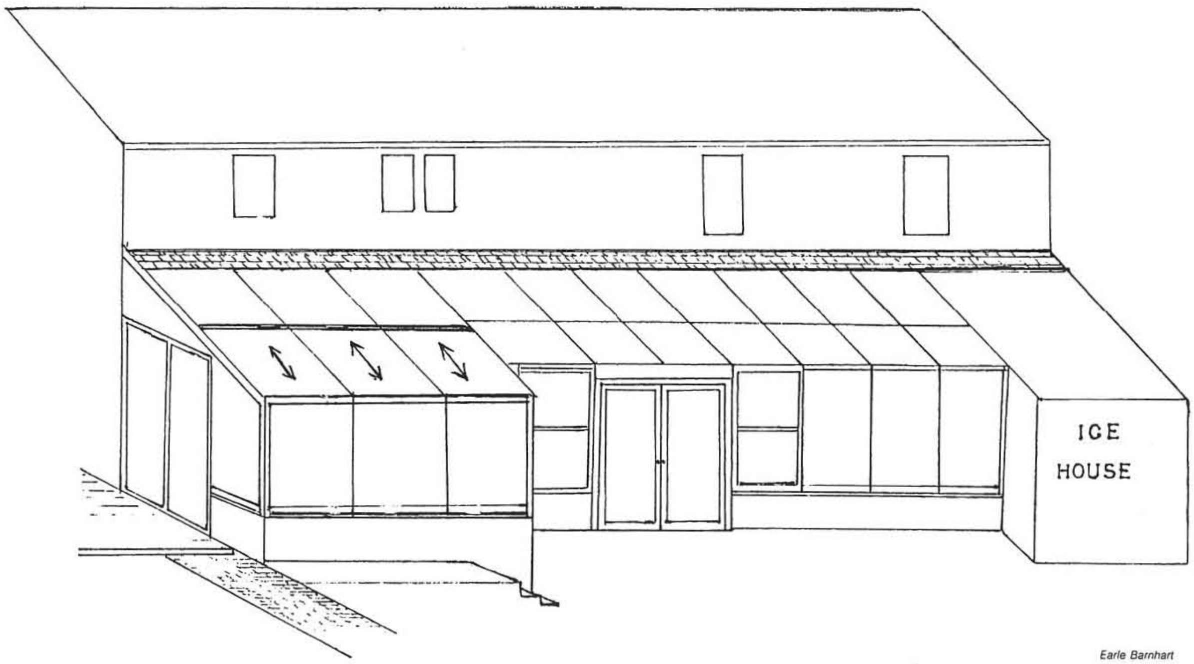
"Earle, dinner!"

Hilde Maingay

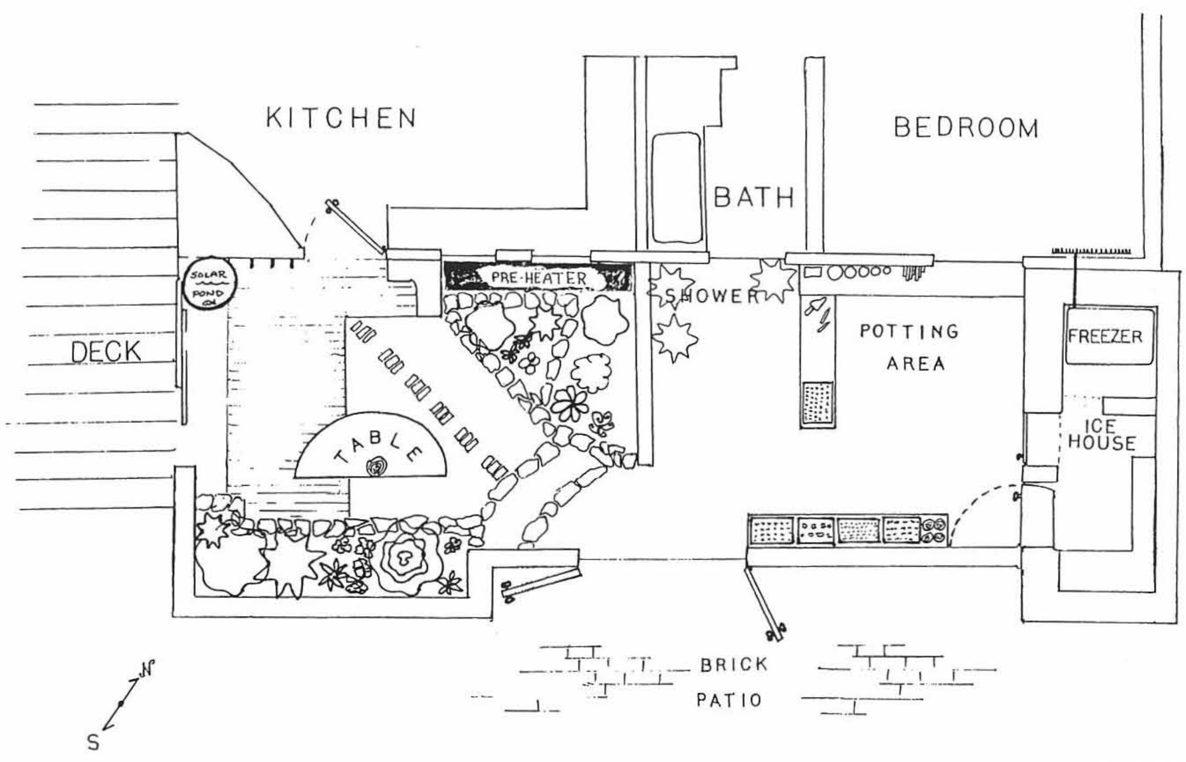
The BAM Greenhouse: It's Great

Ate Atema

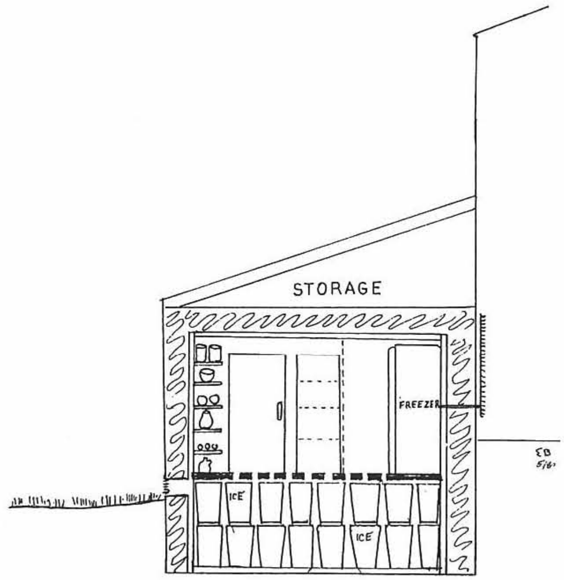
It's great. The greenhouse adds a new feel to the house, a more unrestricted feel. At times, letting the temperature soar to 120 degrees and the humidity to saturation while reading or just simply relaxing can be undeniably therapeutic to mind and body.



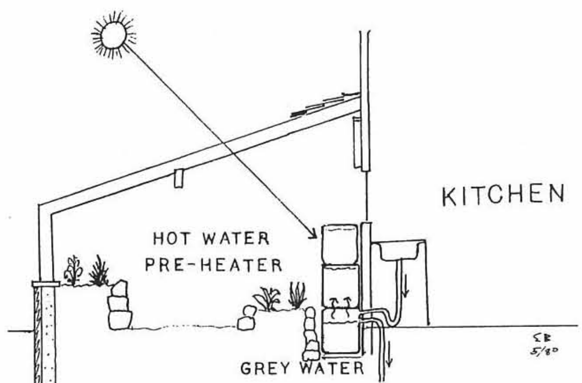
Earle Barnhart

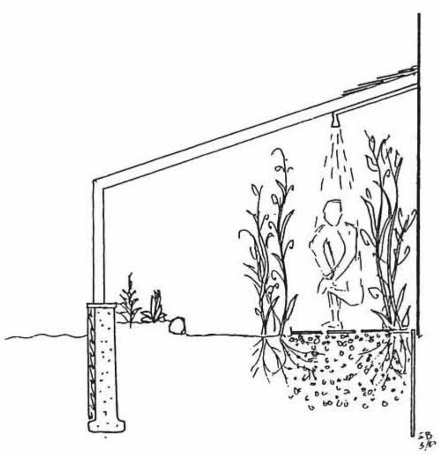


Earle Barnhart



ICE HOUSE FOOD STORAGE





SHOWER AND GRAVEL BED

Earle Barnhart

An amazing fact of life with the greenhouse is its truly open warmth in the winter. If only we could tear down the wall separating it from our dining room; it would be quite an experience to have a formal meal by candlelight under the stars and surrounded by a crush of foliage in the midst of December.

Having the greenhouse is fantastic. As a matter of fact, it's so much fun, I don't think I could imagine having a house without at least something like this.

The BAM Greenhouse: Notes on Intent, Function, and Form

Earle Barnhart

In the lineage of bioshelters, the several attached home greenhouses built by New Alchemists this past year are not so much a second generation as they are stepchildren. Each is descended partly from New Alchemy's experimental/research bioshelters and partly from individual family style, and the resulting forms are surprisingly different. As an institute we will continue to evolve successive generations of experimental bioshelters to explore concepts, but as individuals we will find that these at-home systems will be the real test of practical viability.

Our greenhouse was designed to include several qualities either overlooked or lacking in the Ark. We wanted it to be architecturally durable, domestically comfortable, and relatively maintance-free. The clearest lesson we learned by planning and constructing the greenhouse is that there are great advantages to building carefully and slowly: carefully so that shortcuts are not forever-after regretted and slowly so that serendipitous changes can be considered and included. We did all of the construction ourselves, slowly, and in many instances suddenly saw that a variation from the original drawings would be much more convenient or aesthetic. These were invariably matters of perception, unpredictable from paper drawings, such as where was most pleasing to walk and what shapes of corners or heights of ceilings seemed comfortable. Often an array of strings or light poles at the proposed position would decide the matter.

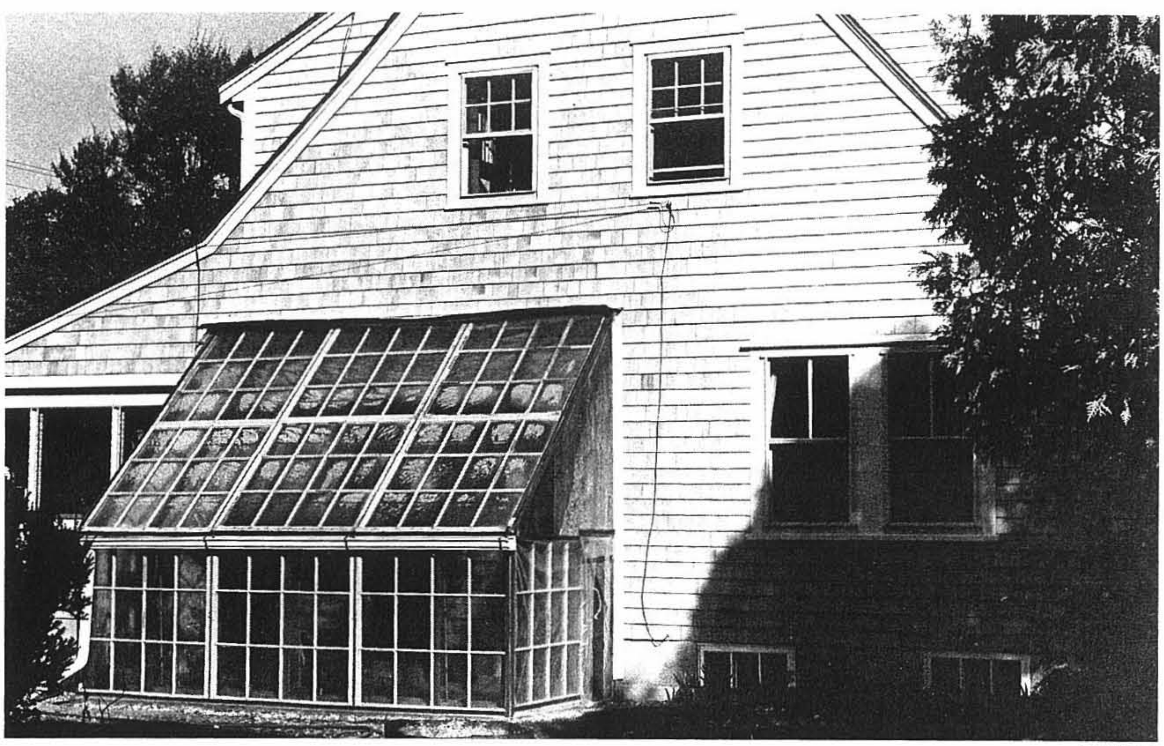
Concepts and details of design that may be of interest include the following:

Durability—We wanted a structure that we would not have to worry about, replace, nor repair for a long time. The post-and-beam construction we chose will support every conceivable snow load and minimizes lapping lumber, which is prone to hold moisture. Thermopane glass inlaid into the beams minimizes maintenance. All connections are screwed for easier replacement.
Annual Function—There is a tendency for new greenhouse designers to think only of heat and only of midwinter. In reality the greenhouse is growing plants year-round, and for most of the year heat is not as important as enough light. We adopted the strategy of using the money normally put into several small vents toward large doors that open in summer and three glass roof panels that slide open. These changes reduce the distinction between inside and outside and let the greenhouse approach outdoor conditions.
Practical Matters—Our greenhouse has places to grow food, start seedlings, propagate perennial food plants, take a shower, eat lunch, and store food. Getting high and meditating through one means or another will not be treated in this section.
Innovation and Testing—There are a few ideas about bioshelters that can best be tested with the interactions of a household. We would like to test such integrations as: (1) Using heat from daily graywater to heat the greenhouse in the winter; (2) Using a wind-powered freezer to cool the icehouse adjacent to the greenhouse; (3) Gradually propagating the perennial food plants needed to landscape the property; (4) Exploring the physical, psychic, and spiritual implications of someday living in a larger, community-scale bioshelter.
Architectural Aesthetics—Appearance and material beauty count as much as efficiency in a living space. We wanted to be able to see into our back yard, to have a table for greenhouse dining, and to be able to enter or travel through the area easily, enjoying the materials used. Our ideal is to have such a blend of plants, floors, glass, and terraces that one can't be certain whether one is inside or outside.

We Scrounged and Recycled

Denise and Dick Backus

Each winter afternoon at dusk the cry of "shade and curtain time" goes through the house as one of us reminds the rest to draw the shades and curtains against the night. We've also added insulation and used laminated reflective backing on curtains to seal up northern windows (unimportant in our house) in our attempts to keep in that precious heat we've paid so dearly for. What to do next?



Denise Backus

The main rooms of our house—the kitchen and the living room—face due south and invite the attachment of a solar greenhouse. Because we have a lot to learn, we have begun by putting up a small and inexpensive structure. The greenhouse is about 13 ft long, 6½ ft from front to back, and 10 ft high at its point of attachment to the house. It encloses two living room windows and two cellar windows. The living room windows open high up in the greenhouse and the cellar ones at ground level, offering a good arrangement for setting up a natural convection loop. When the sun shines and the windows between house and greenhouse are open, warm air flows into the living room and cool make-up air enters the greenhouse from the cellar.

The principal element in the construction of the greenhouse is 11 recycled window sashes, each about 50 in. on a side. Three sashes form the vertical front and two rows of three the sloping roof; there is one sash at the front of each of the end walls. The sashes are supported by a simple frame of two-by-fours that rests on a concrete footing. Inch-thick styrofoam extends 24 in. into the ground outside the footing. The end walls that are not glass are plywood with styrofoam insulation on the inside. Monsanto 602 stapled over the outside forms the second glazing. One end wall has a 4 ft high door, which is the only entrance. Two 55 gallon drums filled with water add to the thermal mass inside. Plastic stapled over the joint between house and greenhouse mostly eliminates the infiltration of cold air. Near the end of the greenhouse's first winter, we are still adding to it and altering it.

The make-up air entering the greenhouse through the cellar windows at first came directly from the cold cellar. Now we lead it from the coolest part of the living room through a floor register into a duct formed on the cellar overhead by boxing in two of the floor joists. The duct leads to one of the cellar windows and is connected to it by a plastic skirt. This way the make-up air entering the greenhouse is already somewhat warm.

If the windows between house and greenhouse are opened when the greenhouse is cool, the convection loop runs backward; warm air flows from the living room into the greenhouse and cold air from the greenhouse wells up into the living room via the cellar window, duct, and floor register. To prevent this from happening we installed valves in the windows between house and greenhouse. We tacked pieces of fishnet over the windows. Sheets of very light plastic, like the kind in which dry cleaning is returned, are fastened on the living room side of the net in the living room windows and on the greenhouse side of the net in the cellar windows. When the greenhouse is hot, the plastic is easily wafted away from the fishnet in both windows by air flowing in the directions we want it to flow. When the greenhouse is cold and air wants to go the wrong way, the plastic is blown up against the fishnet, and the flow is stopped. This arrangement lets us open the windows between warm house and cold greenhouse early in the morning before we go to work with the assurance that the house will only gain heat from the greenhouse, not lose heat to it, no matter what the day's weather turns out to be.

Articles about solar greenhouse designs generally discuss a night-curtain last, if at all. If the greenhouse is a small one like ours, a night-curtain is absolutely necessary. (Large greenhouses can get by without one, because they have a large thermal mass in proportion to the area of the glazing through which heat comes and goes.) Designing and making a good night-curtain is not easy. An outside curtain is simple to fit, but it must withstand wind and weather and so is necessarily expensive. An inside curtain is hard to hold up into place.

We opted for an inside curtain. It is held up against the glazing by pieces of ½ in. electrical conduit at greenhouse ends and middle bent to follow the sloping roof and vertical front. The curtain itself is a so-called Roman curtain. It is made of two layers of Bubbl-pak®, a plastic material incorporating cells of air. Made for packing fragile articles for shipment, Bubbl-pak® is not bad insulation. Light strips of wood run across and are attached to the curtain at 1 ft intervals, and four sets of screw eyes are twisted into the strips. Four cords for accordioning the curtain run through the screw eyes and raise the curtain when pulled.

There are two main spaces for growing things in our greenhouse. Leafy vegetables can be grown in a ground bed along the front of the greenhouse. Plants in pots or flats sit on boards spanning the space between the two upright 55 gallon drums at the greenhouse rear. (There are also a few plants growing in the ground around the feet of the drums.)

Measuring greenhouse performance is a difficult thing. At present we can only say that on a sunny day we see and feel warm air coming from the greenhouse into our living room, raising the temperature there. And though it has mainly been a heater so far, we also have had things growing in the greenhouse when outside all was frozen. An alpine strawberry charmed us all winter with its glossy green leaves, flawless white blossoms, and red fruit.

So the greenhouse warms us a little and gives us a few plants to eat and to please the eye. It is

Ron Zweig

a serene and toasty place to sit for a few minutes on a winter noon. In all these ways it brings us into a direct contact with our physical surroundings and so, makes us feel more alive. The cost, because we scrounged and recycled, and don't reckon in our labor, is about $250.

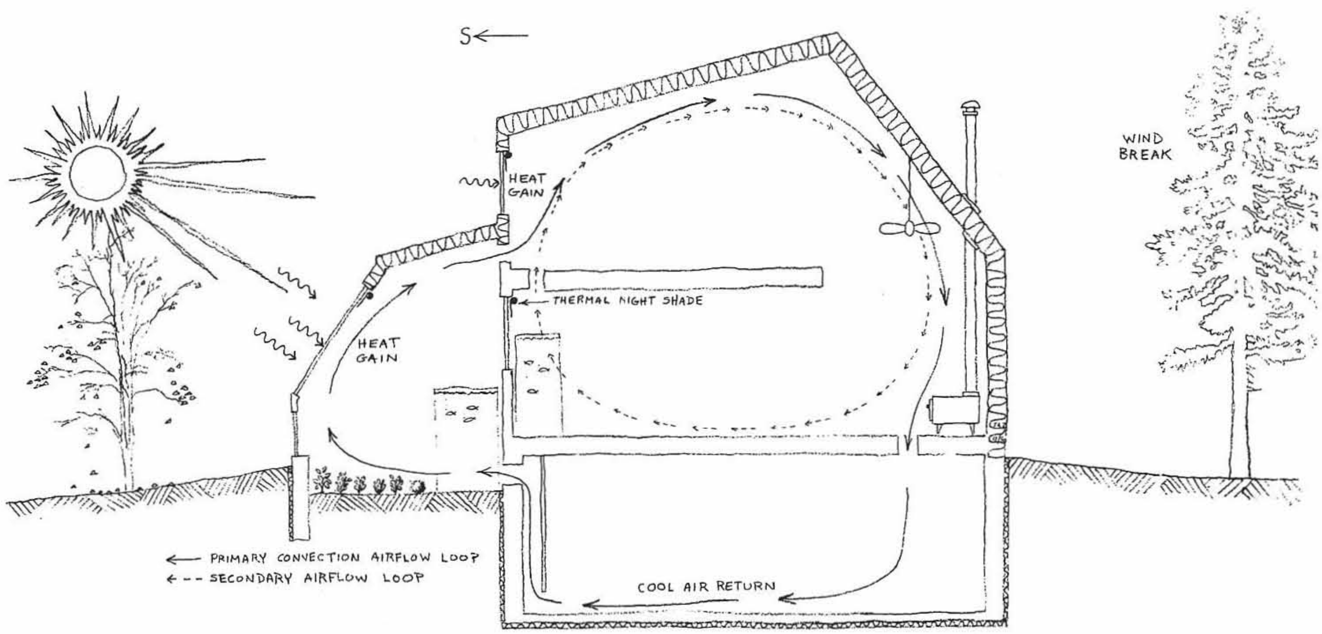
We are weekend gardeners, so the weather is always an interesting topic at our house. And, as for most people who work all week, a good weather weekend is a treat and often indicates what work gets done. Now, however, we are more aware than ever of the kind of day it is. And what are we going to do about those nice old cedars that shade our greenhouse for part of the day? They are our trees but also supply some of the only shade our close neighbors have in their tiny backyard. We have also become thermometer buffs. How hot in the greenhouse? What soil temperature? How many degrees of heat did it add to the house? Today, in mid-April it is 50 degrees outside; our house is 70. No heat is on. We still have a long way to go in our efforts to get off the oil habit, but getting there is a lot of fun and a continuing challenge. And the first one out of bed still checks out the day. Aaaah . . . another sunny one.

From the Ground Up

Christina Rawley and Ron Zweig

On our land we have planted two apple trees, two mulberry trees, a black walnut, and a copper beach. These and other deciduous trees will replace the pitch pines we removed to create an opening in the forest for our new house. On the cleared ground we have seeded buckwheat as the first cover crop and have started a vegetable garden just to the east of the house. As the summer unfolds it will stand amidst a sea of buckwheat. From the south, it appears to be sailing easterly, where it is greeted by the sun over Deep Pond each morning. The design, a modified saltbox, sits unobtrusively in its Cape Cod setting, facing south on Lily Pond.

We had searched for a house within bicycling distance of New Alchemy for nearly two years, but were unable to find one that could be modified for passive solar heating without major and expensive changes. Finally we chose to build from scratch.



The house incorporates a synthesis of old and new concepts in both heating and cooling. Many are untested so far since we have just been living in it since early spring. The summer and winter months ahead will test it. The climate control lies in air convection through the house. There are vents in the floor and walls and a minimum of closed off areas.

The main convection heating loop incorporates the entire air volume including the greenhouse and basement. During the winter, air warmed in the greenhouse will rise into the second floor living area through air vents in the intervening wall. Cooler air will drop to the basement through floor vents on the north side of the first and second floors. A basement window in the lower level of the greenhouse provides a channel for the coolest air to circulate into the greenhouse for heating, thereby completing the convective loop. This should raise the temperature of the masonry, the cement foundation and basement walls and floor as the outside walls of the basement are fully insulated. At night the vents to the greenhouse will be closed. There will be solar-algae ponds in the greenhouse.

A wood stove back-up may be necessary on colder winter nights. When it is in use, south floor vents will be opened and the north ones closed. A ceiling fan in the stairwell will circulate heat through the house, minimizing stratification that would create a second air flow loop. the direction of the fan is reversible so that, during the summer, it can force cooler air upward and warmer air out upstairs open windows. So far the air flow pattern works quite well. We'll know how well by winter. It will depend largely on the effectiveness of the wall and ceiling insulation and the window shades we have yet to install.

We feel the house's real treasure is the greenhouse. We will be able to raise some of our food all year and apply many of the techniques we have developed and tested at New Alchemy. the agriculture/aquaculture will keep us in close contact with living plants and animals. Our work with New Alchemy's bioshelters has given us this more as vistors than co-inhabitants. We anticipate that the constant exposure to the micro-ecosystems in our greenhouse will give us an ongoing relationship with living things even in the starkest periods of New England winters. We shall be living as co-inhabitants in the processes and as co-cartakers of this dwelling and parcel of land.

Why Not a Solar Greenhouse on the Second Floor?

Barbara Chase

I first visited New Alchemy in the fall of 1978. At that time I was primarily interested in growing better food. I had decided to eat only organically grown food, having experienced six months of the ill effects of poisoning of some kind—possibly from grupper fish, which is high on the food chain, or from a cumulative effect from many poisons. Doctors could not determine the exact cause, since the poison had left my bloodstream quickly and settled in my nervous system. However, the helpless feeling and the ill effects were enough to make me determined to avoid all potentially harmful substances.

Ron Zweig

I was impressed with the accomplishments and the environment I found at New Alchemy. In January 1979 I became a volunteer. I worked with Earl Barnhart on experiments in tree propagation and with Hilde Maingay in the Six Pack solar greenhouse.

My time there, so close to nature, especially enjoying the sun in the greenhouse on long, cold winter days, was healing and inspiring, and gave me new hope.

I began to think a lot about whether I could incorporate such a greenhouse into my own house—and where. I have a steep hill at the back of my house on the south side. This slope of the land would make a first-floor greenhouse difficult, if not impossible. But why not on the second floor, where we have a walk-in closet off our bedroom on the south side of the house? I thought it could bear the weight because the house is framed in steel, and I've had a water bed on the second floor with no problem.

I called Solsearch, the architectural firm that helped design the Ark. Ole Hammarland drew some rough sketches for me with structural requirements and detail for materials. He gave me fair assurance that the second floor could carry the weight required.

I spoke to a neighbor in the business of remodeling houses who was interested in the uniqueness of the project. We agreed on a price, and much to my surprise, within a week construction was underway.

By mid to late April I was able to start seedlings for my outdoor summer gardens, a joyful experience that has increased with each new step toward completion of the greenhouse.

In the fall my husband built two garden beds for my vegetables and put up a shelf for potted plants. I began filling the beds with soil, compost, and peat moss. I moved plants from the outside garden to their new home for the winter.

To wake up in the morning to the sun shining on green growing vegetables, flowers, and aromatic herbs was a wonderful reward for the work almost completed. I put small stone for drainage into zinc pans, covering the wooden floor, and patio blocks the color of red bricks for walking between the garden beds. We put four solar-algae ponds in place and filled them with water for heat collection and storage.

In October 1979 I went to work for David Engstrom, assisting with the water chemistry and learning about aquaculture. I wanted an understanding of this in order to care for my fish.

By January I had twenty-two tilapia occupying two solar-algae ponds. I felt a sense of tranquillity watching the fish drift quietly or swim exuberantly. The sunlight, especially the first morning rays, showed them off beautifully. The pond water was fertilizer for my plants. The system evolved into a balanced ecological cycle. My tranquillity comes from the search for an ecological balance and progress toward that end. All this life brought into a home gives me a feeling of rebirth. My happiest days are spent working in my solar greenhouse. I am recording information that will soon reveal how much food I'm growing. From what I've learned this year, I will be able to produce more next year.

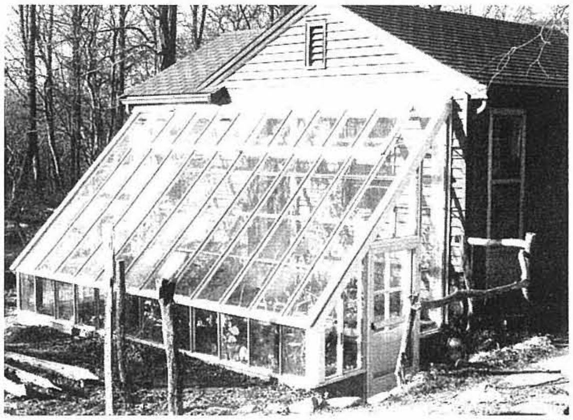
Some of the energy I'm collecting is blown into the room below the bedroom with a half-horsepower fan. It is used to conserve other forms of energy-consuming heat, and is therefore turned on at opportune times, so as not to waste electricity.

Collecting heat from my solar greenhouse is an added benefit. I will soon tabulate statistics to show how much fuel this supplementary heat conserves.

My solar greenhouse symbolizes the ability to conserve nonrenewable energy resources. However, using the same energy to grow food and for heat is no symbol. My solar greenhouse is only my first step in the use of soft technology. The expanded use of solar greenhouses and other soft technology gives me hope in the larger scheme of world affairs. Our environment can become healthy without the need to use nuclear power and other polluting energy sources, and I hope the need for war over a limited supply of oil, or any essential life-sustaining resource can be eliminated.

Many people have the potential for growing some food all year round with the help of a passive solar addition to an existing house or a passive solar beginning for a new one. Once such a lifestyle is initiated, I believe the joy will be incentive for expansion.

The final benefit to me is a new opportunity for learning. I find the opportunity for exploration of nature intriguing and boundless, and the working toward an ecological balance equally so.



Rick Beck

Notes From a Professional

Rick Beck

Tanis Lane's greenhouse was designed and built to meet requirements she set forth. The main purpose of the greenhouse was to provide heat for the house, to allow plants to be grown year round, and yet to be roomy enough to feel comfortable and pleasant. Of course, it had to be as inexpensive as possible.

The design and construction of an attached bioshelter presents special problems not encountered in normal residential construction. The greenhouse designer must keep in mind that the design characteristics that yield maximum net heat gain are opposed to those that maximize biological production. Just as important is the careful consideration of details. As in most other activities, attention to detail makes the difference between adequacy and excellence. In the case of a bioshelter, it also determines the durability of the structure. Presumably any building addition beyond the most rudimentary should last as long as the house to which it is attached. I should like to relate these general problems to the design that evolved for Tanis's site.

The design emphasized the following:

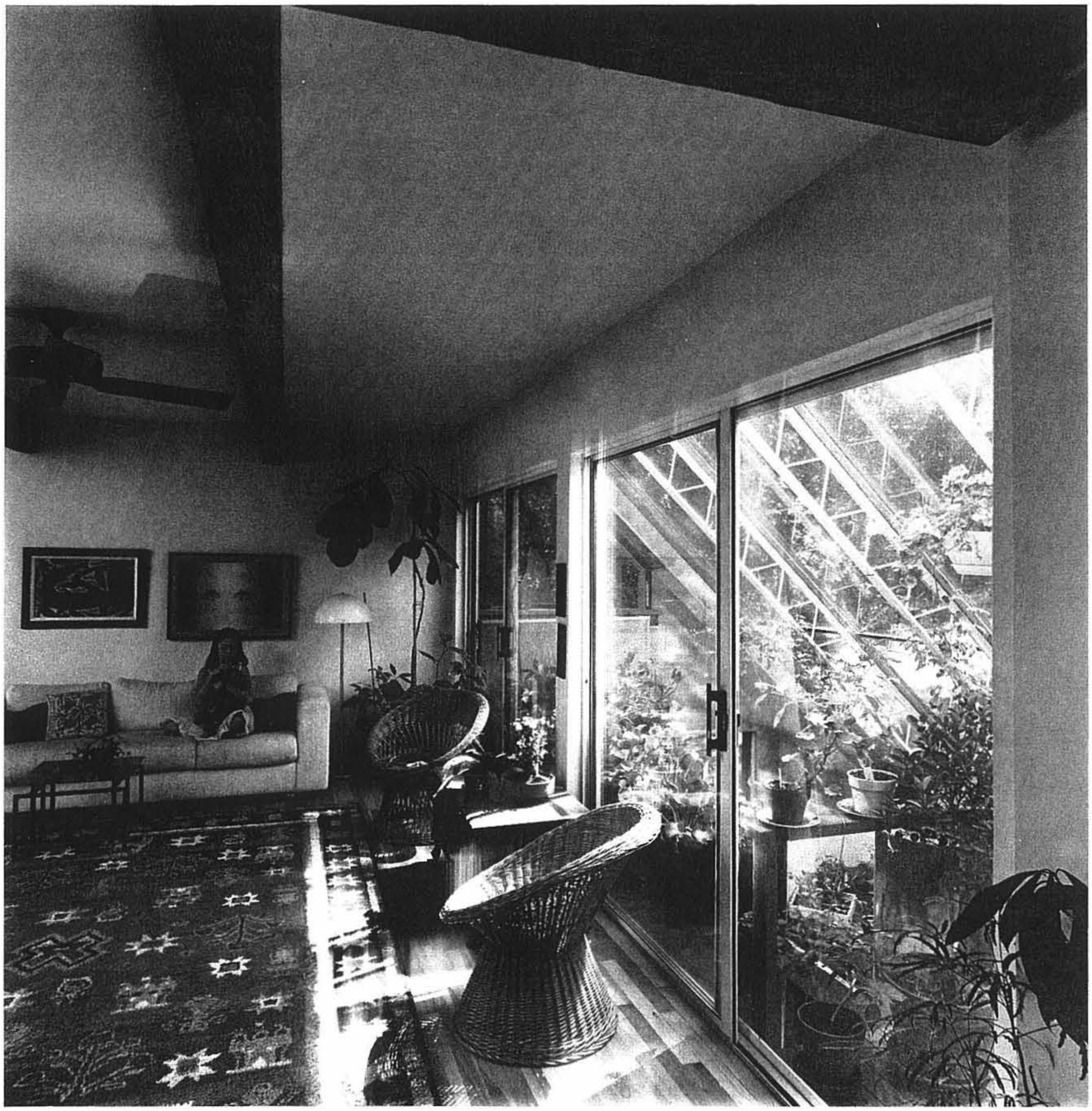
1. Glazing all the way to the house wall to allow overhead light for plants.
2. Glazed end walls to allow maximum light in spring and fall. Removable insulation panels remain in place during winter to reduce heat loss.
3. Pit design to fit appropriate glazing angle to house and landscape, and to provide headroom inside.
4. A vent on the west wall, a door on the east wall, and a continous ridge vent to provide adequate ventilation.

The first and second design characteristics are somewhat opposed to those of the popular "sunspace" design, but from my experience with greenhouses, light penetration is very important if plant production is desired.

I researched the next set of problems, the construction details and choice of materials, carefully. The main enemy of a well-used greenhouse is rot. Clever construction copes with water and high humidity in two ways. Flowing and standing water from irrigation and condensation can be reduced by sloping all structural members and/or providing drainage holes. Water and humidity also require the use of corrosion and decay-resistant materials. I met these problems, and the problem of cost, by using salvaged materials from commerical greenhouses. These are materials designed and chosen to meet industrial durability standards. Redwood, cypress, galvanized iron, and glass are the main materials, and their worth is proven. They are milled to shed water, are of the finest grade, and can be reconstructed as energy efficient structures. Wood over fifty years old in excellent condition can still be found. With a little elbow grease, the wood and related hardware can be cleaned and repainted to be as serviceable as new materials in both appearance and structural integrity.

Such framing materials are easily adapted to many systems of double glazing, using combinations of glass, fiberglass, plastic, or insulated glass. In Tanis's greenhouse the outer glazing is recycled glass in the traditional lapped style (the upper pane of glass overlapping slightly the pane beneath it, like shingles). Inside we used a plastic film, which we are replacing with a second layer of glass, because the plastic has been destroyed several times by the household dog. Any of the inexpensive plastic films are subject to puncturing.

Commercial greenhouses are available for salvaging near most urban areas. They were designed for the age of cheap fossil fuels, and are not profitable in light of increased energy costs. When a commercial grower goes out of business, his greenhouse becomes a liability, and he will usually be very happy to relinquish it free, or at a very small price. Recycling then, seems sound, ethically and financially, particularly if redwood or cypress are wanted. From an ecological standpoint it is hardly justifiable to continue cutting redwoods, let alone cypress, for greenhouse construction, as they are being cut far faster than they are being replaced. Cypress management is not practiced because the trees grow so slowly as to be unprofitable.



We Threw Caution to the Sun

Nancy Jack Todd and John Todd

The house we have lived in for over ten years began its life as a late sixties ticky-tacky. It was heated by natural gas, and the insulation was close to nonexistent. It was definitely not the sort of house that lent credibility to our advocacy of the use of renewable sources of energy. Yet by some odds unlikely in so much of modern housing, our house was pretty. Its lines are good. It is on an acre and a half of land that slopes down to a pond. Some of the trees are quite large for the Cape. We have oaks and maples and locust and wild cherry, sumac, a poplar, and some willow. In the spring a dogwood hangs poetically over the pond. We love it here. It is where our children have grown and it is home.

Two years ago, however, we felt ourselves prompted by motivations for change more pressing than well-intentioned environmental ones. At that time the house had a deck on the east side. The door from the deck, which we always referred

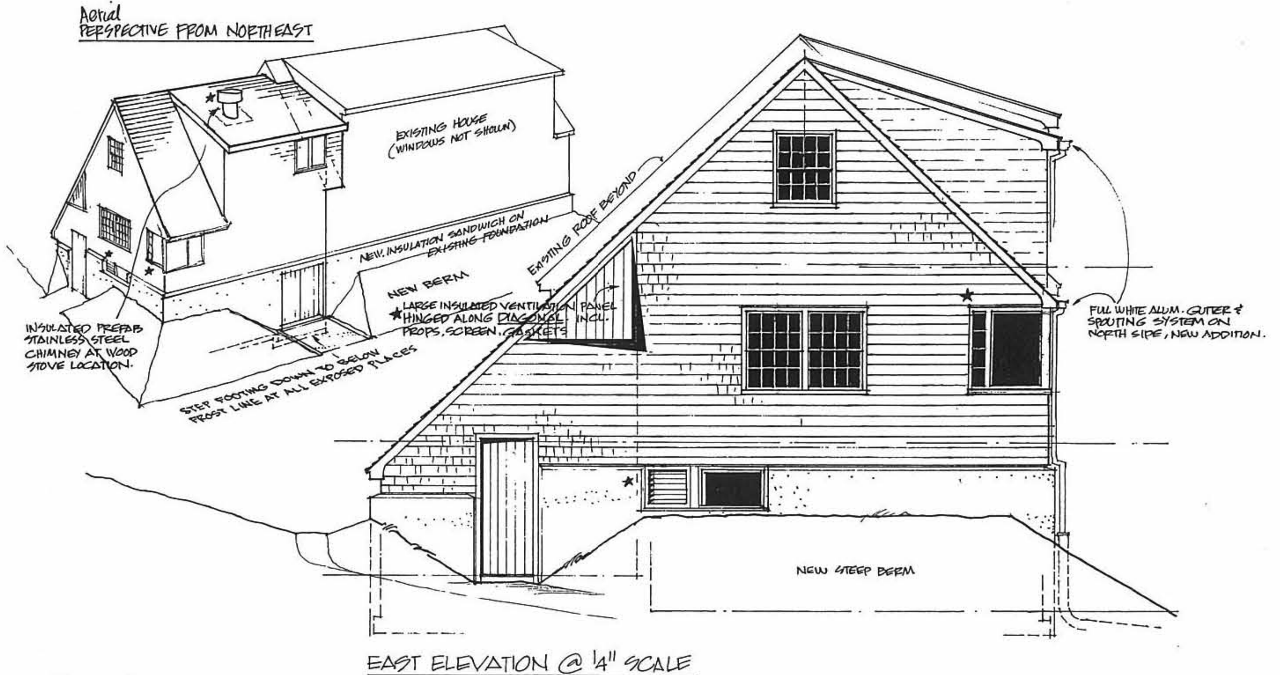


Figure 1.

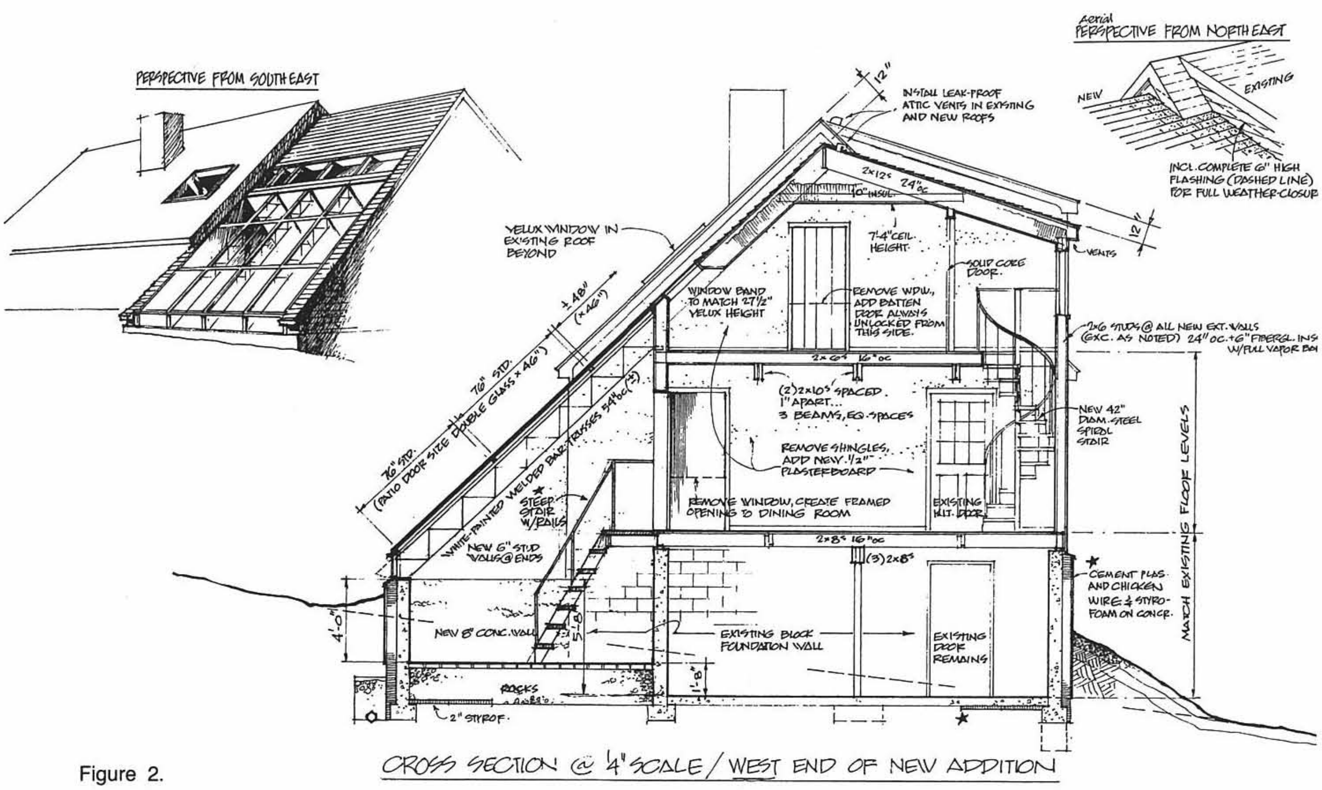


Figure 2.

to more familiarly as the porch, led into the kitchen and was the entrance to the house that everyone used. The porch was a wonderful place for early morning cups of coffee and sleepy conversations, and the railings made serviceable clotheslines. But slowly it was beginning to disintegrate. By Christmas of 1978 there were several planks loose or missing, and a shaky step. I was worried that my mother might trip during her Christmas visit.

The house posed another problem, this one a source of some friction. It was very small for a family of five, particularly when three of the five persisted in getting larger. One Sunday, as we were setting out on a late afternoon walk, while I was waiting for John to finish puttering with the goats, I paced about the porch. Then, as we headed toward the beach, I burst out . . . "What if we . . ." And the ideas tumbled out of both of us . . . "retrofit the whole house, then tear down the porch, replace it with a living room and a room above it for Jonathan. And in front of it . . . a greenhouse, solar heating, plants, vegetables, fish tanks, our own bioshelter."

We asked a lot of the project when we decided to retrofit our existing house to use less heating fuel and to add a new solar addition. We wanted the sun to do most of the work of heating not just the new addition, but the whole house as well. A wood stove was to provide the only backup except in extreme weather, when our old furnace would act as a standby. Another condition was that the electrical requirements for heat circulation and storage be minimal, say equivalent to two or three lightbulbs. We also wanted a fish farm as part of the deal, and last but not least, an interior that would be exciting for a lifetime. Architect Malcolm Wells came through with a solar design to match our heating and living goal and solar engineers Joe Seale and John Wolfe figured out how to keep electricity consumption to a minimum. We designed into the greenhouse area a household-scale solar fish farm for raising tilapia, catfish, trout, and eventually oysters in sea water.

The workings of the house are really quite simple. The fish farm, situated against the north wall of the partially submerged greenhouse, is made up of 10 "organ-pipe" translucent fiberglass tubes 8 ft high by 18 in. in diameter (see Figure 1), a variation in shape on the traditional New Alchemy solar-algae ponds. They serve double duty as fish-culture units and as primary heat-storage components. The tubes efficiently absorb solar energy during the day and release heat at night, warming the greenhouse and adding heat to the house as well. The other heat-storage component is the basement. Malcolm Wells recommended that it be clad on the outside with 4 in. of styrofoam and stuccoed. Now the interior basement walls and the contents of the basement, including furniture, boat, firewood, tools, and so forth, store heat blown in from the greenhouse.

The solar heating is primarily passive as the design called for a lot of thermopane tempered glass on the southern exposure (see Figure 2, Figure 3, and Figure 1). This effectively captures light and heat. Once trapped, the heat follows two basic routes: it is either stored in the fish tanks or is drawn by a 36 in. diameter fan powered by a 1/6 horsepower motor down from the apex of the greenhouse into the basement. Here it circulates the full length of the house before being recycled back into the base of the greenhouse. (See Figure 2 for air flow patterns through the house.)

Heat distribution to the living areas of the house is both active and passive. Air vents in each of the rooms and stairwells permit a passive upward flow of warm air from the basement. A more even and rapid distribution of air can be accomplished by activating the old blower system from the hot-air furnace. A ceiling fan in the living room allows us to circulate warmed air from the wood stove.

In the summer the glass on the southern side acts as an air accelerator, sucking cool outside air in, through the house, and up the stairs to exit via the north windows. The house is now much cooler in the summer. The solar heating cycles have worked well so far. We do not yet know if we will have to turn the old furnace on during extreme conditions in the dead of winter. Since the house was redesigned to be primarily, although not exclusively, heated by solar heat and a single wood stove, we would not see occasional use of the furnace in the future as a setback. A less-obvious reason why the house has performed as well as it has is the internal insulated shutter system created by Terry Eisen and Greg Wozena. The shutters placed on all of the vertical windows are elegant, easy to operate, and very saving in heating needs.

Malcolm Well's drawings (Figures 1 and 2) illustrate how we attempted to refine traditional Cape Cod architecture to solar needs. We think the synthesis and use of traditional roof angles works if one is lucky enough to live in a south-facing house as we are.

The project is by no means over. Future fantasies include a "zome-works"—a Steve Baer solar hot water collector installed in the upper part of the greenhouse interior. The collector would be connected to a hot tub in the greenhouse. The tub in turn would help keep a dancer's muscles (Nancy's) supple in winter, and the fish would like the warmed water pumped into their tanks after the people were through. It's a case of hedonistic closure of solar cycles. We contemplate more.

Now, as I write on the autumnal equinox, the first day of the fall of 1980, it is gusty and warm. It's hard to feel convinced that soon every evening we shall be closing the shutters that have stood open all summer. It seems very far away right now. But even I who crave warmth constantly can think even a bit smugly as I see the first traces of yellow leaves, that the green in our greenhouse will remain, that the geraniums and lettuce and parsley, the bamboo and fig and orange will last even as the green outside fades and is gone. The smell of moist earth too will stay as the ground freezes. And one day we'll look out at the first snowfall, but we'll see it through a screen of plants and flowers.