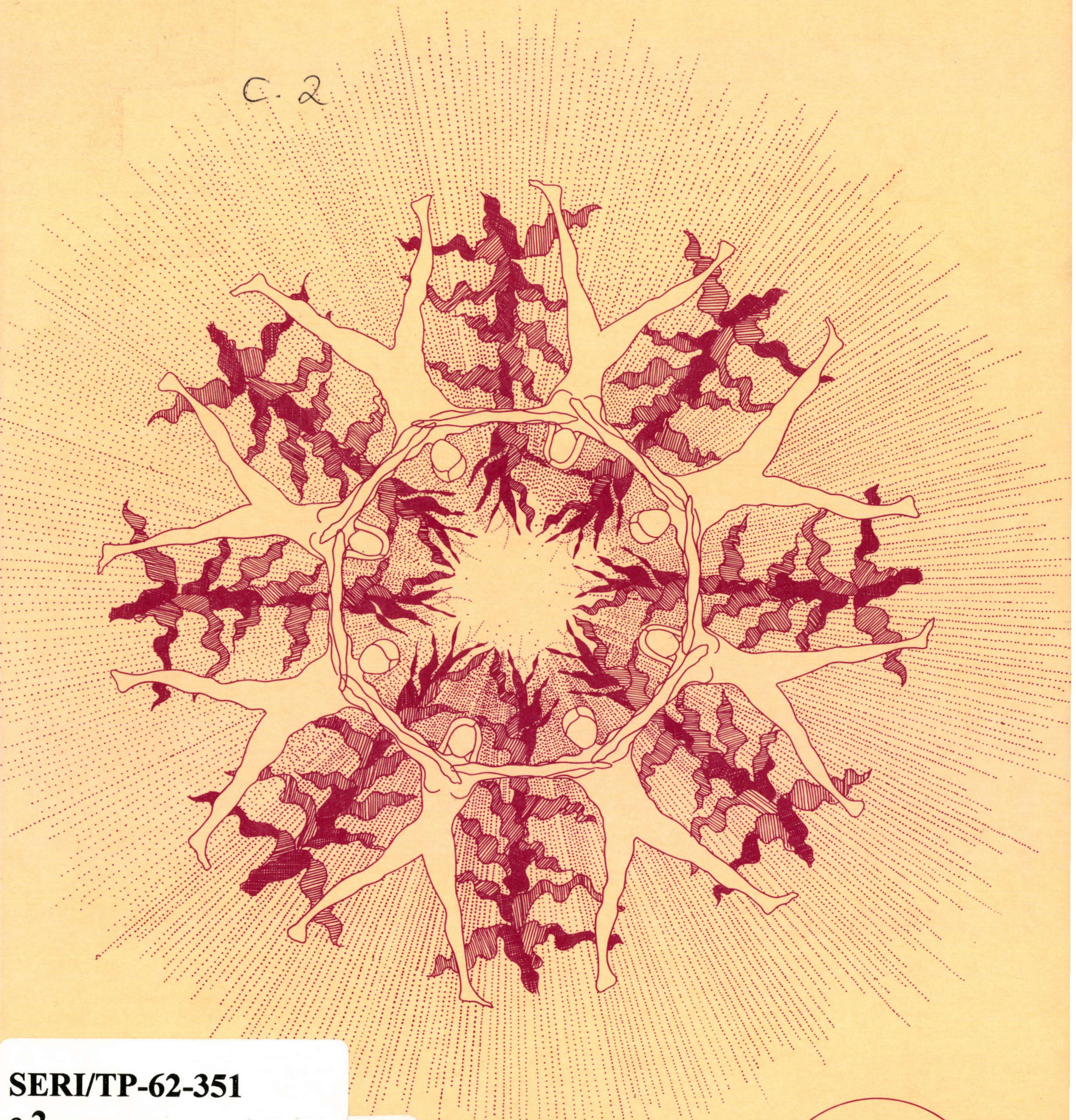
Humanistic Energy Choices



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NOTICE

Humanistic Energy Choices

Aspen Energy Forum 1978 Proceedings
Roaring Fork Resource Center
Aspen, Colorado

Editor: Barbara Glenn
Technical Editor: Gregory Franta, AIA

August 1979

Solar Energy Research Institute
1536 Cole Boulevard
Golden, Colorado 80401

A Division of the Midwest Research Institute

Prepared for the
U.S. Department of Energy
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FOREWORD

Humanistic Energy Choices is a compilation of edited papers presented at the Aspen Energy Forum 1978 in Aspen, Colorado. The papers address many aspects of humanistic choices for energy and resource development with emphasis on socioeconomics, political implications, solar heating and cooling, biomass, and wind energy.

The Aspen Energy Forum 1978 was the fifth annual forum coordinated by the Roaring Fork Resource Center (RFRC), a nonprofit, educational and research organization dedicated to the preservation of natural resources through the use of alternate energy sources. The forum was conducted May 26-28, 1978, at the Aspen Institute for Humanistic Studies. The Market Development Branch of the Solar Energy Research Institute (SERI) cosponsored the forum. The Pitkin County Government in Aspen also cosponsored the forum.

SERI appreciatively recognizes the diligent work by the volunteer staff of the Roaring Fork Resource Center for the conduct of an excellent forum. Particular recognition is given to the following RFRC staff: Ann Chapman, Jon Chapman, Amory Cheney, Debbie Dykes, Heidi Hoffmann, Debra Karls, T. Michael Manchester, Anne Oakes, Kenneth Olson, Sigrid Strecker, Linda Teich, Gail Weinberg, and Shari Young. The conference logo as illustrated on the cover of this book was designed by Linda Teich. The work of each author in preparing his/her paper is also gratefully acknowledged.

These proceedings were prepared by the Communication (CB) and Market Development (MDB) Branches in the SERI Technology Commercialization Division with Barbara Glenn (CB) as the editor and Gregory Franta (MDB) as the technical editor.

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ENERGY CHOICES AND HUMAN VALUES*

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During the past several years it has become evident to many of us that the energy crisis involves much more than the price of gasoline at the pumps.

As much as anything else, it adds up to a crisis in our lives: of how we re-orient ourselves to perform the routine task of living, and which of a competing set of values we can, and must live by—and why.

From the human perspective, the central issue in The Great Energy Debate is the sort of people we must become to support our energy choices, both today and tomorrow.

For most, this realization is no more than a few months old. It was not until the fall of 1976, with the appearance of Amory B. Lovins' "Energy Strategy: The Road Not Taken?" [1] that mainstream audiences began to appreciate that their energy choices and their life prospects amount to much the same thing.

In that article, Mr. Lovins argued what is rapidly becoming the common sense of the matter. We are presently at a juncture in our energy decisions, he noted, where we must choose between two mutually exclusive energy paths.

One will probably lead to the extinction of the human species in the foreseeable future and to the loss of civility along the way. The other might take us to what Mr. Lovins regards as the start of a truly humane existence for us all.

Should Americans continue along the "hard," or high-intensity energy path, they will experience ecological and social breakdown by the year 2000 as a result of trying to satisfy their insatiable energy appetites, according to Mr. Lovins.

However, they might avoid this unhappy prospect by taking the other, or the "soft" path—that of energy conservation, increased energy efficiency, and a determined move toward putting American society on a sustainable, nonpolluting, and renewable energy base.

The prime benefits of taking the soft path are not technological but human, Mr. Lovins is persuaded. The soft path, he believes, will make it possible for each generation to live into its maturity and for people everywhere to free themselves of utility, energy company, and government control of their energy supplies. Freedom and equality will follow.

For Mr. Lovins, energy independence is the independence that individuals and small groups of people might reasonably be expected to enjoy as they reverse increasingly elitist, inflexible, and centralized energy postures.

"Underlying energy choices are real but tacit choices of personal values," he writes, and those values accompanying a soft energy future are the humanly prized virtues of "thrift, simplicity, diversity, neighborliness, humility, and craftsmanship" [2].

Mr. Lovins' view has received widespread attention for several reasons. First of all, he has taken the precaution of clothing much of his argument in the language of number, the lingua franca of people living in a technological civilization. By using nonverbal "words," he has been able to communicate with scientific and technical audiences that humanists like Lewis Mumford have never been able to reach.

More importantly, though, Mr. Lovins has been heard because of what his numbers say. They tell us that if we desire, we Americans have time enough to make the transition from the hard to the soft energy path without sacrificing our current lifestyles, without civilization coming apart at the seams, and without having to take the fatal step into an unmanageable and reversible radioactive future.

There is then in Mr. Lovins' thought the prospect of hope and of new beginnings for a tired, ideologically bound world.

The soft-energy path offers

> advantages to nearly every constituency at once: it can give you jobs for the unemployed, capital for business people . . . savings for consumers, chances for small business to innovate and for big business to recycle itself, environmental protection for conservationists and better military security for the

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*An oral expression of these views was first offered at The Colorado Energy Symposium Forum on Energy Alternatives and Colorado: The Human Factor, April 6 and 7, 1978, Adams State College, Alamosa, Colorado, funded by a grant from The Colorado Humanities Program.

> military, world order and equity for globalists, energy independence for isolationists, exciting technologies for the secular, a rebirth of spiritual values for the religious, radical reforms for the young, traditional virtues for the old, civil rights for liberals, local autonomy for conservatives [3].

What Lovins, and other like him see then, is what the late E. F. Schumacher saw. We could make energy choices as if people mattered if only we used that intelligence and those modest technologies already available to us, and in this way, avoid fouling our nest, avoid being reduced to a universal condition of poverty, and avoid energy futures filled with energy-induced wars.

But none of this is happening.

What is happening instead, Mr. Lovins and many others are convinced, is that present day energy choices are driving the world to the brink of thermonuclear war and environmental exhaustion.

As nation-states seek energy independence, they are committing themselves to the nuclear alternative and, with that, assuring atomic weapons proliferation and the radioactive contamination of the biosphere through the manufacture of extremely long-lasting, carcinogenic wastes which the human species does not know how to neutralize.

And this leads Mr. Lovins, as it has led so many others before and after him, to the more depressing realization that what really is at issue in the energy debate is the Nuclear Age itself.

The energy crisis is forcing us to decide whether humanity can learn to live with the atom, or whether we must now and forever renounce its use in human affairs.

These reflections have been challenged on a number of grounds.

Many believe the nuclear commitment can, and must, be extended without incident or delay to keep civilization afloat and misery at a distance.

What's more, they say, there isn't a chance of halting the process of A-bomb and nuclear waste proliferation. Japan and our European allies are determined to reprocess plutonium in order to get free of American, Soviet, and Arab energy dominance; and Third World countries will "go" nuclear if only to gain economic and political parity on the world stage.

Or, it is said, Lovins' choice between the "hard" and the "soft" paths is not as exclusionary as he makes out. We can have our energy cake and eat it, too. Nuclear and solar together and not one or the other.

Or, energy is not the basic problem at all. Instead, it is symptomatic of a more fundamental crisis present in all growth economies and/or of an even more profound crisis of civilization itself as collectively we build a less-and-less meaningful world for more-and-more people.

We need not choose up sides today, although we shall have to do that soon enough. Rather, we shall do what the occasion demands.

We shall ask ourselves, instead, what role(s), if any, we humanists can play, and have played, in a public policy matter upon whose resolution the continuance and conduct of life depends?

Thought of in this way, what many regard as the most useless of occupations—the study of language and literature, philosophy and history, culture and the fine arts—may be seen as the most practical of activities.

In the first place, were we unable to cultivate our senses and utter meaningful phrases, the energy problem would not be a problem at all. It would be a brute, because mute, fact of existence instead.

Without humanistic activity, we should neither notice nor regret the passage of life on and from this planet. We should be without commitment and concern, without <u>meaning</u> itself, and, consequently, without guidance or direction. Unable to use creative and ethical action to position or angle ourselves in relation to the world, we should collide with our environments and each other.

This, then, is what philosophical and aesthetic activity does. By removing the thickness from events, it opens a clearing in which deliberative, attractive, and peaceful action may occur.

I am advancing nothing new. Virtually every major thinker has understood that without our human voices, our human songs, there would be no freedom here on Earth, no respite from necessity, and that we would never discover paths other than the hard ones.

Moreover, when we operate out of our humanistic mode, I think we also understood the importance of the discussion process in running our daily and our public lives.

We see conversation as therapeutic. It helps us end our ignorance and therefore our confusions and resentments about the world by getting us to assume the other guy's point-of-view. Indeed, conversation could not proceed without such empathetic understanding. Any exchange of views is really an exchange of ourselves and of our situations, an act of friendship and of trust.

But it is creative, too, more-often-than-not yielding inventiveness and possibilities not available before our dialogues began. When we talk we show-off; we perform for each other.

Each of these hidden features of discussion must now be used in resolving the energy crisis. We must trust each other to get our bearings in the world. We must talk with each other about our energy futures and decide what options are available to us and with what consequence.

Indeed, it might be argued, a prime reason we are in such horrible shape in our energy resolve today is that too many of us have done too little talking about the matter. Misconceptions have arisen as a result, resentments have grown, opportunities have been lost, and destructive—but hopefully not irreparable—decisions have been taken.

It seems to me, then, that one of the more important things that humanists can do as they join the energy debate is to recommend that the issue be given the verbal attention it deserves. That it be placed at the top of everyone's agenda. That we begin talking about the problem as if life itself depended on the outcome of our words . . . as now it does.

In addition, we humanists might also bring to this dialogue both our special language and our unique insights into the human condition. We might offer the energy discussants the suggestive, AND NOT PERFECTLY CLEAR, language of the ambiguities and some limited, but essential wisdom about our limits as humans derived from our centuries-long inquiry.

Both would be useful. The provisional and halting language of the humanities—the language of tone, of motive, and of nuances—might do for the energy conversation what it does for any conversation. It might induce the participants to think before they act.

By raising difficult questions, questions which may have no definitive answers at all, we might be able to slow the rush toward disaster.

Does nuclear power bring with it an end to human history by requiring all future generations to replicate much of present-day civilization to guard radioactive wastes? Is the call for a "soft" energy path an apology for maintaining the status quo? Can we avoid a fatal breach of the peace without assuring energy, as well as other, equalities for all?

Seductive questions such as these might do what they are designed to do: they might bring a pause or a moratorium to our ill- or nonconsidered energy actions and help us avoid unwanted and irreversible damage to ourselves and others.

As importantly, the humanities might be able to offer some insight into which of our energy options might be more humanly supportable, and which not, given the fact that we are mortal. After all, humanists have been talking about the contours of the human dimension for a very long time now, and they ought to be able to say something enlightening on this subject.

For example, if we agree that to err is human, must we forego all energy technologies which as they malfunction would create havoc certain? I am thinking especially of potential failures in the operation of high-technology solar space stations should they orbit the Earth and of nuclear accidents.

One is reminded of Murphy's Law here. If things can go wrong they will go wrong precisely because humans are imperfect and because all objects carry with them the imprint of their makers and users.

Or, if as humanists have frequently noted, people become most human by using reason and empathy, then what sort of energy choices might be most compatible with these parts of our natures? What would truly human goals look like?

In my view, the pursuit of reasonable and loving human goals would surely consist of:

* trying to provide for as many generations of human and other life on this planet as possible so that novelty and diversity might continue to enter the world;
* feeding those who are born, and permitting the land's ability to renew itself seasonally to set the population limits in any single generation;
* eliminating all forms of organized violence, from wars to structured economic, political, and social inequalities;
* persuading each generation and each person to consume as little energy and nonrenewable resources as possible so that others might have an equal chance at life; and
* creating a world in which service and the manufacture of meaning might become our prime occupation.

And this suggests a final role the humanities can, and I believe must, play in the great energy debate.

I think humanists must begin to convince themselves and others that their preoccupation with values and their decision to enjoy life is neither wicked nor frivolous as many continue to believe, but that it is essential for the conduct of purposeful life on this planet, as I have intimated already.

One example will do.

Throughout these and similar proceedings I have been concerned about the willingness of some to accept a worsening of the energy situation and, consequently, a worsening of the circumstances of some people's lives, as necessary to protect the sanctity of private property, profits, and an ill-defined American lifestyle.

Two things disturb me about this attitude: the failure of those who share it to perceive that they are promoting value-laden arrangements which have been challenged by humane people historically, and their equal willingness to accept human and ecological harm as the price one must pay to satisfy these abstract, gratuitous, cultural inventions.

The human community has stood against this way of acting for centuries.

By identifying areas of bias, and by celebrating life in the face of it, humanists have sought to elevate life above the mundane so that existence might receive the passion it requires to get on in the world.

The time has come in our energy considerations when we must choose between a competing set of values: between war and peace, freedom and slavery, equality and inequality, living in harmony or in discontinuity with ourselves and our physical surroundings.

What the humanistic tradition teaches us in this regard is that living is learning how and what to choose, and then choosing one value above the next, and that it is only by choosing generously that everyone's life chances are improved.

It seems to me that the prime role that the humanities must now play in the energy, as well as any other, crisis is to give us all reason and hope for living, and to remind us that neither is possible without the actual celebration of life.

Out of our abstract world, then, I think the human part of us is announcing that we humans are stuck in a devil of an energy fix and that we simply must get through it without destroying either ourselves or other species in the process.

Some energy choices are, and will continue to be, more human than others. It is your business, and mine, to discover which ones they are and to implement them just as quickly as we can.

As I noted at the beginning of these remarks, how—and if—we resolve the energy problem will decide the fate of the most promising life-form in the known universe and set the direction of life on this planet for centuries to come.

This conference, and others like it, is important because it reminds us that if humanity should endure, it will do so only by resurfacing its most basic interest—the human interest—and by acting on its behalf.

Hopefully, we shall have a posterity to remember that we acted for it, and not ourselves alone, in reaching our energy resolves.

REFERENCES

1. Reprinted in Amory B. Lovins, Soft Energy Paths, (Cambridge, Mass., Ballinger Publishing Company, 1977), pp. 25-60.
2. Ibid.
3. As quoted in an interview with Lovins in Development Forum, United Nations, Volume VI, Number 1, (January-February, 1978), pp. 8-9.

HARD QUESTIONS FOR SOFT SOCIETIES

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Questions are useful tools. We find ourselves asking questions whenever we are confronted with an unusual situation. Indeed, formulation of questions at these times is necessary for the resolution of conflict or crisis with which we are faced. And questions can often lead us naturally into further explorations and ultimately conflict resolution and creative activity. Without questions we would live in an insane world.

So it was in 1973 with the first Arab Oil Embargo--our first energy "crisis." It was one of those times in one's life when important and memorable questions come to mind. I was teaching at the University of Minnesota School of Architecture. Until 1973 the teaching of architecture had been founded upon an energy affluence paradigm. With very few exceptions most "modern" buildings (those buildings following the discovery of fossil fuels in the 18th century and the consequent industrial revolution) had been designed as though there were "no end in sight" to our supplies of fossil fuel energy—and "out of sight, out of mind." The conservation of energy was simply not a function of the modern design process, and this was not limited to the design of buildings. All our environmental design processes, from the design of cooking utensils and farm machinery to entire cities and agricultural land use, were conceived without reference to limitations in world fossil fuel supplies.

The Embargo was called a "crisis" by those of us who for the first time were forced to ask questions like:

What are the limitations of world fossil fuels?

What percentage of the national energy budget is consumed by the built environment?

And the answers returned quickly:

By the year 2000 natural gas will have been exhausted, and as much as 80% of our (U.S.) oil will be imported. Although we have vast coal reserves (perhaps 400 years worth), we lack the water necessary to convert coal to liquid and gaseous forms; we haven't the technology to cope with either the resulting sulphur and carbon dioxide pollution or the increase of background atmospheric radiation from trace radioactive elements contained in the coal. Nuclear energy is not a panacea, because it is not economic in the long run, and its byproducts are poisonous to life for 250,000 years (forever!), thereby requiring a "police state" world safety system.

We discovered that fossil fuel was intimately linked to all aspects of our man-made environments. About 30% of the U.S. energy budget is consumed by the built environment. A measure of our inordinate consumption can be grasped by a comparison with a Western European nation such as the United Kingdom: with one-half the energy per capita of the United States, the built environment in the United Kingdom accounts for 50% of the energy budget. Clearly, design practices in the United States result in a tremendous over-consumption of fuel.

So in 1973 it seemed "reasonable" to ask if there were new methods for designing tea kettles, buildings, and cities which would conserve energy. By looking at historical examples of indigenous traditional designs we also amazed ourselves by asking if it were possible to design completely energy self-sufficient environments. I say we, because it was at that moment that a chain reaction was occurring in the design world. Environmental designers everywhere saw that an epoch was ending and that we were now at the dawning of a New Post-Industrial Age as different from the Industrial Age as it was from the Pre-Industrial Age.

Everywhere people were beginning to say that our present socioeconomic structure, based upon centralized mass production, mass distribution, and mass consumption, simply could not hold together indefinitely in the face of the energy crunch. The large-scale disruptions which may occur are well beyond our control—just as the mass system which may be disrupted is beyond our control and comprehension now.

Everywhere people were beginning to work, some almost inadvertently, some quite purposefully, toward a new way of life, based on decentralization, smaller and more rational units of production and distribution, and reliance on the natural energy flows of the biosphere.

Everywhere people were searching for human-scale alternatives.

OUROBOROS: A DRAGON'S TALE

With these questions in mind, we initiated in 1973 at the University of Minnesota a series of exploratory energy conservation studies, culminating in a series of projects called OUROBOROS, after the ancient mythical dragon which devoured itself to be reborn a symbol of the world, which the ancients always considered to be a closed system of finite resources. In a world of "no end in sight" mentality, Ouroboros offered a model for eternal recycling, or as Barry Commoner would put it, "the closing circle."

I was teaching at that time a class called Environmental Design. It's an introductory course for students in pre-architecture—there are about 150 students in the class each year. The subject of environmental design covers everything, so it's a very free kind of format for an instructor. In 1973, with the Embargo upon us, I assigned the class to design an energy-autonomous house.

I find quite often that as students enter architecture school they have tremendous enthusiasm. They have all kinds of preconceptions about what architecture is, and what is really should be. Then they go through five years of professional school and come out as drudges, fully prepared to go into an office and continue irrelevant and energy-ignorant practice. They've lost whatever it was that they had. So I speculated that if in the pre-architecture year you could give them the opportunity to design something, especially if it were in a new and really radical context—like autonomous houses—you could skim off the cream of this creativity and prove to them that they really were capable of dealing with whole new fields of environmental design.

So we took the class of 150 students and broke it into teams of 10 students, and each team was assigned a research topic. One team did solar energy, one team did construction materials that conserve energy, another team did wind energy, and so on—all the alternatives we could think of. At the end of three or four weeks we put together the reports from all the teams and pulled together a document of about 100 pages that became the design program for the proposed autonomous house. I then assigned them to design structures of about 1,000 sq ft that would be as energy-conserving and as self-sufficient as possible. By the end of the winter quarter we had 12 architectural models and construction drawings sets for these projects. Any one project could have been interesting to work with; but we held a class competition, and the students voted on the one they thought was best. There was so much enthusiasm that I thought, "Why not just carry this through and see if we can actually build this next quarter?"

Our first intent was to build the house in Minneapolis. My feeling is that the future isn't going to see a lot of new construction out in suburbia, but rather a rebuilding and revitalizing of the central city. As it turned out, the only available land owned by the University was in Rosemont, about a half-hour drive south of Minneapolis.

I was so naive that I thought we could build the whole thing in one quarter. With that idea in mind, I approached several local businesses during the term break. For example, I approached the electric power company, Northern States Power (NSP), and said, "We'd like to do this; it has solar energy involved, and this might help the power company eventually by cutting the peak." They gave us $2,500 very quickly, within about a week. With that we were able to purchase materials to begin construction. When the spring quarter started, I said, "We're going to build this house," and a cheer went up in the room. It was just the most natural thing to do. In my office at the University I got on the phone—I think I got cauliflower ear that quarter from the telephone—and managed to raise about $30,000 locally for materials—not enough for the whole project, but it got us on our way.

I'd say we constructed a third of the project that quarter. We didn't get into any major systems, but the building was roughed in and enclosed. In 1976 we finished off the first phase of construction. We see now that it will evolve indefinitely into the future, transforming itself as time goes on—new materials and new systems being applied as we discover them or find that they're applicable.

The shape and orientation of the house (see Figure 1) are closely adapted to the Minnesota climate, with its cold, blustery winters. At its base, Ouroboros/South (as this project is called) is a trapezoid with its longest side facing due south. Earth is piled against the north, east, and west walls. The sod roof, sloping backward to the north, almost to the level of the ground, protects the house against fierce north and west winds. The walls and roof have at least 9 inches of fiberglass insulation throughout. In winter, snowdrifts collect on the roof and around these walls to provide extra insulation where it is needed. In summer the sod helps to keep the roof about 50°F cooler than conventional roofing.

The entire south side of the house is devoted to collecting solar energy. Its upper part is tilted at 60°, the optimum for winter collection at this latitude (45°N). Vertical south windows and a greenhouse, both double-glazed, occupy the lower part. The 600 sq ft trickle-type collectors originally installed in the south-facing roof were covered with two panes of glass because of the extremely cold weather. Solar heated water was drained to a 1,000 gallon basement tank surrounded by 35 tons of crushed rock. Air blown through the rock carried heat to the house.

Mechanical engineering master's student, John Ilse, replaced half of the trickle-type collectors with a sandwich-type collector of his own design. Water flows between two sheets of cold-rolled steel that have been dimpled and spot-welded into a single unit. Water is pumped up through the cavity between these plates and drains from the roof ridge to the basement tank. The two types of collectors have been working side by side since March 1975, and Ilse's collectors have performed consistently better than the trickle-type collectors. In

Fig. 1. Ouroboros South

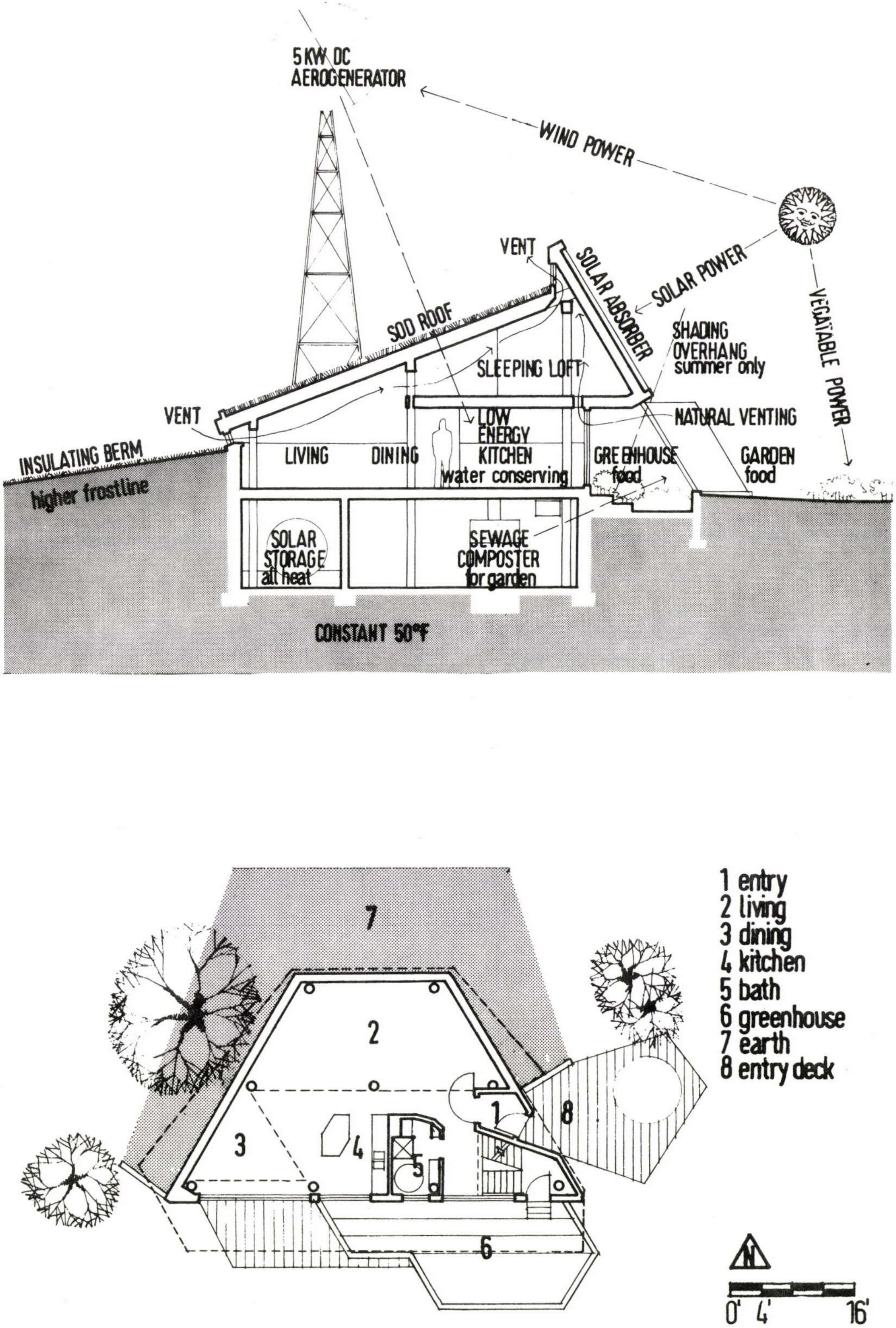

Fig. 1A. Ouroboros South

February 1975, the earlier sets of collectors were removed and replaced with a complete set of Ilse collectors. The rock-air storage system was replaced by a passive storage system.

Summer cooling is not as crucial as winter heating in the Minnesota climate. Some summer cooling is provided by part of the south wall, which forms an overhang to keep almost all summer sun off the south windows. Natural ventilation through vents in the north wall and roof peak, aided by evaporation from the sod roof, carries off excess heat.

The entire project cost, $95,000 including student supervisor wages and student transportation, was funded entirely from local sources. I am proud of its independence from federal support; the project wouldn't be built by now if we had waited for such money. Local funding has also generated local involvement.

Because it is so important to raise the consciousness of local people to projects like this, it must be understood that the most important mode for involving these local people is fundraising from the grassroots. Money and materials solicited from local regional sources help to get local brahmins involved. Later, when the projects become tangible to the community, the project will be more rapidly accepted and embraced.

That is not to say that money from the highest governmental levels won't help. But we have observed in the past that money from high places tends to isolate institutional research from the people. And noninstitutional grassroots research (while maintaining strong popular connections) typically has difficulty in procuring high government funds.

For all of us working in the area of alternatives and appropriate technology, it is important to remember that if we are doing what is right, money will not impede us. That doesn't mean that if we wear halos, money will flow in without a great concentrated effort. Raising money for alternative demonstrations will always be hard work.

Although some of the most important human-scale alternatives work will continue to come from highly organized, highly educated grassroots groups (New Alchemy Institute, Zomeworks, Windworks, Brace Research Institute, Farallones Institute, etc.), it is important to recognize that, through "networking," universities and institutions of higher learning can be catalyzed to community "A.T. service learning." It takes at least one individual in each milieu to start the ball rolling.

The University is still (despite what most of us thought in the 1960s) a viable institution in which to develop and organize new forces for social and technological change. Some of the reasons are:

- availability of experimental lands;
- proximity of interdisciplinary students and faculty;
- "service-learning" and "learning-by-doing"--now widely accepted pedagogical methods;
- "established" tradition of universities (normally considered in the pejorative by grassroots groups) can facilitate certain openings to fundraising and media coverage. (It is important to transmit the A.T. message with "power" and "frequency");
- large possible numbers of students can provide necessary momentum to ongoing projects of relatively large scale and comprehensive scope;
- "mistakes" and "failures" are still valid expressions of learning in the university (of course, successes are too!); and
- by exposing the openminded freshmen to human-scale technology and its raison d'etre, the university will undergo promising changes (Student Power in IN!)

OUROBOROS/EAST: TOWARD AN ENERGY CONSERVING URBAN DWELLING

In 1974, another 150 students came along, and in the fall, I asked a few of them to go down to the Rosemount house and help finish it off. But you can't ask a whole class to do somebody else's work. They're just not that interested. Meanwhile, by the second year, we had talked with the City of St. Paul. Originally, we had thought it was the more conservative of the Twin Cities; but the city administrator of St. Paul, Thomas Kelley, got really excited upon seeing the Rosemount house, and said, "You people should be doing this in an urban house. Let's go to the Department of Housing and Urban Development and see if we can get one of those old houses that they're going to demolish." We did that and we got a house for $1.00. The Science Museum of Minnesota, located in St. Paul, got interested in the project and joined us very early.

A consortium of the three--the University, the Science Museum, and Tom Kelley's organization, called Urban Laboratory--formed and signed a contract saying essentially, "We'll share responsibility over the construction of the house, and when it is built, the Science Museum will take it over and operate the educational programs for the public with the University's advice." Tom Kelley also maneuvered a code and zoning variance through the City Council which allowed us to experiment very freely.

Ouroboros/East (as this second project is called), a house built about 1910, is very typical for houses in St. Paul. It is also a very efficient energy form: basically a cube with a hipped roof. (See Figures 2 and 2A.)

Given the house's construction, insulation, and energy backup systems, we asked, "How can this house be changed to conserve energy optimally?" The approach we took was not a consistent one. We developed it as a museum, to demonstrate as many alternative methods of retrofitting as possible. In a sense the project is a kind of catalog of energy conservation possibilities.

The primary objectives of the project are to:

- demonstrate economically feasible techniques of reducing energy consumption in an urban dwelling by:

Fig. 2. Ouroboros East, street elevation

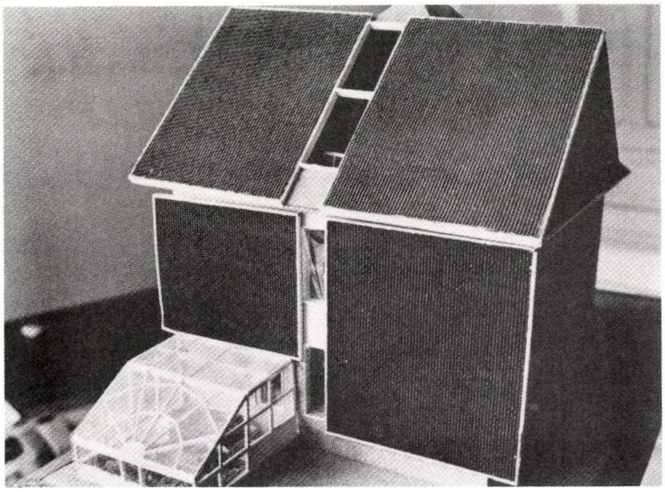

Fig. 2A. Model of Ouroboros East showing proposed area of active collectors

- using natural and nonpolluting energy sources (solar and wind) rather than diminishing fossil sources,
- utilizing individual human initiatives and energy rather than high energy consumption mechanical sources,
- recycling construction materials wherever possible,
- diminishing per capita interior residential space requirements and altering interior space usage, and
- growing supplementary food in an urban environment;

- catalyze individual and community concerns toward making necessary reduced energy lifestyle changes through an educational program in which
  - students learn by research, doing, and experimenting; and
  - individuals and the public-at-large will learn that the changes are possible.

From the front (north, Figure 2A) the house scarcely looks different. It is painted a dark color to better absorb the sun's heat. From the back of the house, three major changes are visible. A "victory" garden is planted to supplement the food supply, and a greenhouse is built onto the south wall to extend the growing season.

The third change is the most apparent. Solar panels are attached to a high south roof in order to heat water from collected sunlight. This process will supply about 80% of the heating needs of the house. Sealed metal units are fitted into sheets of glass mounted on the roof. Pressurized water is forced up through the sealed metal units. As the water flows upward, heat from the sun is absorbed. The heated water is drained into basement storage tanks. From the basement, air is forced past the hot water through heat exchangers and vented to the rooms above. A backup system supplements heating needs during sunless winter periods. The extensive venting system in the house is used to heat areas of the house as they are being used. Vents are opened at night to allow warm air into the sleeping rooms. During the daytime, these vents are closed, and the heat is redirected to the living areas. Summer ventilation is accomplished with the use of a rooftop fan ventilator and windows.

In addition to reducing window size and making the walls thicker, various types of insulation will be tested to augment the heating system. Storage areas on perimeter walls prevent excessive heat loss from the house. Double glazed windows can be shuttered at night. Doors are weatherstripped and weather-locked to prevent cold air infiltration, and landscaping provides buffering from winter winds.

Another innovation is the water system. Spray mist faucets and showers reduce water consumption by one-third. Bath water will be recycled and used in low-flush toilets. The laundry is equipped with a water conserving machine. Collected rainwater will supply the needs of the greenhouse.

The most radical change is in the sewage system. A clivus multrum (sloping sewage compost box) is installed to collect all human and kitchen wastes. The composting system uses air bacteria to eliminate disease-producing organisms and to reduce the waste within 6 months to usable fertilizer for use in the garden and greenhouse. In addition, the clivus also conserves as much as 60,000 gallons of water per year for a single household, since no water is used in the process.

And finally, the electrical system is redesigned to consume less energy. Attempts to conserve electrical energy include less use of electrical appliances. Daylight will be used as much as possible for illuminating the interior of the house, and task areas rather than entire rooms will be illuminated.

One of the rooms in the house will be a library where we'll have all the literature about any product that's of any relevance to energy conservation or alternative energy. We'll have all the cost data available. When the Science Museum operates this as a public program, people will be able to take workshops and classes.

In the sense that these energy-saving alternatives are not in common use in our urban environments, the house will be an experiment. But application of the results will be tangible. The concepts and designs being tested will prove that there are more energy-efficient ways of living. The only "unknown" factor is and will be man's reaction to this new way of life.

Project Ouroboros was the first step in Minnesota toward establishing a community which is energy efficient. As each house in a community becomes a more efficient user of energy, the collective energy needs of a city, a state, and the nation will be reduced.

The specific objective of the Ouroboros houses has been to educate and introduce to people the technology and the means by which to make dwellings, especially urban dwellings, more energy conserving and efficient, as well as better suited to the climate.

During the first Sun Day (1978), 5 years after the Ouroboros Project began, both houses became central focal points of the Twin Cities' solar celebrations.

WINONA: TOWARD AN ENERGY CONSERVING COMMUNITY

Winona grew out of the earlier Ouroboros projects, when in 1975 I asked a group of 20 senior architectural design students in my Energy Design Studio if we could implement the principles of conservation and alternative sources of energy at a total existing community scale. To what extent could a community become energy and food self-sufficient, and in how short a time? If we could retrofit existing houses such as Ouroboros/East, could we retrofit entire existing cities?

The students selected the Minnesota community of Winona and worked a whole year on the project. Winona was chosen for these reasons:

- its size, its age, and its economic activity make it typical of many Upper Midwest river towns;
- with a population of only 27,000 it is manageable in terms of energy conservation;
- it has a state university and two private colleges;
- it is a center for the surrounding agricultural communities of southeastern Minnesota;
- it is not suffering from out-migration; and
- its climate (ranging from -30°F in the winter to 95°F in the summer) is sufficiently challenging to make it a good test case.

In preparation for the project the students made a thorough and careful onsite study of the City of Winona. Consideration was given to the effect of rising energy costs on systems of transportation, food production, shelter, and communication, and the consequent effects on people and their neighborhoods. Discussions were held with the Winona Planning Commission and the Winona Chamber of Commerce, and the public was invited to several open meetings.

However, this project does not pretend to be a blueprint for Winona or any other community. It does present a possible direction for the city with its evolving physical, social, and economic needs in an era of dwindling traditional energy sources.

Among the proposals developed are plans for neighborhood food/waste/energy systems; food and craft cooperatives and neighborhood markets; industrial-scale food and waste systems; a community dairy; revitalization of the central business district, including the Latsch building, currently scheduled for demolition; riverfront development; and proposals for Winona State College and the now-unused Monastery.

Not all energy-conserving methods are fully tested, and improvements are constantly being made. Moreover, developments are taking place at such speed that there can be gaps in communication while new techniques are being investigated. This project therefore is aimed at stimulating thinking and planning at all levels. It emphasizes what individuals and neighborhoods can do for themselves, without fighting city hall or big government; it shows possible ways an entire community can change creatively, and demonstrates that a better quality of life is possible with less energy consumption.

The students of the Energy Design Studio have developed projects which propose how Winona could approach energy self-sufficiency by the year 2000, through careful conservation of energy, coupled with the introduction of sun, wind, and biofuel technologies. Their projects represent a variety of viewpoints, and no attempt has been made to force them into a consistent mold. They do not promise Utopia; they simply face blunt realities. They all offer specific suggestions for sections of the city as they now exist.

One of the students, Rolf Stoylen, provided the following scenario as to how the transformation of a town like Winona could occur:

> Stage One: Limiting the needless waste of fossil fuel energy and expansion of household and neighborhood food production. Reduced use of automobiles and recreational vehicles would save gasoline. Walking and biking would become more popular. Energy would be saved by re-insulating existing buildings, replacing wornout windows and doors, and improving weatherstripping. Heat pipes will be added to existing units to recapture some of the heat loss of the chimneys. More people would grow some of their own food. Backyard gardens, fruit trees, berry bushes, and beehives would reduce dependence on the supermarket.
>
> Stage Two: Conversion to energy systems that do not require fossil fuels. The new systems are already developed, but they will not become economically competitive until the prices of fossil fuels go higher. Solar energy can dry and cook food, heat water, and heat both homes and places of work. Controlled burning of wood, corncobs, grain alcohol and wood alcohol, and methane gas can supplement solar heating.

> Stage Three: New social patterns would develop. The final phase is the most difficult to describe since there are as many patterns of living as there are people. The efficient use of solar and wind energy and the gradual shift from an energy-intensive to a labor-intensive society will demand sharing and cooperation among larger groups of people. The extended family (grandparents, parents, and children) may return; unrelated people may live together as a family. Do-it-yourselfers may turn into full-time craftsmen; people may live where they work.

Another student, Gary Nyberg, developed the following proposal for neighborhood change: (See Figures 3A, 3B, and 3C.)

> Any effort to produce change needs focus and organization. The likely organizing institution in this neighborhood is the Church of St. Stanislav, with its school, convent, and parish house. It is already a cohesive force in the neighborhood and is the logical rallying spot for local planning.
>
> Neighborhoods can organize for change. In Washington, D.C., recently, a neighborhood pooled its skills in the old barn-raising tradition to renovate its housing. People swapped hours rather than working for pay. Everybody was involved; people without construction skills babysat, ran errands, or cooked community meals. The result was not only a highly successful job of renovation at a fraction of the cost but also burgeoning neighborhood friendships.
>
> Sometimes red tape has to be cut. Building and zoning codes need to be checked out before projects are started. But, with a combination of realistic plans and pressure at the right spots, codes can evolve and become more responsive to community needs.
>
> A vital element in future neighborhood change will be the locally oriented architect—who knows the city, lives with the climate, knows specific neighborhoods, and knows the people who live there. Much of his work will consist of renovating existing houses with natural energy systems, and building between houses. He may also be asked to redesign the interior of an entire city block, whether for a day care center, farming, aquaculture, or commercial use. He may be asked to redesign streets and alleys and plan shelter belts. He may design neighborhood power stations, both solar and wind generated.

One of the most startling proposals in the Winona study was for a food and waste complex by Drew Erickson and Scott Williams: (See Figure 4.)

> This complex could be built on a 600-acre site along the river which includes the city sewage plant. The area is already zoned for commercial use and has existing roads and rail lines. The complex would include a soybean processing plant, a dairy, a livestock and dairy farm, an ultrasonic water purifier, and a new anaerobic digestor to replace the current aerobic system. Construction, beginning with the ultrasonic water purifier as a first step toward reducing river pollution, would be phased over a 5-year period. Construction would also include wind pumps and generators, algae ponds and drying beds, water storage, and barge docks.
>
> With the conversion of the sewage plant to an anaerobic digestor, methane gas could be produced from both city sewage and livestock manure. The gas would power a turbine generator supplying power for the digestor itself, for the dairy, and for about three-quarters of the processes at the soybean plant. The turbine would also produce excess heat which could be used to dry and roast soybeans. Gas production would be speeded up by a solar furnace and heat exchanger. Sludge from the digestor would be pumped for fertilizer to algae ponds, a source of high-protein cattle feed.
>
> Wastewater from the digestor, most of which would inevitably end up in the Mississippi, could be purified in tanks using ultrasonic waves and ozone (which breaks up into oxygen in water and leaves no pollution). The ultrasonic process eliminates both the need for energy-consuming filter beds and the need for chlorine, which is not only expensive but dangerous to produce, transport, and store. Some of the purified water could be used for livestock, pumped through a carp pond and stored in reservoirs suspended in the wind-pump towers.
>
> The soybean plant could, each day, process 75 tons of beans, produce 54 tons of meal, 15 tons of oil, and 6 tons of hulls. The meal could be further processed in the city into flour, meat extenders, and lecithin. The oil could be used for cooking, margarine, and paint. The hulls, ground and mixed with algae and waste fruit and vegetables, could be used as livestock feed. Beans for the plant could be grown on 26,000 acres along the river (about one-fifth of the total agricultural acreage in Winona County), and shipped by low-energy barge transport. One benefit of soybeans as a crop is their capacity to fix nitrogen in the soil, permitting crop rotation.
>
> The cattle and livestock farm and the dairy would be located on the same grounds to minimize transportation and milk spoilage; both would be close to the new sewage digestor for easy transportation of manure. Three double-six milking parlors in herringbone formation would handle the entire herd in 2 hours. Milk storage, lockers, and washup areas would be next to the milking parlors. Deep-well pumps, powered by wind, would provide cooling water for the milking parlors and milkhouse. This pure water would also be used for washing and sterilization. The dairy would supply 1,000 gallons of milk a day, about 70% of what the city needs. The remaining 30% would come from privately owned cattle in the city and immediate area. Cows, sheep, and horses would be housed and yarded on the dike of the existing sewage plant. Calves, yearlings, dry cows, bulls, and feedlots would be located on the pasture lands to the south. The farm buildings would have thatched roofs, such as are used throughout Britain and Scandinavia today, for insulation.

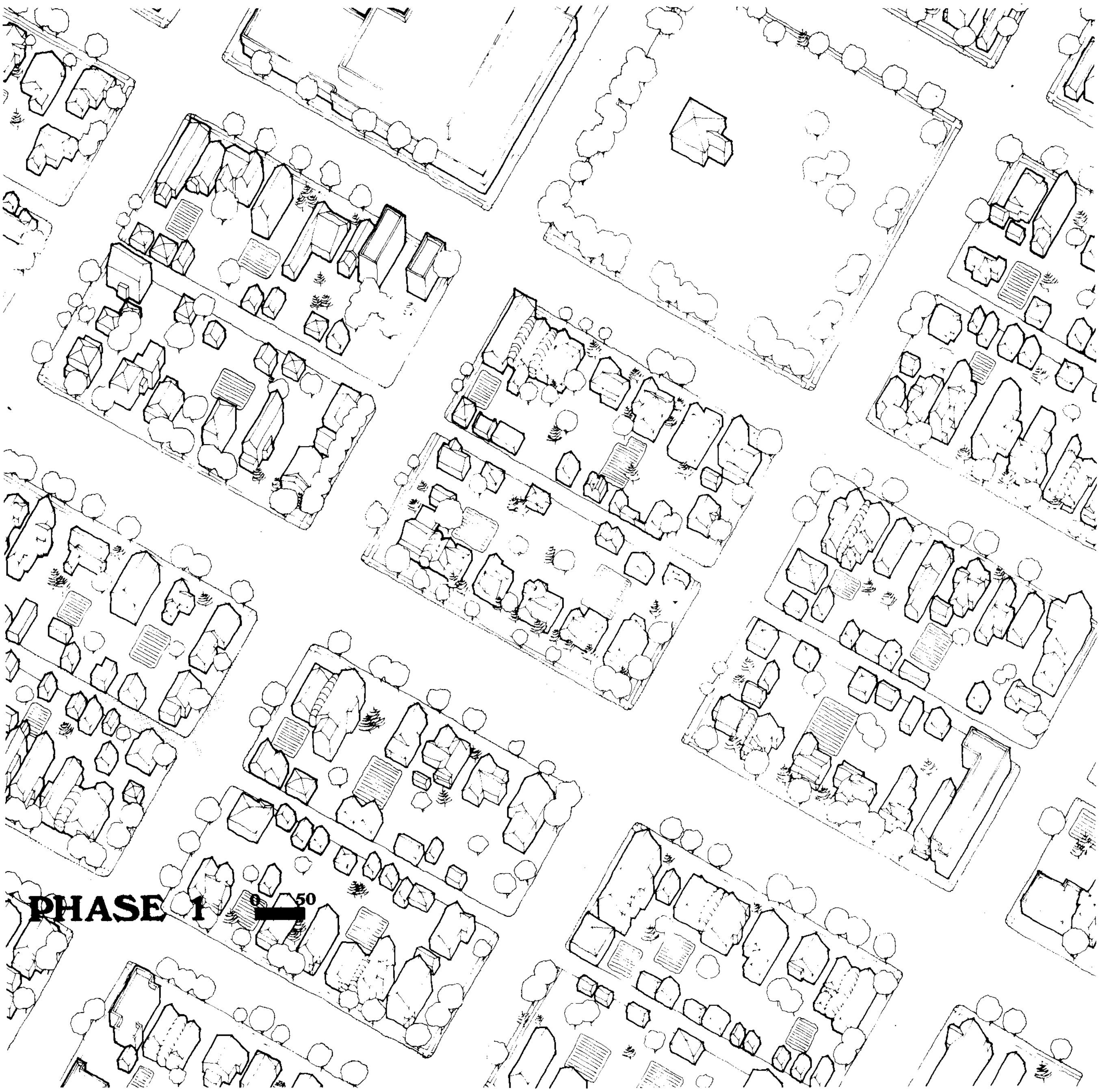

Fig. 3A. Winona, Phase 1

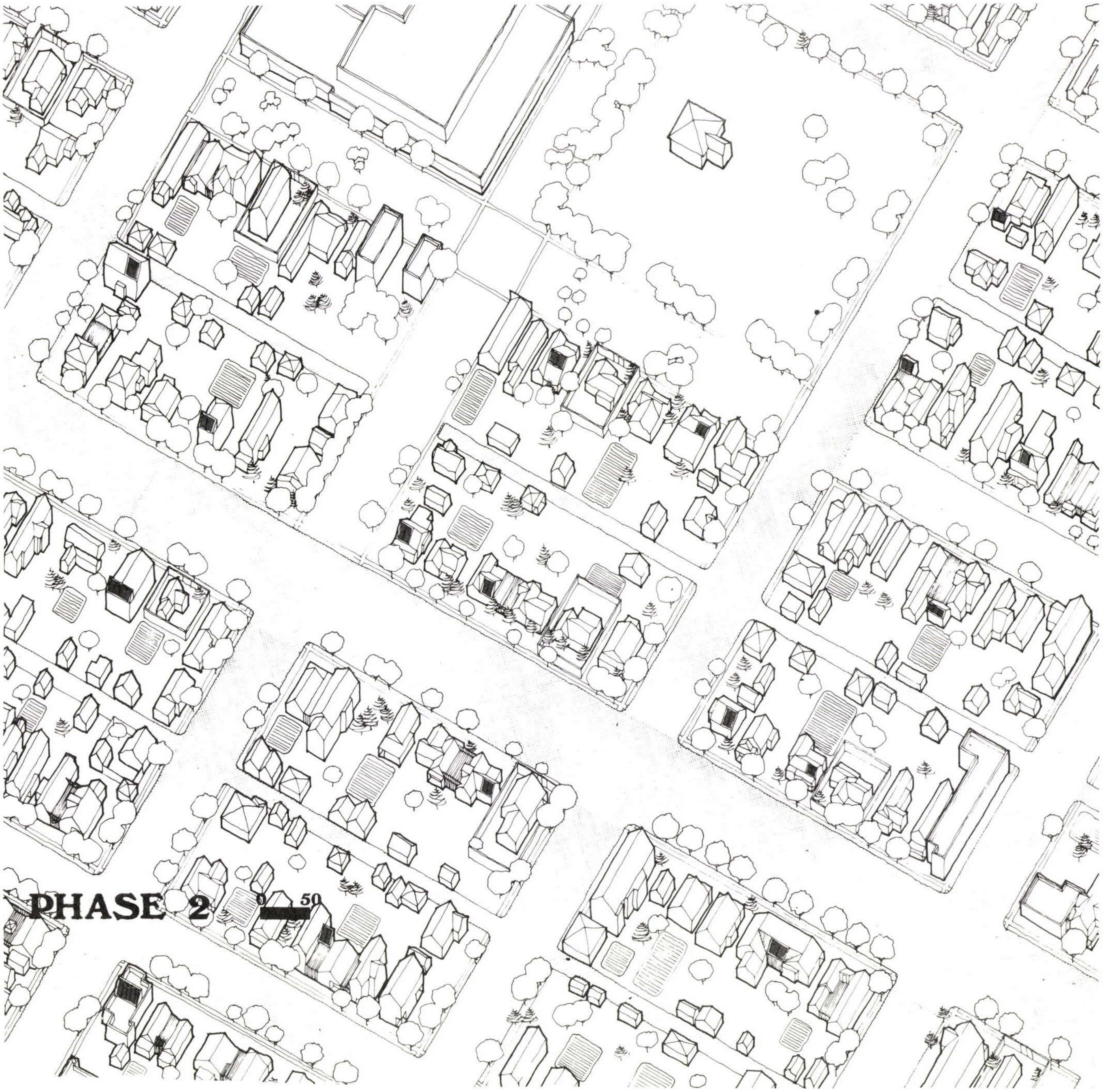

Fig. 3B. Winona, Phase 2

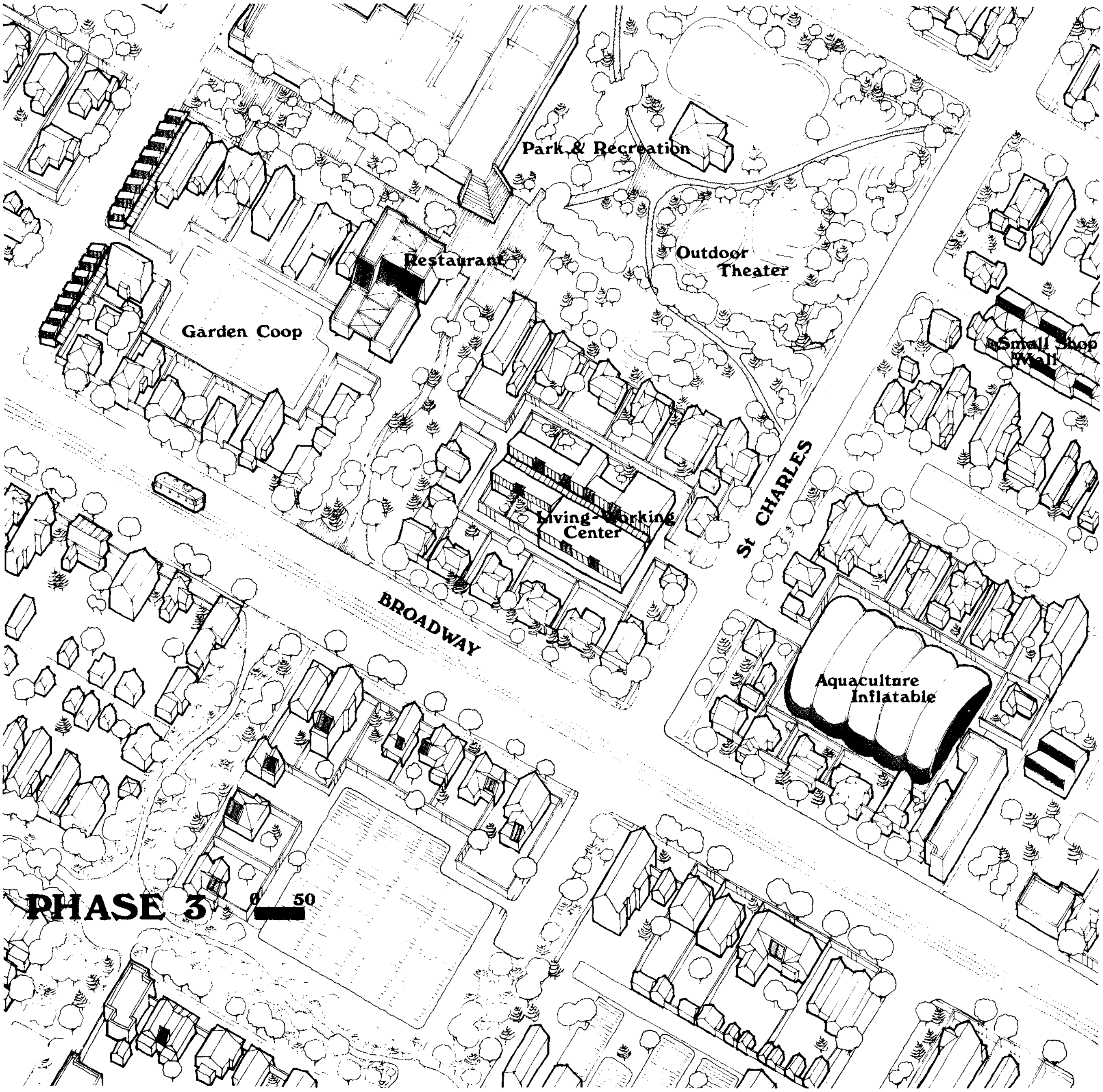

Fig. 3C. Winona, Phase 3

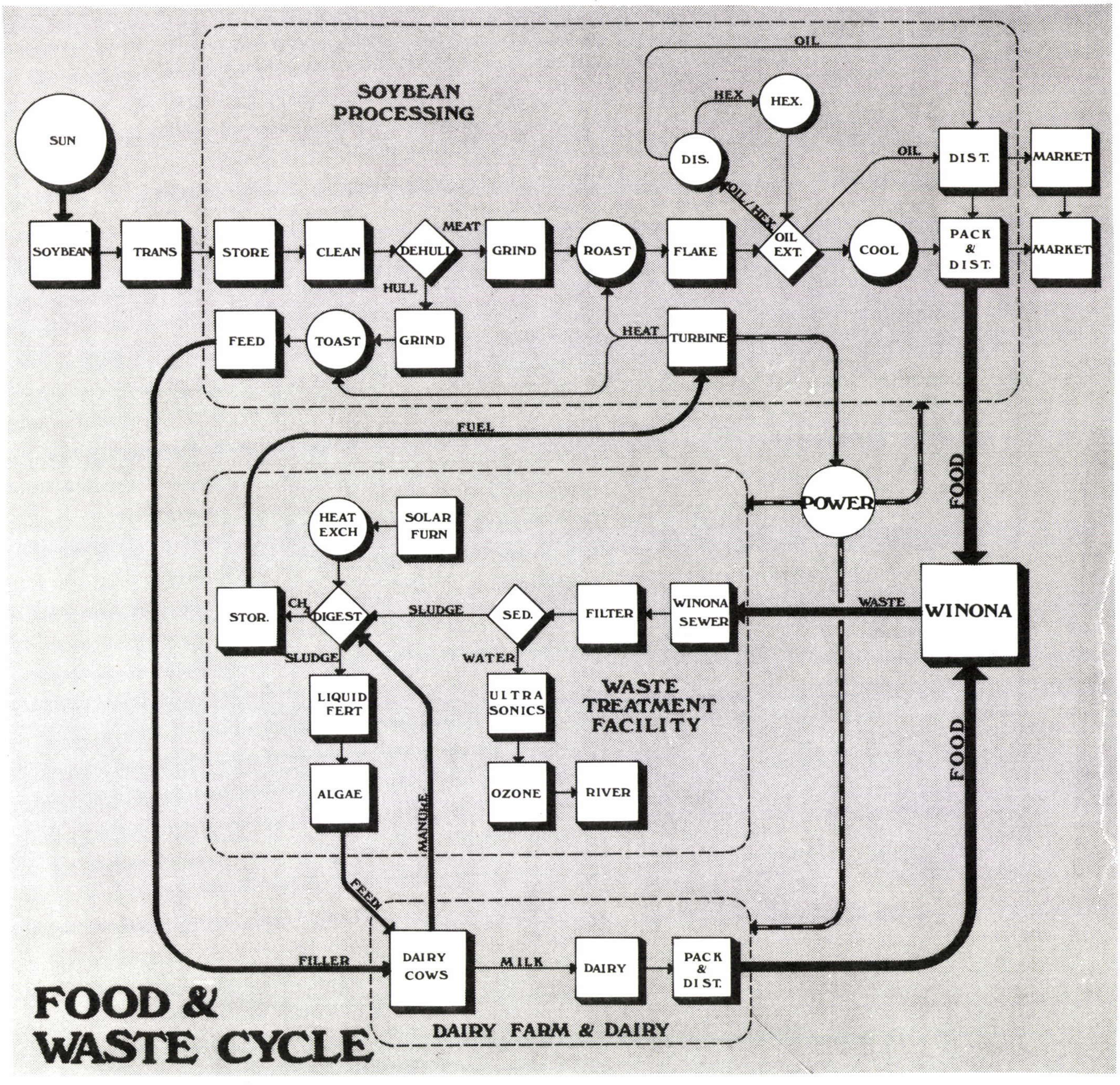

Fig. 4. Food and waste cycle

> Some of the abandoned facilities from the old sewage plant could be put to new uses. The two 155-foot diameter filter beds would make ideal ponds for growing algae on digested sludge from the new anaerobic digestor. Two tanks remaining from the old sewage plant would be used to mix and store dry food (soybean hulls, dried algae, and dried waste food and vegetables) to be auger-fed to the livestock at the feedlot.
>
> This proposed complex would be publicly owned and, by introducing new industry, provide needed jobs. It is a concrete example of how energy-conserving planning can interlock a variety of systems so that they approach self-sufficiency.

As the students became more involved in the project, their enthusiasm found no limits. A report was published (see bibliography) followed by the assemblage of a traveling exhibition of drawings, photographs, and models illustrating "the New Vision," as we referred to it.

The model of the transformed Winona was probably the best communication tool since it gave an extremely detailed view of how a range of appropriate alternative energy and food technologies could be employed. When the show traveled to Vancouver, B.C., for display at the U.N. Habitat Forum in 1976, more than 100,000 people saw it. The impact of the Winona Study has probably been more important at the international level than in Winona itself.

Some critics of the project maintain that the hardware of the proposal is three or four times greater than is practically feasible given "certain" economic constraints. But this doesn't really concern those of us who have produced the study. The point is: 20 students have shown in a dramatic and visionary way how an existing community could be transformed. If they have overstated the case—that's fine—we need propaganda that can open a new collective community vision for the future.

One of the dilemmas we now face in North America is a lack of vision of a meaningful future. If you lived in the '40s and '50s, you will remember the powerful images of the future illustrated on the covers of such magazines as Popular Science and Popular Mechanix—robot kitchens, atomic-powered furnaces in every home—which we now know will not come true. This was the heyday of modern high-tech propaganda. Because these earthly high-energy visions have not, and will probably never, come to pass, a new vision is actively being cooked up for us by the princes of high-tech: the unearthly high-tech, "low-energy" NASA/L-5 Society Space Colonization Vision. This effort to "save" us will fail for precisely the same reason that high-tech hasn't worked on the planet: it doesn't take into account the human factor—the real needs of people. A friend who attended the recent California Space Colonization Conference (supported by Gov. Jerry Brown) said that for the two days of the conference hype, not one behavioral scientist spoke.

The so-called Appropriate Technology Movement needs powerful media (using the same Madison Avenue hype techniques used by the L-5 Society) to propagandize the silent majority into action toward a new world view founded upon new sources of energy and new concepts of an earthly human-scaled community.

THE BIG QUESTION: HOW DO WE GET FROM HERE TO THERE?

So far in this paper I have been talking about how several big questions in 1973 activated some experimental projects in Minnesota. With the successes and failures of our experiments and hypothetical models we realize that a dream about human-scale alternatives is really possible in North America. But the most enormous question looms before us. HOW DO WE GET FROM HERE TO THERE? How can we build this new vision of the future?

In the past few months several of my collegues at the University of Colorado, College of Environmental Design, and I have thought about the question in preparation for the College's "Grass Roots in High Places" (GRIHP) Conference to be held in the Autumn of 1978. One way of approaching this question of "getting from here to there" is to break the question down into a set of subquestions related to it. We believe this will present us with entities which we can handle. And we can then actively seek answers which, when added up, may answer the bigger question.

Hard Questions for Soft Societies*

1. COMMUNITY-BASED ALTERNATIVE SOURCES OF ENERGY

   How much energy do we consume, and in what ways can communities and neighborhoods organize to conserve energy?

   What is a community energy recovery system, and what steps must be taken to implement such a system?

   What is the potential of solar energy, wind energy, biofuels, and water power community- and neighborhood-based systems?

   What alternatives and strategies exist for community and neighborhood energy supply-crisis resolution (e.g., Crystal City, Texas)?

   How much influence do our communities have on the allocation of fossil fuels within the region?

   How must our community values change in the transition from a wasteful to a frugal society?

   Can we increase aspirations and life satisfaction while reducing consumption?

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*Note: The above list of questions was prepared with the help of Professors Spenser Havlick, William Hendrix, Margit Johansson, Joseph Juhass, and Elinor Saboski, University of Colorado, College of Environmental Design.

How must our definition of neighborhood change in this transition?

What substitutes do we have to conspicuous consumption as a measure of status and prestige in the community?

2. WATER CONSERVATION

What has been the historic role of water in the development of the high plains conurbations and agriculture?

What is the current legal structure of our ecotone water management?

What are the legal strategies for urban and rural community cooperative management of ecotone water?

What technologies exist for integration of urban and rural water supplies and wastewater treatment systems?

What technologies exist for wastewater recycling, water treatment, and water supply?

Can changes in community values benefit or facilitate the transition toward a water-conscious society?

What are the alternatives to wasteful urban water consumption (i.e., urban lawn watering vis-a-vis drought resistant native varieties)?

How should our watersheds be managed?

How should our flood plains be managed?

3. LEGAL AGRICULTURAL PRODUCTION

What are the historical roots of our present agricultural dilemmas?

What technology does our present agriculture depend upon and what are the historical developments leading to our present technology?

What is the energy efficiency of our present agricultural production?

What determines farm prices?

How does our agriculture affect people in other countries?

Is there an agricultural technology more appropriate than the one presently in use?

What steps can be taken in communities and neighborhoods to implement:

- alternative fertilizers,
- pest control management,
- use of intermediate-scale machinery,
- community-based food distribution systems,
- community markets and food co-ops, and
- organic gardening/community gardens?

How can we develop a regional plan for population decentralization, return to the land, and rural homesteading?

What are the regional implications of a shift from agribusiness to home-owned farms?

How can we best utilize the biomass of urban lawns?

What effect on the carbon dioxide content of the atmosphere does the biomass of our region have?

4. TECHNOLOGY AND VALUES

What is the effect of technology on human relationships?

What are the relative effects of appropriate and inappropriate technology on our definition of "human being"?

What are the historical relationships between tools and machines?

Is there a relationship between our ethics and the ways we use tools and machines?

In the transition from the affluent to post-affluent society, how must our values change?

Can we develop a healthy relationship between community life and human life cycle in the emerging post-affluent society?

Can changes in our basic technological values and ethics result in a more satisfying life in the years ahead (symbiosis vs. co-evolution)?

5. COMMUNITY-BUILDING

How can neighborhood government be organized from the grassroots?

Can we optimize neighborhood participation in each stage of the life cycle?

What financial aid, state and federal, is available to neighborhoods?

Can a grassroots organization implement practical incentives for community resource conservation?

What strategies exist for the formation of co-ops?

- tool co-ops
- food co-ops
- funeral co-ops
- laundry co-ops
- labor co-ops
- child care co-ops
- transportation co-ops

How can a community implement a communication system (i.e., newsletter, oral, electronic)?

What is the relation between neighborhood size and formation of community? Is there an optimum size?

Is a small-scale community a valuable goal?

Is there a relation between the physical design of a neighborhood and its capacity for community formation?

How can community formation occur in a mobile population?

What is the relation between sense of self and sense of community?

6. SHELTER

Throughout the history of this region, how have cultures conceived of and built shelters?

How can a community foster indigenous art and architecture?

How can our existing shelters be made more energy conserving?

Is there a legal structure through which a community can alter local building codes on a broad issue (i.e., energy conservation; chicken coops, rabbit pens, and goats in the city; clivus multrum, etc.)?

Does this region contain potential new or alternative indigenous building materials?

Can the building industry benefit by adopting the principles of "appropriate technology"?

What state and federal weatherization assistance programs exist?

Can we build shelter affordable by low-income people?

How can a community organize and control self-help housing?

What appropriate technologies and alternative service systems can benefit a community retrofit process?

How can we modify our mental image of the "Ideal North American Home"?

Can spaces around existing buildings be put to better purpose, and what new controls (i.e., solar) are necessary?

How can a community organize a community greenhouse?

7. CONSUMPTION PATTERNS

What strategies exist for altering community consumption patterns?

What is the history of changing consumption patterns in this region?

What social and philosophical values have been the conditions for our historical consumption patterns?

How much of what we consume comes from other regions?

In what ways is our consumption wasteful?

Can community organization reinforce consumer power?

How can we close the circle of our consumption patterns in this region?

What are the politics of changing consumption patterns?

What new consumer options are necessary in the low-income market?

Is there a fundamental difference between urban and rural consumption patterns?

What substitutes do we have to conspicuous consumption as a measure of status and prestige in the community?

Is the doctrine of "let the buyer beware" the proper basis of producer/consumer relationship?

8. RECREATION/OPEN SPACE

Are there alternatives to our present form of tourism which conserve energy and reduce pollution and environmental degradation while putting people in close contact with our region's natural wonders?

How can new forms of recreation alter our need for tourism?

What legal strategies exist for community creation and preservation of open space?

Does our region need a more coherent open space plan?

Does open space mean residual space?

Is there a "tao" of open space planning?

9. TRANSPORTATION

How important is the "personalized" value of our present automotive transportation?

Does the need for a "personalized" vehicle result from a deeper need for "privacy"; and can a modern society offer privacy in other ways, thereby increasing the viability of energy conserving alternative transportation forms?

In what ways will the emerging alternative transportation systems alter the structure and form of our regional conurbation?

How can space presently used for transportation be re-zoned for neighborhood/community use and vice versa?

To what extent can the bicycle function as an alternative urban transport systems?

How can communities organize car pooling, community taxis, and health care transport systems?

How can a community organize a community-owned auto maintenance center?

What are the historical relationships between community form and dominant transportation mode?

How can transportation systems be extricated from present zoning and codes?

What is the connection between urban air quality and transport mode/technology?

10. ALTERNATIVE INDUSTRIES

To what extent can appropriate technology development create new labor in our region?

How can we increase worker satisfaction?

What is the history of industrialization in this region?

What is the relationship between craftmanship and fundamental human values?

How can communities foster indigenous crafts, encourage native inventors, and establish community-based industry?

How can indigenous industry benefit the unemployment and low-income community?

How can we integrate production units within walking distance of place of residence?

Can the achievement and knowledge of modern industrial technology and production aid us in the emerging nonfossil fuel age?

SATISFACTION IN A COLD ROOM

There is a traditional way of sitting in conversation in Japan. Because houses were without central heating systems, the primary source of heat was a small charcoal brazier placed in the center of the room. Cushions for sitting in the Zen manner were placed on each side of the brazier so that two people could sit facing each other. A quilt was then placed over the brazier also covering the extremities of the bodies, the hands and the folded legs of the two friends. With the extremities thus warmed by the charcoal and the backs warmed by heavy robes, only the faces were exposed to the cold room air. Two warm bodies and two cold faces, conversing about some aspect of the human condition. This is the literal expression of taoism of the East—an experience of beauty founded upon contrast, in this case between hot and cold.

Examples of aesthetics founded upon contrast are profuse in our own literature. Herman Melville in Moby Dick relates how wonderful it was to be in a nice warm bed with one foot extended into the cold room air.

Both of these examples contrast with our uniformly heated ("blah") modern environments. Can we be satisfied while consuming less? The answer seems so obvious.

We cannot forget that we are living in our children's house.

Everything that we do in our lifetime is going to affect the next generation more drastically than the effects of all previous generations combined.

During the past 30 years we have affected our future generations in a dangerous way by allowing technology to control our world unchecked. We must begin to feel the tremendous responsibility to alter the "hard" course we have taken, so that our children may have the inheritance of a healthy world.

Let us begin.

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PROBLEMS IN SOLAR DESIGNING AND THE ARCHITECTURAL ROLE OF SERI

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ABSTRACT

The Solar Energy Research Institute (SERI) intends to assist in the acceleration of solar technology commercialization through the design profession. The solar architectural market development role is to continuously identify the problems and implement appropriate programs to mitigate these problems. At present, these problems and barriers are in the area of effective technology transfer and attitudinal, legal, governmental, and institutional barriers. As a result of the problem identification activities, SERI can properly plan and implement effective technology transfer programs, education and training seminars, and other market development activities that will productively accelerate the commercialization of solar technologies through the design profession.

INTRODUCTION: THE PROBLEMS

There are a number of problems hampering the rapid diffusion of solar energy technologies through the design profession of the solar infrastructure. These problems are primarily related to the effectiveness of technology transfer activities and attitudinal, legal, governmental, and institutional barriers. These commercialization problems apply to many solar technologies, but the principal architectural concern at this time is the solar heating and cooling of buildings (SHACOB). SERI's architectural role is to identify these problems, a continuous process, in order to prepare and implement program plans that can mitigate the various problems. The intent is to induce an accelerated utilization of appropriate solar energy technologies through the design profession.

One major problem in solar designing is the lack of awareness of the appropriate design process and of current design tools by many architects, engineers, planners, and environmental designers. The appropriate process and tools for designing solar-oriented buildings, both active and passive, are being developed by various designers throughout the United States. However, these are being developed by relatively few designers, and the technology transfer is limited. More appropriate information needs to be compiled, edited, reproduced, and disseminated to other designers.

It is a slow process to effectively change the standard practice of architecture and the acceptability of new aesthetics. In 1973, William Ewald of the Midwest Research Institute estimated that, "On the average, technological change (in construction) requires 17 years from first commercial use to general acceptance as standard, state-of-art option or practice [1]." Some technology transfer programs, governmental and private, have been highly successful; but the total impact has been minimal on the total building profession. The profession is huge, and a number of good programs are needed to effectively accelerate the commercialization process of solar technologies. In the United States, there are approximately 60,000 licensed architects and 150,000 homebuilders. In addition, there are hundreds of thousands of engineers, planners, nonresidential builders, and building regulators who must have proper data and education in order to make intelligent decisions regarding solar energy applications.

The architect, in the long term, can play an important role in reducing our national energy demands. Approximately one-third of our nation's nonrenewable energy use is for buildings, with approximately 22% used for space and water heating [2]. However, architects are limited in their direct impact on residential construction. According to unpublished 1976 data of the National Association of Home Builders (NAHB), only about 10% of its nearly 100,000 members have architects or designers on staff, and 45% retain architects on a fee basis for certain projects; but architects can also have a significant indirect impact because many builders who do not retain architects often purchase plans designed by architects of model homes through magazines and other sources. This would indicate that the majority of home designs in the United States are architect-derived, directly or indirectly. Nonetheless, the primary practice of architecture by the large firms in the United States is for nonresidential uses. For example, Skidmore, Owings and Merrill, an architectural firm in Chicago with nearly 800 professionals on staff, provides approximately 95% nonresidential services (commercial, educational, medical, etc.) and only 5% residential [3]. This is somewhat typical of many large architectural firms in the United States.

According to Robert Balivet, AIA, architects must face five basic problems in the energy dilemma:

- Public image,
- Education of selves and consultants,
- Education of clients regarding the cost-benefits of architectural services,
- Self-images as designers of new buildings, and
- Contracting building and research services [4].

The attitudinal barrier of "public image" is a major stumbling block. Architects are often not directly considered in the home designing process by many average American home buyers. Architects are thought to have costly and "far-out" solutions. Construction costs are already high and rising steadily with the average U.S. home in 1977 costing $45,000 according to NAHB. This attitudinal barrier prevails even with the leading energy-conscious architects. In a recent survey, Balivet asked energy-conscious architects their response to public requests regarding more energy information on subjects on which the firm was known to have expertise. The general reply was, ". . . requests were referred to HUD's Solar Information Center - which was considered a disaster [5]!"

The attitudinal barrier of architects themselves may also be a major constraint. Philip Johnson, FAIA, is a world-renowned architect (of nonsolar oriented buildings) and winner of the 1978 AIA Gold Medal Award. Mr. Johnson was recently asked when he would start including solar applications in his design process. His response was, ". . . only after all of the other architects do [6]." Another leading architect, John Dinkeloo, was quoted during the judging of the 1977 Progressive Architecture Awards Program as saying, "I'll be glad when 10 years have passed, and everybody has gotten off this solar kick. They'll find out what a bunch of bologna it is, and get back to work [7]." The attitudinal barriers of leading architects may be a much more serious problem than many people care to admit.

The architect's attitude toward solar may be unfavorable because he is unaware of the seriousness of the energy dilemma and of the solar design process and tools, or he may have been exposed to existing examples of poorly performing and/or costly solar-oriented buildings. The attitudes of many designers, builders, consumers, and others in the construction-related industries compound the problems that hamper or halt the technology commercialization of active, passive, and hybrid solar systems. If the designer is aware of the appropriate design process, he or she may encounter resistance to use of a passive or hybrid system from builders who do not understand the systems and who are not convinced of the systems' potential, and from consumers who are unwilling to alter lifestyles necessary for some systems or are not convinced of the economic and energy payback. In these cases, the designer must be capable of educating the builders, designers, and others.

Legal, governmental, and institutional barriers are also common problems that the solar designer will encounter. In some cases, building codes and zoning regulations will not allow the design flexibility necessary to adequately utilize solar applications. For example, a county zoning regulation in Colorado does not allow for underground structures, even if the safety requirements of the building code were met. This restricts the use of passive solar dwellings where the north, east, and west exposures are totally or primarily underground. Other zoning regulations and subdivision standards may restrict the use of active systems and may be based purely on aesthetics. Financial institutions may have lending standards that also restrict or limit the use of nonconventional heating and cooling systems.

These problems must be further defined and understood to allow for proper national program planning that results in the responsible energy-conscious design of buildings by the majority of architects. As Balivet summarizes it, "The greatest danger is that architects may abandon their responsibilities to the general public to others far less qualified [8]!"

SOLAR ENERGY RESEARCH INSTITUTE (SERI)

The Solar Energy Research Institute (SERI) was mandated by Congress as a part of the Solar Energy Research, Development, and Demonstration Act of 1974. SERI's primary mission is to function as the U.S. Department of Energy's lead institution for solar energy research, development, and demonstration. SERI formally opened on July 5, 1977, in Golden, Colorado, and is managed by the Midwest Research Institute. In June 1978, SERI had about 300 staff members. SERI should stabilize in the early 1980s with 600 to 800 staff members.

SERI has developed an organizational structure consisting of four main operating divisions and one support division: Research; Information, Education, and International Programs; Analysis and Assessment; Technology Commercialization; and Administrative and Technical Services. The diffusion of solar technologies through architecture falls in the Technology Commercialization Division (TCD). TCD maintains extensive communication links with all sectors of the solar community and assesses the market readiness of each solar technology. This division collects and distributes information on materials, markets, standards, regulatory requirements, business risks, market barriers and constraints, and consumer attitudes.

Technology commercialization is the dynamic process of developing a healthy, growing, and self-sustaining private solar industry based upon a particular field of technology. It deals with both supply of, and demand for, solar products and services and is the deliberately stimulated movement of the technology from research and development, through economic verification and demonstration into production, and finally into the consumer marketplace. The objective of SERI's Market Development Branch in the Technology Commercialization Division is to define, through a continuing dialogue with industry and the user communities, those barriers and economic doubts which inhibit the growth of the solar market and to participate in the resolution of those issues. Further, the association of the Market Development specialists with the various elements of the solar and consumer communities provides viable channels for the solar advocacy function of SERI.

MARKET DEVELOPMENT OF SOLAR ARCHITECTURE

The SERI Market Development Branch serves as an interface between the research, analysis, education, and evaluation activities of SERI and the solar infrastructure. The staff specialists, in constant communication with those who influence policy and those who make decisions relative to solar utilization, provide feedback from the various solar user communities for the planning of the scientific, engineering, and analytical programs of SERI and DOE. The Market Development Branch specialists are responsible for maintaining working relationships with the following user communities of the solar infrastructure: Law and Government; Finance; Design and Architecture; Equipment Manufacturers; Small Business; Labor; Development and Construction; Distribution, Maintenance, and Service; Public Institutions; Utilities; and Consumers.

The basic function of the Architectural Specialist is to establish and maintain a dialogue with the architectural profession. The purposes are to understand the current attitudes and problems, to identify the key leaders and policymakers, to encourage a positive attitude toward the solar technologies, and to bring the resources of SERI to the resolution of barriers to the implementation of those technologies.

The market development architectural activities will be primarily concerned with architects and architectural firms that are responsible for the majority of new and retrofit designs of residential, commercial, institutional, industrial, and agricultural buildings. At present, the solar heating and cooling of buildings (SHACOB) is the principal architectural concern. SHACOB is well-introduced into the marketplace and now needs to be appropriately diffused into the architectural profession. SHACOB includes active, passive, and hybrid systems. The advancement of other solar technologies, i.e., wind, biomass, photovoltaics, and process heat, is being carefully observed as to the implications with the architectural profession.

Other specific elements of the architectural activities will have a special emphasis. For example, the problems and planning of large urban areas will have an important role. There are 25 cities in the United States that have a metro-area population of over one million people, which is deserving of special attention. Retrofit applications will be emphasized because new construction will only have long-term impact, and retrofit applications are often more difficult and could provide significant short-term impact if properly implemented. Mobile or modular homes deserve special note because, in 1970, 16% to 34% of all new single-family construction was for mobile and modular homes. Passive technology will also be focused upon due to the unique architectural design character of the systems. Passive systems are so unique as to have a separate branch in the Technology Commercialization Division.

A framework for the design process, reference material, design tools, and other technical data must be prepared and/or collected in a data base and disseminated through technology transfer programs, education and training seminars, and other market development activities. This is a continuous process as new architecture-related developments occur in all solar technologies. The structure of this commercialization process should be developed nationally, adapted to the various regions, and implemented on regional levels through the regional solar centers and locally with the cooperation of state and local solar and/or architectural organizations (i.e., the American Institute of Architects, AIA).

Information Collection

A quality information collection system and an accurate assessment of user needs are essential in order to provide successful technology transfer programs, education and training seminars, and other market development activities. The information collection process should include the identification of potential users, direct contact with users (i.e., meetings, workshops, telephone discussions, etc.), and user needs surveys. A data management program has been suggested by David Christensen in his paper, "Analysis of Data User's Needs for Performance Evaluation of Solar Heating and Cooling Systems," supported by the Department of Energy [9]. This analysis and others will be considered in the information collection process.

In this regard, SERI is designing and developing a Solar Energy Information Data Bank (SEIDB), which will contain a broad range of information and data to serve the research community, legislative bodies, commercial and industrial groups, and, eventually, the public. Builders, installers, manufacturers, and architects/engineers should take note that data bases on products; system performance and cost; and financial, insurance, and regulatory information are being considered for inclusion.

As part of the information collection for the planning of the diffusion process, unofficial national advisory committees will be established with the architectural and construction related professions. For example, a working relationship has been initiated with the American Institute of Architects for cooperative programs to diffuse appropriate solar technologies. Over 40 design, construction, and building regulator associations as well as government agencies have been contacted in this regard. The purpose of these contacts and advisory committees is to assure that SERI receives timely information on which it can act promptly. This information will also provide a source of feedback to other SERI branches (i.e., Technology Evaluation Branch, Information Systems Branch, Education and Training Branch, International Programs Branch, and other branches in the Analysis and Assessment and Research Divisions), Department of Energy, and the regional solar centers. Such feedback is vital to the entire SERI effort and illustrates one of the key ingredients of the interrelationships between the research, analysis and assessment, education, and commercialization activities of SERI.

Technology Transfer

The technology transfer activities of the solar architectural market development primarily relate to the information dissemination for designers and for assistance to the education and training programs. The activities will complement the DOE Solar Technology Transfer Program and the technology transfer programs of the regional solar centers. A framework for the design process, reference material, design tools, and other technical data is the primary information that will be developed and disseminated. The information will be disseminated through SERI communication channels, governmental technology transfer programs, and professional organizations.

The technology transfer process will utilize the information generated from the solar research development and demonstration activities of SERI. For example, a recent report from SERI's Research Division identifies a method for sizing solar energy space and water heating systems. This method, the subject of the Simplified Solar Design Workbook, is a sizing technique modeled after the successful F-CHART method. It is now being developed as one of a series of architectural design tools by the Market Development Branch. As other developments occur in the various SERI branches, appropriate design tools or other information will be compiled for dissemination.

Coordination of solar design processes and tools from the private sector is also necessary. For example, Steven Ternoey of HOK, Inc., a large architectural firm in St. Louis, Missouri, is in the process of developing "energy conscious design tools." To date, the work has three major parts. The first part introduces the process and tools and builds a vocabulary of alternatives. Among the topics analyzed are solar heating, building shading, internal and external building loads and forms, and daylighting. The second part consists of the tools and methodologies used in applying the principles to any particular project. The third part is the predesign data for specific projects, analyzing baseloads and potential energy systems in order to make intelligent design decisions during the schematic design phase. Another example is the Energy Analysis Workbook for Architects being developed by Michael Sizemore of Sizemore/CRS in Atlanta, Georgia. These projects and others deserve special consideration in the program planning of SERI's architectural activities.

A close association and coordinated programs with DOE, the regional solar centers, and the professional organizations will result in a stronger technology commercialization impact. For example, DOE recently contracted Doug Balcomb and Bruce Anderson to develop design guidelines for passive systems. SERI, AIA, and passive solar experts are reviewing the guidelines. The results should be coordinated dissemination activities from DOE with SERI, AIA, the HUD Solar Information Center, and others. Another example is the AIA Energy Notebook with its periodic updates. SERI anticipates providing input to these updates. A multitude of impact levels and coordinated, cooperative programs are needed to produce successful acceleration of the technology commercialization process.

Education and Training

Education and training programs for architects are being coordinated with SERI's Market Development, Passive Technology, Communications, and Education and Training Branches. The programs are intended to provide a framework for the design process accompanied by design tools. The national programs will lead to regional state and local programs.

The objectives of these education and training seminars are to:

- Educate the architects about the appropriate design process and tools for designing solar-oriented buildings.
- Illustrate the available options (especially related to performance and economics) as part of the energy-conscious design process so that the architect can make intelligent decisions regarding solar applications.
- Increase the market development of solar architecture technologies by removing misconceptions and providing factual design information.
- Train educators for seminar implementation at regional, state, and local levels.
- Provide avenues for education and information that are easily accessible to the architect.

One of the first SERI-sponsored and coordinated solar architecture seminars is a two-day seminar in cooperation with HUD Region VIII during late summer 1978. The seminar is for housing authorities throughout the HUD Region VIII and their architects. This seminar is oriented toward the architectural solar applications for low-income housing. This is a prototype seminar that, if successful, will be implemented in other HUD regions. Other seminars will be planned and coordinated with other governmental agencies, the regional solar centers, and professional organizations (i.e., AIA).

Another education and training activity of SERI's Market Development Branch is the cosponsorship of major solar programs. As an illustration, SERI is providing significant cosponsorship and support for the 1978 annual meeting of the American Section/International Solar Energy Society in Denver. This event should host between 2,500 and 3,000 participants. Another was the cosponsorship of the Aspen Energy Forum 1978, "Humanistic Choices," in Aspen, Colorado.

Design Competitions and Demonstrations

Another good tool for solar technology commercialization is the use of design competitions and demonstrations. This can stimulate the market diffusion by bringing architectural attention to solar technologies, encouraging architects to become aware of the various solar applications, and providing opportunities for information dissemination of the resulting designs.

As part of this type of SERI's commercialization effort, the SERI Passive Technology Branch is coordinating the technical reviews of the HUD "Passive Solar Design Competition and Demonstration, #H-8600." This is a $2 million program that should stimulate many architects to include passive solar applications in their residential designs.

Other Programs

A variety of other architecturally related programs will be developed in conjunction with the Market Development Specialists in the areas of Law and Government; Finance; Equipment Manufacturers; Small Business; Labor; Development and Construction; Distribution, Maintenance, and Service; Public Institutions; Utilities; and Consumers. Formulating market development programs is by nature an ongoing and changing process. It must be ongoing and changing to meet the objective of defining and helping to resolve, through a continuing dialogue with industry and the user communities, those barriers and economic doubts that inhibit the growth of the solar market.

Constraints

Many constraints may continue or change along with SERI's program planning in regard to the technology commercialization of all solar applications. For example, many of the same technical constraints, although changing, on which P. Richard Rittelmann, AIA, gave testimony to a House subcommittee in 1973 still apply. Rittelmann's technical constraints to the emergence of applied solar technology are summarized as: meteorological data, lack of hardware, lack of design procedures, data translation, limited research and development, architectural interface, and operation and maintenance [10]. These constraints have changed since 1973, but the general topics are still applicable for consideration of all solar technologies that relate to architecture.

Rittelmann further points out technological constraints to commercialization of solar systems summarized as: market aggregation, proof-of-concept, industrial engineering, prototype testing, vertical structuring, mutual dependencies, code approvals, and education [11]. Again these outlined constraints may still be topics of concern in the continuous commercialization process of solar technologies.

SUMMARY

There are a number of problems hampering the rapid diffusion of solar energy technologies through the design profession of the solar infrastructure. These problems of effective technology transfer and attitudinal, legal, governmental, and institutional barriers are quite diverse in nature. Jeffrey Cook, AIA, who has been involved with various surveys of solar users, states: "A sociological or census profile of solar consumers also reveals that solar applications attract divergent sets of the population and for different reasons. It appears that the universal acceptability of solar energy is based on selected values that are not always common [12]."

The diverse and changing problems must result in continuous and flexible planning for national programs. SERI's plans are intended to reflect this attitude through technology transfer programs, education and training seminars, and other market development activities. Through sound and comprehensive program planning, SERI can provide major assistance in the commercialization goal of accelerated utilization of appropriate solar energy technologies through the design profession.

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SOLAR DECISION MAKING

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INTRODUCTION

At an Energy Forum focused on "Humanistic Choices," it is probable that most of the participants are predisposed. By participating, they may become more aware of alternatives; but, in general, their decisions have been made. Whether or not it appears in the title of the conference, or in the title of the paper, the word solar is implicit. It is the hidden agenda.

HUMAN VALUES

Solar is the key to "humanistic choices," not necessarily because it is a neat way to keep warm, although it may be. Nor is "solar" fundamental to an interest in new and inspired hardware, although it also may be. Rather, "solar" is the ubiquitous background of new human values because it is the essence of a reorientation to the natural world. It is the key to a new born integration of man's life on his Earth.

REALITIES

Such profound idealism is surely tempered by the raw realities of our emerging solar world. Solar like every other subject is a question of strong human content. But then there are no questions raised by man without human content.

Among the many values revealed by built solar applications are expressions of environmental and ecological concern. These could be contrasted with economic goals and intentions of wealth and capital gain. Solar in its many manifestations has a variety of sociopolitical implications. And last, but not least, it can become an expression of personal and ideological values.

SPECIALISTS

But these values become distorted by the act of translating idea into object, as well as by the description of observers. The results of nonspecialists in a new field can be disastrous. Not only can they appear to be "non-pretty," but they frequently lack objective thermal or economic viability. However, even solar specialists tend so far to display rather unbalanced views. In some cases their new solar landscape is as frail as a monoculture as the old one they hope to replace.

MYOPIC VISIONS

Specialists tend toward concentricity. Most specialists working in a field tend to project the paradigm of their own experience and idealism in describing their field. Sometimes, they are too close to the trees to see the forest. In a new field such as solar energy which has a major potential of modifying the man-built environment, these projections can be misleading. For instance, mechanical engineers active in solar applications visualize the problems and opportunities of this emerging field within their own range of contact and experience. Similarly, architects, builders, and bankers all project their own myopic vision—each a sharply different idea of what solar applications are about. Predictably, both their descriptions of the field and their concepts of why particular solar decisions should be made are widely divergent. Similarly, their observations of what has actually been built in the field are distinctly selective and colored by their own informed point of view.

SOLAR DECISIONMAKERS

Architects, as specialists, tend to attract certain types of clients. Often, it is a self-fulfilling cycle. Clients are attracted who share the visible and projected values of the architect. The resulting building designs tend to reinforce these mutual outlooks which become three-dimensional examples of a set of agreed and mutually compatible choices. These experiences and the values they represent are not necessarily a meaningful sample of values and attitudes of the general public. They, then, would be a poor basis for projecting the disposition of the public.

Certainly, the best source of the humanistic values represented in solar applications must come not from projecting either personal observation or the myopic views of specialists, but must come from an objective sample of the general public whose occupation is not solar.

The most revealing and critical values will come not from a random sample but, rather, from a solar sample. The most viable reasons for solar decisions are best revealed by those who have already made solar choices in the most meaningful way—they have bought solar. They are, for want of a better term, "solar consumers."

COMMERCIALIZATION

Since the energy issue has become a part of public policy, it is represented in many guises in the activities of various government agencies. At state and federal levels, the concept of solar commercialization seems to have been more easily grasped and promoted than has the idea of solar popularization.

In a variety of activities that are intended to assist and speed solar commercialization, a number of studies have been made which attempt to outline and project the field.

Typically, these surveys and projections have been made by canvassing the specialists. However, although the solar specialist may, indeed, know his own field quite completely, he may not have a very realistic grasp of the whole solar field. Especially, the comprehensive sets of reasons for why the general public should go solar may escape the specialist—because he projects his own myopic experience. Similarly, potential buyers and potential sellers represent hypothetical sources of information and projection. A much more reliable description might come from "solar consumers." In a consumer society one should communicate with the consumer. They are demonstrably the solar committed.

SOLAR SURVEYS

As a researcher, the author has been the principal investigator in several solar surveys using a variety of information gathering techniques. Perhaps the most important aspect of the process of these surveys has been the qualification of the investigative team. The interdisciplinary nature of these teams is revealed by the divergence of vocations represented: architect, historian, biologist, carpenter, anthropologist, and former corporate executive have been part of the effort of avoiding the myopic vision of one or two specialists.

An indepth survey of the Metropolitan Phoenix area of Solar Decisionmakers was carried out during the summer of 1977. It used a regularized face-to-face interview technique to collect highly reliable information from a relatively small sample of 35 solar consumers. The process intended to find out not just the type of solar installations but also the basis of solar decisions and the profile of the public that was making solar decisions. Within the survey area, at least, the results were not as most solar specialists would have projected.

Sample solar inventory work and surveys carried on in several metropolitan areas of the United States, including Denver, Phoenix, Los Angeles, Boston, Washington, D.C, and Miami, demonstrate that there are, in fact, many more solar installations in place than any estimates have suggested. For instance, by April 1978, at least 500 solar installations could be counted in the Denver metropolitan survey area. In Phoenix SMSA, the counted number was around 1,400 although many of these are swimming pool heaters. By experimenting with a variety of information collection techniques, it has also been demonstrated that there is a wide diversity in the quantity and quality of information and, thus, reliability—depending on the inventory method.

FINDINGS

Certainly the results of onsite investigation of solar applications has revealed a great diversity. It is, perhaps, most informative to look at the most extreme examples that such survey work reveals. Typically, they are not the sorts of examples of solar application that are discussed or displayed either in public meetings or in specialist conferences.

It would be easy to assemble an album of solar horrors. But, alternatively, one also comes upon elegant and beautiful examples such as the lean and thoughtful engineering for a system that produces hot water for a 70-unit apartment house. In effect, the direction of solar findings is like any other survey work—highly dependent on the selection of the sample.

CONCLUSION

The reasons for the popularity of solar applications are well known. There is a mixture of incentives ranging from the most altruistic and ethical to the most compulsive, selfish, and self-serving. However, from the limited inventory and survey work already done of actual installations, there are particular sets of criteria that are moving the solar decisionmaker. A "sociological or census" profile of solar consumers also reveals that solar applications attract divergent sets of the population and for different reasons. All of these reasons are important. Some even appear to be in conflict with others. The combination of reasons is a rich mix. It appears that the universal acceptability of solar energy is based on selected values and sets that are not always common. However, their common denominator is the sun. The beauty is in the universality of that source and not in the particular outward expression of solar applications.

PEOPLE, ENERGY, AND BUILDINGS: A GRAPHIC APPROACH TO ENERGY-CONSCIOUS DESIGN*

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Concern for energy conservation may provide the thrust to a new era in architectural design—one in which the form of buildings is a conscious response to the nature of the energy needs of their occupants. Virtually every major decision made in architectural design affects a building's ultimate energy use. Consequently, there are literally hundreds of ways to improve energy efficiency. But, in any specific case some ways are better than others, and some may actually be counterproductive. Designers face such a myriad of possibilities for conserving energy that it is difficult to know which to choose and what the real effects of those choices are.

This paper synopsizes some of the key elements of a process developed to assist designers in achieving energy-efficient buildings. This process is a supplement to the normal design process; however, it is not an algorithm for achieving the most optimally energy conserving design possible. Instead, it is a framework for gathering, analyzing, visualizing, and evaluating pertinent energy related information in the context of a specific design problem. It aids the designer, throughout the design process, in determining which energy conserving measures are effective and what the energy effects of design decisions will be. Thus, it allows the designer to make informed design choices which are equally responsive to both energy efficiency and human occupancy needs.

Energy use in buildings can be attributed to three basic determinants:

- Occupant needs which include comfortable temperature and humidity conditions, illumination, hot water, and power to operate equipment and appliances.
- Climatic conditions which influence the amount of heating and cooling required and the amount of daylight available for illumination.
- Design of the building which determines the rate at which heat is gained or lost to the exterior and the amount of daylight which gets into the building.

Of these determinants, design of the building is the only one which is controllable. The goal of energy-efficient architectural design is to create a built environment which provides for occupant needs with the least possible requirement for fossil fuels. However, this goal can only be achieved by understanding the energy related attributes of occupant needs and climatic conditions, and using these attributes advantageously in design. This involves such principles as:

- Utilizing heat available from climatic conditions and from occupant activities and equipment use.
- Avoiding gain of unneeded heat from climatic conditions and occupant activities and equipment.
- Using daylight for illumination.

In most buildings—both residential and nonresidential—heating and cooling constitute the largest component of energy use. Heating and cooling are required to offset heat losses and gains which a building experiences due to occupancy activities and climatic conditions. Thus, control of heat gains and losses is the key to energy-efficient design.

For purposes of design, it is useful to separate the heat gains and losses affecting a building into four heat transfer components:

- Envelope heat gains and losses--the conduction and convection of heat through the building envelope due to a temperature differential between inside and outside.
- Ventilation heat gains or losses--the net transfer of heat into or out of a building by the forced introduction of outside air for ventilation when an inside/outside temperature differential exists.
- Solar heat gain—heat gained by absorption and transmittance of solar radiation falling on the exterior surface of the building.
- Internal heat gain—heat emitted within the building by people, lighting, and equipment.

Efficient thermal performance of a building can be achieved by appropriate design treatment of each of these four components. In most cases, however, a building designer does not know either the absolute or the

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*The material presented in this paper was derived from work performed under contract with the U.S. Department of Energy.

relative effects of these components—or how to design the building so that each of these components is used most effectively in the total thermal performance of the structure.

A graphic analysis technique for building design has been developed to model heat gains and losses from the four heat transfer components. Using this technique, the potential energy requirements of a building to be designed can be shown visually. This modeling technique can be used both prior to design to show the energy potential of occupancy needs and climatic conditions and during design to visualize the influence of design decisions on thermal energy requirements on the building.

The initial step in the application of the process is the energy modeling of each of the four heat transfer components. An example is illustrated in Exhibit 1. In these models, the expected heat gain and loss in Btu per hour for each of the components is illustrated for an average 24-hour period in each of the four seasons. The shaded areas show a range of possible heat gains or losses—which will ultimately depend on the actual thermal performance of the building elements or systems affected. Thus, these models show both the absolute and relative thermal energy contribution (or deficiency) potential from each of the four components.

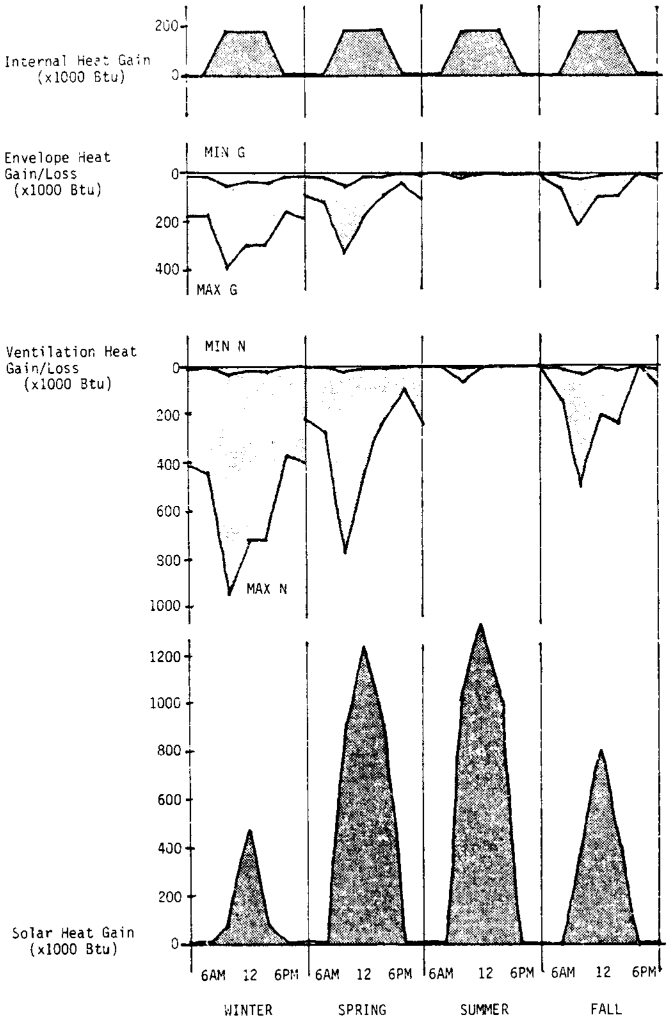

Exhibit 1. Energy modeling of four heat transfer components

Once the four heat transfer components have been modeled, they are aggregated into a composite Thermal Performance Profile which shows the total combined effects of all components. An example is shown in Exhibit 2 in which the shaded areas represent excess heat gains and losses which must be offset by heating or cooling.

The Thermal Performance Profile in Exhibit 2 is developed from a baseline set of assumptions about the thermal performance properties of a building. Modifying these baseline assumptions will alter the profile and will increase or reduce excess heat gains and losses.

The Thermal Performance Profile, together with the individual component models, is used to develop a design strategy for energy efficiency.

- First, the Thermal Performance Profile is analyzed to see when the most severe heat gain or loss problems occur.
- Next, the individual component models are examined to determine the cause(s) of the problem and the potential of each component for reducing the excess gains or losses.
- Depending on the nature of the problem, adjustments are made in the baseline thermal performance values used to develop the profile.
- A revised Thermal Performance Profile is developed with the adjusted component thermal performance values.

This process is repeated by continuing to revise thermal performance values, with the purpose of reducing excess heat gains and losses throughout the year. An example showing the incremental impact of thermal performance modifications is shown in Exhibit 3. However, revisions of component performance values are made only if acceptable within functional and aesthetic design criteria. Ultimately, one or more modified thermal performance profiles are derived from which no further reduction in heat gains and losses can be obtained within the constraints of the design problem. An example of a modified thermal performance profile is shown in Exhibit 4.

Compared with the original baseline Thermal Performance Profile, the modified profile shows a substantial reduction in excess heat gains and losses and, therefore, in energy required. The thermal performance values which were used to achieve the modified profile thus become the criteria for achieving an energy-efficient design. Alternative design solutions can then be explored to meet the criteria. The Thermal Performance Profile is used continually during design to indicate visually how specific design alternatives affect the building's energy use.

* * *

The graphic examples shown are from an application of the process described in the design of an office building in Seattle, Washington.

Maximum Envelope Heat Gain/Loss
Minimum Ventilation Heat Gain/Loss
Internal Heat Gain
Maximum Solar Heat Gain

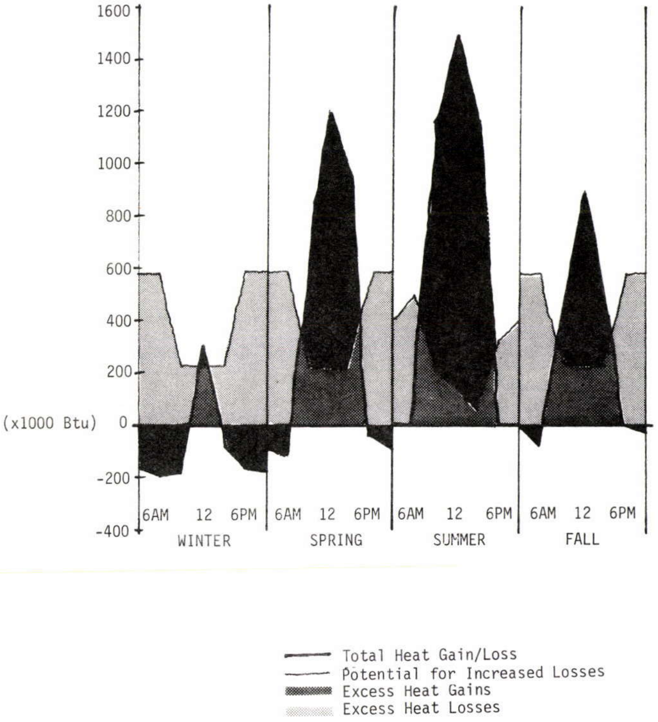

Exhibit 2. Baseline performance profile

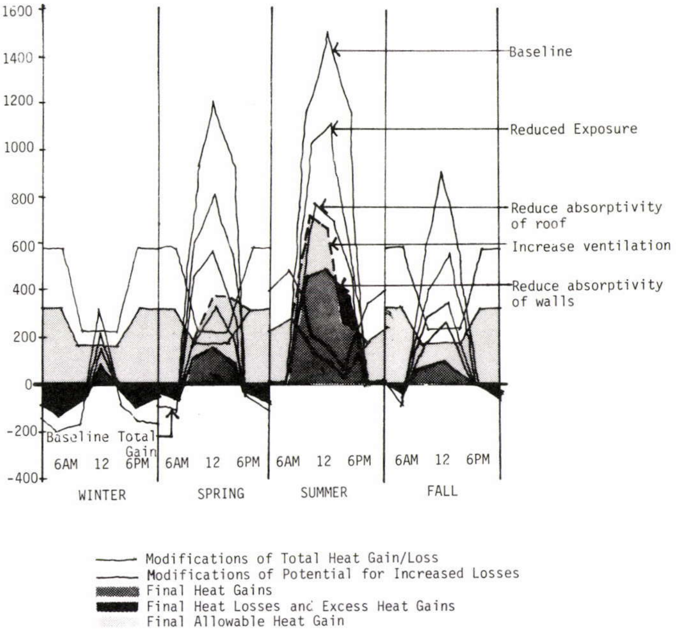

Exhibit 3. Thermal performance profile

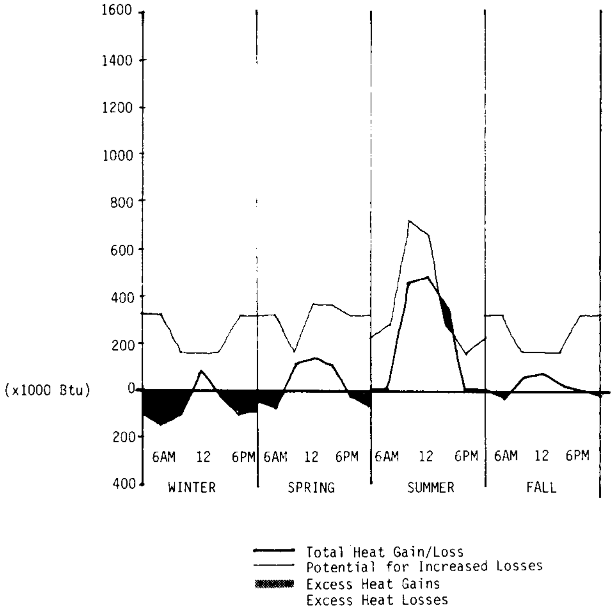

Exhibit 4. Modified thermal performance profile

BRINGING IT ALL HOME

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WHO WE ARE

Humans have long been known on the surface of the Earth for their skill in hunting and fishing and in gathering fruits, nuts, and wild vegetables from the ecosystems they inhabited. For roughly 5 million years we have been living well in this manner. The relatively sudden evolution of our large brain simply added a special cleverness to our ancient primate skills in gathering food from the open savannah and tree tops of the jungle forests. We found fire and invented weapons for killing prey bigger than ourselves, and for killing at a distance. Wherever food was to be found, we could be counted on to run, climb, or swim to it. We have been designed by the hand of evolution for precisely these activities.

From the hunter-gatherer societies still roaming the wilds today we know that it was a good life—a life free from hunger, a life virtually free from disease, a life of immense leisure. Even in the Kalahari desert today the Kung Bushmen spend less than 4 hours a day providing for their food and shelter. The Cuiva in the Venezuelan rain forest spend maybe an hour or two a day. The rest of the time they pass relaxing in hammocks, exploring, gossiping, philosophizing. Our instincts, metabolism, inner chemistry were formed for and by thousands of millennia of this life-style.

As hunter-gatherers we were part of the ecosystem as well as indwellers. We lived in the forest and on the plains as other animals did, taking from the world, our home, the bounty which it offered us. We seldom stored anything for later—the world could be trusted to provide fresh food of some kind every day. All the watering, weeding, soil preparation, fertilizing that our food plants needed for growth were taken care of by the ecosystem.

As an integral part of the tapestry of nature we found no need to "domesticate" animals and plants. We were all in each other's home. We ate the furniture of our house (fruits, seeds, nuts, and tubers) and understood the flora and fauna of the forest and plains with a sophistication rarely matched today by professional ecologists.

Then, for reasons not well understood, over a period of a few thousand years in four regions of the world, our ancestors began manipulating the environment to make certain food plants grew more densely in chosen places. (Thus inventing work.) At the same time they began to <u>feed</u> selected animals. One thing we do know about this new behavior is that it began to occur only after all the continents and regions had human populations. And we know that this new activity began very recently (a mere 12,000 years ago in the earliest case), which means that for 99.75% of our known history we had no use for this kind of activity.

When plants were domesticated, we were domesticated. As hunter-gatherers we had no fixed homes. We followed the seasonal ripeness of plants and the shifting densities of prey to new areas.

Not long before the beginning of cultivation, it seems, clay pots were invented for food storage; and curved, stone-toothed sickles began to be used for harvesting grass seeds. The final addition of cultivated fields allowed settled living. "Our" plants and animals domesticated us and created a line of demarcation between human settlements and the natural "wild" world.

In bringing a few species home with us out of many millions in the ecological food webs we created specialization. Learning more and more about three or four species we no longer needed to understand the rich complexity of the system from which we evolved.

The intimacy of the hunter-gatherers with the biological universe in its wholeness and its matrices, its webs and rhythms, was replaced by a familiarity with only one or two crops and animals in one locale. Once settled and beginning to specialize, these highly evolved hunting-gathering creatures developed the cultural artifact of ownership of land, and then through residence created wealth (i.e., surplus) and thus social classes. Writing, cities, and empires followed close behind. All this in a handful of years, beginning with the domestication of plants. The cultural changes flowing from this decision, in 10,000 years, surpass by orders of magnitude such changes during the previous 5 million years.

WHERE WE'VE COME

As hunter-gatherers we humans were always in touch with the whole natural system. All the individuals in one's tribe were familiar. The universe of plants and animals and their connections through intricate food chains were common knowledge. Every practical thing one touched, ate, wore, or dwelled in was known intimately. The materials, the working of the materials, the design, the biological sources, and the sacred history of each thing were part of a web of understanding that linked the whole of the human experience to the whole of the universe.

When we began to domesticate selected plants and animals, we opened the door to the power and ignorance of specialization.

The farmer needs a stronger back than the hunter but far less awareness of the environment. He lives in one place, so he builds a sturdy, permanent house within which he sleeps deeply, without alertness for wild animals. He pays attention to the plants he cultivates but can afford to pay no notice to the balances and harmonies of the ecosystem around him.

With specialization comes higher productivity of the specialized crop. With complexity comes greater specialization, then more room for and need for complexity—then more specialization to cope with the complexity—and so on. The twin facts that, on the one hand, the individual large-brained primate is limited in what he or she can learn in a reasonable amount of time, but, on the other hand, can communicate with and cooperate with other individuals, provide together an open-ended horizon for specialization. Ever larger numbers of individuals can be trained in even narrower segments of the society's tasks such that all together they create the effect of the holistic work of a large, multiskilled person. Although a complex culture is a whole, the specialists who operate it do not share in an immediate vision or understanding of the wholeness. Even those who are so-called "managing" the work of the specialists are specialists themselves in the narrow skills of "management." In a culture sufficiently complex, no one has a view of the whole. And when all or even most of the individuals in a culture are out of touch with a sense of the whole of things, the culture lurches forward as the sum of the collective ignorance of the people who make it up.

As this century ends we have reached levels of specialization and complexity previously unimaginable. The average individual is unable to design and incompetent to repair the implements and tools essential to his daily living. Very few individuals know how, or even where, their food is grown, their clothes are made, the wood in their houses was cut. The sources of our water and electricity are unknown to us.

It is not easy to assess the social and psychological effects of having one's life dependent in every respect on the will and knowledge of strangers, often half a world away. We do not know the effect on the soul of a lifetime of being supplied from unknown sources.

The specialized systems of exploitation and efficiency which gave the American people the greatest quantity of goods and services known to history—an extraordinary freedom of choice and travel—have made each individual and family more dependent than any people have been. The farmer's loss of knowledge of the ecosystem is now reinforced by the urban dweller's loss of the ability to produce food. As long as this system functions without a major flaw, no one will notice that both the ancient food-gathering abilities and the recent food-growing skills are traits nearly bred out of the human species in the West.

As recently as 1929 when the stock market crashed and the world depression began, over 80% of the people in America either lived on farms or had parents, uncles, or cousins who lived on farms that they could go to. These farms produced enough meat, milk, eggs, and vegetables to feed extended families in the absence of a viable national economy. In the 1980's there will be no such cushion when, and if, the economic net begins to unravel.

No culture before has been largely ignorant of how food is produced. The skills of agriculture and husbandry were for 10,000 years the knowledge base of the peasant majority—a base upon which the culture's specialized knowledges were built and flourished. Now agriculture is one of the esoteric, technological specialties learned in universities, engaged in by an elite 4% of the population.

As individuals we are back to total (no storage) dependency on the environment—but where once the environment was the secure ambiance of balanced ecosystems co-evolved to climax fertility over eons, the environment upon which we totally depend is the kaleidoscopic, adolescent, experimental invention of a newly clever species. Our environment now is a global economy of one-dimensional exploitation and complex trade agreements, put together by chance and intelligence motivated by individual and institutional greed. The lines of supply are long and fragile, even for such essentials as chromium (for making steel) and petroleum (for powering nearly everything).

Any social-economic system this immense has a key characteristic that is usually overlooked: an individual has no power to enhance the whole system. With the rarest of exceptions an individual is powerless to make the system as a whole work better. But, nearly any individual has the power to sabotage it in some way, a way which will be felt, at least through the media, across the whole system. Vast systems, with long lines of supply, based on refined and unforgiving technologies are especially vulnerable to terrorists.

Furthermore, the need of individuals for recognition within their whole context remains as strong as ever it was in the hunter-gatherer tribe. When the opportunity to make one's mark on the whole in a beneficent way is blocked, there will always be individuals who will accept as a substitute the recognition and power of destructiveness.

A global economic system both causes and invites destruction. Decisions are made in New York and Tokyo to exploit the ecosystems of the Andes or New Guinea. When the system the decisionmaker affects is thousands of miles away, he need never see or feel the scars on the Earth or the social and ecological systems he destroys. Only the profits will find their way with certainty back to headquarters.

In addition, a vast culture influences people not to care for things, since "goods" are replaceable, interchangeable, without history. A system of worldwide television programming, aiming as it must at the lowest common denominator of the vast mass, feeds increasingly vivid images of violence into the new common imagination of the world.

WHERE TO NEXT?

There is no going back to the hunter-gatherer small band in touch with the wholeness of the ecosystem. Agriculture is a permanent adaptation. The human population has soared beyond the carrying capacity of an unbiased ecosystem.

There is never a going back. But at a certain stage of evolution it may be possible to assess the losses incurred through development and to perceive a way to catch up again with certain essential lost relationships at another level of the spiral. No kind of evolution is linear. The evolution of human culture tends to follow a dialectical pattern. Seen in this light we may discover that rather than having gone too far, we have simply not gone far enough. We may be suffering from an incomplete revolution.

In the philosophy of Hegel the development of human cultures is described as a three-stage movement: a thesis, a complex of relationships or state of affairs; an antithesis, a development which in some sense negates the thesis and creates its opposite; and a synthesis in which the opposites come together and blend, thus making up a new thesis for a new triad. Looked at within this frame, the culture of hunter-gatherers living as members of an ecosystem with whole system awareness and dispersed, low populations in the thesis. The antithesis is our separation from the ecosystem by domestication of selected species. Out of this selection come specialized occupations and expertise developed along with ignorance of the greater part of the system. The synthesis could now be: domestication of whole food-producing ecosystems by families and small groups, villages, neighborhoods.

What might this mean? Some relevant examples exist: In 1976, after 7 years of research and prototype development, the New Alchemy Institute on Prince Edward Island completed building a structure heated by the sun, powered by the wind, and encompassing a combined aquatic and terrestrial food-producing ecosystem and human dwelling. Within this bioshelter a food web of composted plant matter, soil, vegetables, insects, bacteria, pest-eating reptiles and amphibians, zooplankton, phytoplankton, fish, crustaceans, tree seedlings, fruit vines, etc., live in ecological balance. The natural nutrient cycles are complete. Besides occasional seeds, the only major inputs to the system are some water and lots of sunlight. Nearly all the species present are human food species or naturally occurring nutrients or foods for these species. Pests such as nematodes, fungi, or insects which attack human food plants are kept in balance by the rich variety of competing bacteria in the soil; protective natural chemicals from companion flowers; ultraviolet light from the sun; and predatory lizards, toads, spiders, and insects inhabiting the biological matrix.

The ecosystem is designed to provide a balanced gourmet diet for the human inhabitants year-round in the north, where 20% of the winter heating comes from sunlight reflected onto the solar collectors from the offshore ice sheet. As it matures, the ecosystem is expected to produce a monetary income for the residents (human) through the sale of excess fish produced and fresh salad vegetables in winter.

The wholeness of the domestic ecosystem is important for several reasons. When the circular pathways of nutrient flow and transformation are reconnected, there is no need for fossil-fuel-produced fertilizer. When a rich diversity of animals is present, no one pest species can get completely out of hand. When the biosystems contain diverse species, the serving bowls of the human residents can be filled throughout the year with balanced meals and changing menus direct from the inner garden.

As dwellers in this whole system we see and feel again the life cycles of the food we eat. The dwelling is heated by the same rays of the sun that grew the food. All stalks, husks, fish bones, etc., that we do not eat are returned to the soil. And after two years the composting toilet will return a fine, clean, and dry nutrient-rich soil supplement. There is no concept of waste here. By saving seeds from each harvest, the home-bred plants will adapt to this particular environment better each year in a guided micro-evolution. Young fish, saved in aquaria over winter after the fall harvest, will parent next summer's crop. Nitrogen and trace-mineral-rich fish pond water irrigates the garden. Garden weeds and plant residues feed the fish, in turn.

The first farmers replaced system knowledge with species knowledge. The ecosystem farmer must understand both the species and the system if he or she is to culture it. This will require that the systems developed be small for the holistic farmer does less work (machine labor) but must pay more attention (human awareness) than the species farmer. The miniaturized ecosystem itself teaches the new farmer how to raise it, much as children teach their parents how to be parents. By close attention to timing and interconnections, population densities and predator-prey relationships, solar radiation and thermal mass storage capacity, algae densities and cloudy skies, etc., the ecosystem farmer learns to enhance the health and productivity of the system in which she or he lives.

Small is beautiful, not because it is small, but because it allows us to comprehend things in a whole range of their relationships. When we work with something that is fragmented, it gradually fragments us. When we work with a whole, it influences us to greater balance and sanity.

Secondly, small whole economic systems allow relative autonomy, a degree of self-sufficiency, independence. The power to supply all one's basic needs is within one's own control. When households, villages, neighborhoods, friends cooperate in this dialogue between whole ecosystems and humans as stewards, all are enriched in the interchange.

Many of the principles of ecosystem agriculture have been known for a long time. Edgar Anderson describes American Indian gardens he visited in Mexico and Guatemala, one of which he mapped and measured in detail:

> Though at first sight there seemed little order, as soon as we started mapping the garden, we realized that it was planted in fairly definite crosswise rows. There were fruit trees, native and European in great variety: annonas, cherimoyas, avocados, peaches, quinces, plums, a fig, and a few coffee bushes. There were giant cacti grown for their

fruit. There was a large plant of rosemary, a plant of rue, some poinsettias, and a fine semiclimbing tea rose. There were two varieties of corn, one well past bearing and now serving as a trellis for climbing string beans which were just coming into season; the other, a much taller sort, which was tasseling out. There were specimens of a little banana with smooth wide leaves which are the local substitute for wrapping paper and are also used instead of cornhusks in cooking the native variant of hot tamales. Over it all clambered the luxuriant vines of the various cucurbits. At one end of the garden was a small beehive made from boxes and tin cans.

In terms of our American and European equivalents the garden was a vegetable garden, an orchard, a medicinal garden, a dump heap, a compost heap and a bee yard. There was no problem of erosion though it was at the top of a steep slope; the soil surface was practically all covered and apparently would be during most of the year. Humidity would be kept up during the dry season and plants of the same sort were so isolated from one another by intervening vegetation that pests and diseases could not readily spread from plant to plant. The fertility was being conserved; in addition to the waste from the house, mature plants were being buried in between the rows when their usefulness was over.

The garden was in continuous production but was taking only a little effort at any one time: a few weeds pulled when one came down to pick the squashes, corn and bean plants dug in between the rows when the last of the climbing beans were picked, and a new crop of something else planted above them a few weeks later.

Edgar Anderson, Plants, Man and Life. Berkeley: U. of C. Press, 1969, pp.136-141.

Near a small village in Japan, Masanobu Fukuoka has brought the wisdom of Japanese agriculture, based on maximum nutrient recycling, one step further toward ecosystem farming. In a warm climate with reliable spring rains he has found he achieves respectable productivity on soil left uncultivated for 25 years.

> In growing vegetables in a 'semi-wild' way, making use of a vacant lot, riverbank or open wasteland, my idea is to just toss out the seeds and let the vegetables grow up with the weeds. I grow my vegetables on the mountainside in the spaces between the tangerine trees.
>
> The important thing is knowing the right time to plant. For the spring vegetables the right time is when the winter weeds are dying back and just before the summer weeds have sprouted. For the fall sowing, seeds should be tossed out when the summer grasses are fading away and the winter weeds have not yet appeared.
>
> It is best to wait for a rain which is likely to last for several days. Cut a swath in the weed cover and put out the vegetable seeds. There is no need to cover them with soil; just lay the weeds you have cut back over the seeds to act as a mulch and to hide them from the birds and chickens until they can germinate. Of course the weeds will come right back, but by that time the vegetables will already have a head start. Usually the weeds must be cut back once or twice, but sometimes even this is unnecessary.

Masanobu Fukuoka, The One-Straw Revolution, Emmaus, Penn.: Rodale Books, (quoted in CoEvolution Quarterly, Spring 1978, p. 65).

Orville Schell, in a recent trip to China, was shown an example of extremely efficient space and nutrient use through reconnecting diverse species in a polyculture food web.

> Through years of practice, says the guide, we have learned to use fishery as our main undertaking, but also to raise mink, pigs, chickens, and oysters at the same time. You see, what we discovered was that mink love to eat eggs, fish heads, and guts. Chickens are very fond of mink droppings. And, in turn, chicken droppings made good pig food. It also just happens that pig droppings make good fish food. The oysters can be fed to the pigs or the fish, or we eat them ourselves, and the pearls we grind up to make traditional medicine, a very effective anti-coagulant. Then, in the fish ponds, we have a system of tiered high-density production. We have black carp and Chinese ide living at mid-depth. The carp eat snails, and the ide eat grass. Their excrement nourishes microorganisms which feed the silver carp and big heads on the surface. Then, in turn, their excreta feed golden carp and common carp, which are bottom fish.

Orville Schell, In The People's Republic. New York: Random House, 1977, p. 127.

As more species are included, the ecological farm begins to resemble more the ecosystems we evolved within. One of the most promising future strategies for preserving soil on hilly land and increasing productivity of marginal land is forest farming and husbandry. A variety of nut, fruit, and pod-bearing trees, many of them leguminous, enriching the soil with nitrogen, interspersed with fine hardwoods, are planted on hillsides. There poultry, cattle, and pigs, at various periods of the trees' growth, can be grazed on the trees' random, fallen crop and semishaded, manured, moist grasses.

> The general pattern of three-dimensional forestry is to have large belts or blocks of economic trees interspersed with narrower grazing strips or grasses or other herbage along which move herds of livestock, fed from woodlands, and producing meat, milk, eggs, wool, and other items. The system forms a natural biological cycle, into which man fits perfectly: he can eat the food harvested from the trees and the flesh or produce of the forest fed livestock, or sell them. The manure of the animals is returned to the soil and encourages health and vigorous growth of plants.

J. S. Douglas and R. A. Hart, Forest Farming, London: Watkins, 1976, p. 8.

We have come to a point where we live in a world that reflects back to us all our own deviations. Our daily environment is a congeries of human artifacts sharing our smell and resonating the narrow range of human vibrations amplified, without the damping effect of the ancient nurturing community of our evolutionary cousins and the softness of living soil.

In biological metaphor, our technological economy and culture are one organism. All of us are cells. Each cell depends on oxygen and predigested nutrient brought by the bloodstream. The bloodstream receives the nutrient from centralized food processing operations—the stomach and gut. These in turn depend on the shredding and moistening machinery of the mouth. A centrally located set of lungs collects all the oxygen for brain, liver, and toe.

The single complex organism is a wonderful creation of evolution—but not if you are reduced to the level of a specialized cell within it, while you are in fact a whole creature in yourself.

A more correct biological analogy for a society or culture is that of an ecosystem. An ecosystem is comprised of organisms all seeking their oxygen and nutrients on their own—organisms who can relate directly to the outside environment. The order in the ecosystem derives from no centralized control box. It is not the result of purposeful striving, as is the order in an organism. The order of the ecosystem occurs through time as each species adjusts in its own way to a pattern allowing high diversity of species and maximum system stability.

Among those who have advocated the single-organism analogy for the State, Alfredo Rocco, Chief Theoretician of Italian Fascism, stands out most clearly.

If we and our children lose entirely the experience of ecosystems, there is a chance our culture as a whole could go insane. If we and our children lose entirely the ability to provide for our own most fundamental needs, there is a strong chance that we will have to give over our lives to a centralized political power.

Often the least tolerable situations are those where, through failure of nerve or foresight, we hang back from the intelligent and courageous next move. At this point in cultural evolution the proper next step would seem to be to rise beyond a monocrop agriculture performed by specialized technicians and teach ourselves again to be a whole people, in touch with the land, subsisting and working with our neighbors in local food-producing ecosystems.

Once our urban and suburban areas begin to bloom with food by the touch of many hands—maybe, we would then have the wisdom and local productivity to let some of the fertilizer-burned, plow-sliced rural lands return to natural wilderness.

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IMPLEMENTING THE HOLISTIC APPROACH

Peter van Dresser
Author and Designer
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Viewing, as I do, the present proliferation of countermovements protesting the excesses of megatechnics from the perspective of 45 years involvement since the Decentralist and Distributist efforts of the 1930s, I have not been able to escape the feeling that these newer movements have not entirely freed themselves from some of the tendencies which have characterized industrial society since the beginning. I refer to the tendencies toward compartmentalization, specialist organization, and reliance on technological and "gadget" solutions of problems which are actually social, cultural, and ethical in most of their dimensions, and which are intertwined with the whole body of society.

Thus we find a proliferation of organizations and schools of thought forming around such abstractions as "environment," "conservation," "alternate energy," "appropriate technology." Each of these schools develops its own expertise, convictions, and vested interests. Committees, commissions, and lobbies are formed to press for implementation and adoption of various programs of action—programs which often enough do not jibe with those of other special interests. (Examples of this are all too easy to call to mind: for instance, the long-standing confrontation between conservationists vis a vis lumber- or cattlemen, or the more recent one between nuclear-cybernetic technicians vis a vis the earth-and-sun disciples.) The net result may actually be intensification of the dissensions which mark our age.

As an alternative to the fragmented and somewhat doctrinaire "alternative" approach to the development of an enduring social order on the planet, we are hearing more these days of "holistic" endeavors. This is an attractive philosophic concept but one hard to embody in a definable course of action since, by definition, it implies an omniscience which seems beyond mortal abilities.

Brushing aside such inhibitions, however, I will define this approach as the attempt to view our social economy organically, to seek to understand its formative principles, and to modify these principles in such a way as to guide its general evolution in the direction of ecological balance with the natural world. In other words, rather than applying countermeasures to specific malfunctions of our society (e.g., antipollution laws, energy-conserving regulations, environmental policing), we work toward molding a social and economic order which in the normal course of its functioning will not—does not need to—destroy the land, strip the minerals and fossil fuels, or resort to dangerous technologies to satisfy a preposterous appetite for energy.

How do we reduce this ambitious and highly generalized mandate to a recognizable program of action? A wide choice of scales is possible, ranging from one's personal life to the entire planet and beyond. But for my purposes and after 30 years immersion in life and livelihood in the southernmost Rockies, I have chosen the State of New Mexico as a feasible "sphere of influence." Historically, much of the New Mexico community still adheres to a life and livelihood pattern relatively close to the land, and the complexities of the urban-industrial economy do not dominate as completely as elsewhere on the continent. And the State is a geographic and political entity within which are focused and manipulated many of the key formative factors controlling the shape and functioning of our society.

Granting this "limited holistic" sphere of endeavor (limited geographically and philosophically), what sort of conditions—economic, demographic, and logistic—would we wish to bring about within this regional community, and what instrumentalities could we work with to help bring about these desired conditions?

For the past several months I have been collaborating with the Energy Committee of the Santa Fe Sierra Club in an attempt to answer these questions in a fairly specific way. I should like to quote from the statement entitled "Towards a Sustained-Yield Policy for New Mexico" which I prepared as a result of this collaboration.

> Efforts must begin immediately to move the economy of our State in a direction which will permit its communities to develop and sustain an acceptable level of health and amenities on a permanent basis. Such development must be achieved with improvement rather than degradation of the natural environment and without excessive dependence on nonrenewable energy and material resources.
>
> Such an economy cannot be achieved by technological innovations alone. It will require also modifications in the density and distribution of population; the shape, size, and composition of our communities; patterns of land use; and of industrial and agricultural production and distribution.
>
> These changes can be expedited gradually by the collective and cumulative actions of decisionmaking and policy-setting agencies within the State. These actions must be in harmony with the democratic process and should enhance traditional

American values of self-reliance and self-determination for individuals and communities. They can furthermore be compatible with healthy economic growth, provided such growth is channeled in ecologically viable directions.

The broad objective of such public policy must be to develop a regional economy and productive plant capable of provisioning, housing, and otherwise supporting our population at a high level of well-being. Such an economy presupposes careful management and utilization of renewable natural resources of the State on a sustained-yield basis as well as minimal use of fossil fuels, high-energy materials, and massive industrial processes. Its effectiveness stems in large part from scientific use of skilled manpower as well as on internal logistical efficiencies. Such techniques must replace traditional economies of scale and capital intensive, centralized mechanization which depend on cheap and plentiful fossil fuels.

Sufficient understanding of regional economics and energetics now exists to map the salient features of this kind of economic development. Some of these features may be summed up briefly here:

1. A balanced development of numerous urban places, including villages, towns, and smaller cities, should be encouraged to absorb population growth. Such centers should be located in an efficient geographical relationship to the natural resources (primarily land, water, and plant life) and should supply most of their basic needs with a minimum of energy-consuming transport. They exist in embryonic, though imperfectly developed, forms in the many small towns and communities of the State. Such a settlement pattern would minimize water consumption and unproductive land use. Diminution of growth of the larger cities would reduce their wasteful and polluting industrial and transport requirements.

2. A wide spectrum of small- and medium-sized industries will be required to supply the basic needs of each of these communities as they develop.

3. Industries producing for export should be of the locally owned type which add high value to the raw materials in order to maximize resulting revenues and minimize the drain on natural resources.

4. Intensive and diversified agriculture and husbandry, capable of supplying the basic food needs of the State and its subregions, will be required. Food processing, storage, marketing, and distribution for local and regional uses should be integrated with this pattern of agriculture.

5. Forest yields should be processed in integrated wood technology centers in close proximity to forest-located communities. Again high-value finished and semifinished products should be exported from such centers and all byproducts, including fertilizers and fuel, should be utilized. Higher cash yield from such products should maximize local employment and would justify more complete care of our forests than is now considered feasible.

6. Technology appropriate to such decentralized industries and intensive small-scale agriculture and silviculture should be encouraged, including widespread use of solar radiation for space heating, greenhouses, crop drying, and other feasible applications. Other renewable nonpolluting energy sources (as windpower and biomass) should be employed to the maximum. Extensive use of low-cost, low-energy materials, particularly in home construction, should be encouraged.

7. Industries based on mass extraction and export of exhaustible resources (e.g., oil, gas, coal, uranium) should be closely regulated to conserve the supply for future needs and to minimize destructive impact on the environment. A portion of the revenues derived from these resources should be earmarked for expediting a future long-term, sustained-yield economy.

8. All of these trends, many of which are already operative within the State, can be substantially enhanced by appropriate actions in such fields as:

   Education, vocational, and technical training

   Technology research programs

   Investment and credit policies

   Licensing and regulating practice

   Taxing policies

   Highway planning and design

   Water management policies

   Forest management policies

   Energy policies

   Transportation policies

   Municipal corporation, land development, and special-district franchise provisions

   Decentralization and community orientation of social, cultural, health, and educational services and facilities

   Systematic socioeconomic and technical studies should be undertaken to generate a rationale to guide statewide decisions in these and other key fields toward a New Mexico of stable and fruitful communities, in an unpolluted environment of natural beauty and productivity.

An obvious and quite conventional next step toward implementing these ideas is to form an association to explore and articulate them in a systematic way. This step a number of us have taken with the incorporation in February 1978 of The Council for Sustainable Growth and Appropriate Technologies in New Mexico.

It was felt essential to incorporate the term growth in the name, since growth is a universal process in living nature and fear of its negation has done much to alienate the environmental, conservation, and similar movements from the workaday community. But note the essential modifier sustainable, by which I mean growth in population, with its accompanying refinement of habitat and life-support systems, in modes which can be sustained mainly by the renewable biotic and flow resources of the region. In some circumstances and periods this obviously may mean zero or negative growth; in others it may mean intensification, diversification, or refinement rather than increase in size or number.

We hope this association, with its "limited holistic" mandate, may develop into an effective focus for thinking and working toward ecologically and humanistically guided development in the State. We hope it will differ from other special-purpose organizations in that it will not pressure for solar energy or wilderness protection or clean air and water or organic farming or windpower or community health and self-reliance, but for an "institutional environment" which will encourage economic arrangements and relationships which produce such results in the normal course of its operations. An underlying premise is that many of the basic hopes and motivations of people are in these directions and—given supportive rather than restrictive social, political, and fiscal institutions—private, cooperative, corporate, and community initiative and competence will realize the desired goals.

One cannot help being aware of the enormously complex and subtle nature of such an enterprise, of its dependence on intuitive and aesthetic judgment as much as on scientific methodology, and of its liability to abuses and excesses of its own. Nevertheless, it is an enterprise which seems essential in this state of affairs, and a few of us in New Mexico are naive enough to make the start.

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ECONOMICS AND THE ENVIRONMENT HOW DO THEY RELATE TO THE NATION'S ENERGY FUTURE

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INTRODUCTION

Although I am here to speak of energy, I will begin with some interesting facts regarding inflation, because I feel it relates to the energy problem, just as environmental issues bear considerable impact upon our nation's energy ills. All three—energy, the environment, and the economy—interrelate in a web which confuses many, and because of its complexity has created misdirection which holds us in the current energy dilemma.

Before I start, I would like to say that a considerable amount of the material used in this presentation was taken from Barry Commoner's book entitled The Poverty of Power first published in 1976. This book more clearly articulates many of the points I will make today, and I would highly recommend it to all of you who are interested in learning more about the relationship of energy, economics, and the environment of modern day America.

Recently, Time Magazine, in its April 24th issue, had an article on inflation. That article had a variety of consumer commodities compared cost wise over the past 10 years. I took the Time information and indexed it using 1967 as the base year. Since the index was then prepared relative to 1972 and 1977, an annual percentage increase in these commodities could be determined. Of importance is that from the period from 1967 to 1972 the annual level of inflation which occurred was in the range of 3% to 7.5%, the increasing cost of autos being the low, and home mortgage payments being the highest. Now, for the period from 1972 to 1977, the range increased to 6.9% to 29.1%, with clothes being exceptionally low at 6.9% and home mortgage payments skyrocketing to a 29.1% average annual increase. The average annual rate of increase of these seven basic commodities over the past 5 years was about 17%. How is that for an inflation rate? How does that compare with government statistics on inflation which claim about 5% to 7% annual inflation, except 1974 which was calculated at 11% or 12%?

What caused the large leap in inflation over the last 5 years? I would say a recognition of our nation's vulnerability to being energyless, the rising cost of energy since the 1973 oil embargo, the excessive amount of federal spending which has created ever less availability of capital resources, an increasing concern for our environment which has increased costs of many products, and the inefficient use of our energy resources.

Inflation can cause havoc with a nation. As it gets out of hand, social unrest develops, as pockets of society become affected to a larger degree, and they protest. We have seen the effects of uncontrolled inflation across the world, and Italy is a prominent current example, with recent rates of inflation of 15% to 20% and higher.

INTRODUCTION TO ENERGY

The dawn of concern regarding this nation's energy problem came upon us with an immediacy rarely experienced before in the United States. Pearl Harbor was an immediate shock to many citizens back in 1941, but that happens to be the nature of the situation when nations seek to overcome each other. During late 1973 this nation was attacked similarly; and after that first skirmish, the oil embargo, was over, the U. S. populace and politicians went back to business as usual, not even recognizing that the country was in dire straits, and had just been clubbed in the back of the head with a "2 x 4." Jimmy Carter is correct when he says that the energy problem is the moral equivalent of war. The President has watched his proposed energy legislation sit in the laps of uninterested, or special interest oriented Senators for over a year now, while the problem looms larger than ever.

As the problem is unraveled, it becomes apparent that there are many subissues which all relate. If these smaller issues were coordinated in an effort to expand energy production by using methods and techniques which are beneficial to the U. S. economy and at the same time harmless to our environment, the energy problem could be overcome and at the same time the environmental picture of this nation could be markedly improved.

COMMENTS ON CURRENT ENERGY SOURCES

There are four major energy sources which capture most of our attention. These are petroleum and natural gas, coal, nuclear power, and the sun. These four energy sources combined currently account for about 96% of all energy consumed in the United States. I would like to do a brief examination of each one of these categories, to look at their past histories, and to analyze the future prospects of each. I will start with petroleum and the closely related fuel, natural gas.

Petroleum and Natural Gas

A first interesting comment I would like to point out regarding petroleum and the claimed end of the "cheap energy" era is a reflection on the price of gasoline. A comparison has been made of the price of a gallon of gasoline relative to the average mean incomes of U. S. workers in 1960 and 1977. Guess what? It is cheaper today to buy a gallon of gasoline than it was back in 1960. Don't count on people switching to bicycles or buses soon. Unless, of course, the roof collapses, and the Arabs decide to go to war with the United States.

Fifty-four percent of our petroleum is used for transportation purposes and 21% for space heating. When one also recognizes that petroleum and natural gas provide us with 74% of our total energy needs today, we can see just exactly how dependent we are on this one source.

Next we logically ask, how much do we consume each year, and how much do we have. Currently the United States consumes about 8 billion barrels of oil annually, of which some 50%, or 4 billion barrels per year are imported. In order to relate this to money, 4 billion barrels of oil equals $52 billion per year of imported oil, slightly more than 10% of the entire federal budget for 1979.

Although estimating domestic crude reserves is an inexact science, through the use of several different techniques, and estimating based upon their variances, it appears that there are some 350 billion barrels of domestic reserves today—35 billion known plus 315 billion yet to be discovered. At current usage of 8 billion barrels per year, this would mean that if the United States provided all its own oil (no imports) we would be good for another 40 to 45 years. Well, one might quickly assume that the energy problem just does not exist. After all, if we can last for 45 years without imports, that means 80 or 90 years with 50% of the product imported. But there are problems, two very significant ones, called capital and findability. Findability is a term I use and can best be described through the following example. Imagine yourself standing in a living room with thick carpet flooring. You are holding a string of 50 pearls and it just so happens that the pearls are dropped off the string, and they all scatter on the thick carpet. Now, you know that there are 50 pearls and you begin the campaign to find them. The first 25 are relatively easy, as they lay at your feet. The problem of finding the 27th pearl, the 35th pearl, and the 42nd pearl, not even to mention the last one, becomes greater and greater. The increasing difficulty of finding a scarcer and scarcer item is what I call findability. Findability is a formidable problem for U. S. petroleum, as the first 25 pearls have already been found. Good indications of the findability already exist in that the United States has ever increasing amounts of oil drilling on the continental shelves and in highly remote areas such as northern Alaska.

The problem of capital is also a great task. In discussing this problem, all dollars I speak of are 1973 adjusted dollars.

The oil industry has an economic term called "productivity of invested capital," which in simpler terms means the amount of oil produced per dollar invested. This productivity of invested capital in 1974 amounted to 3.0 barrels per dollar invested. If we were to look at producing 80 billion barrels over the next 10 years, the productivity of invested capital would fall to 0.8 barrel per dollar invested. This means a 3.75-fold increase in capital investment to get the same return now being received for less output. In terms of cost per barrel, a production price of $15 to $16 per barrel (1978 dollars) would be the result, versus a $7 to $8 cost per barrel (1978 dollars) for the existing level of domestic supply.

It is not so bad that the cost of domestic oil would double, discounting usual inflation, but what is worse is that the capital is not available. Furthermore, it should be noted that the current price of Arabian oil, at $13 per barrel, is slightly less than the cost to the United States to invest in more domestic production. You can be certain, then, that the productivity of invested capital factor will always have a strong influence on the price of imported oil. Consequently, the United States will always be dependent to a large extent (50% or greater) on foreign oil since the foreigners now have a large capital investment in oil production facilities and will continue to set their prices at levels low enough to not make it worthwhile for the United States to expand its own production. America, in one swift blow, has lost its ability to be independent of the rest of the world, and now must play the game of international power for real—at least until an economically viable alternative to oil is developed. I am not suggesting that dependence on foreign governments is a problem for the United States; I am only pointing out that we got in that position unwittingly, by not recognizing our energy situation in advance. It is obviously called "sleeping at the wheel," and should be recognized as such.

What about natural gas, that clean and efficient fuel that was burned off at the oil well heads until the 1930's and 1940's? The American Gas Association placed the national reserve of known natural gas at 216 trillion cubic feet, at the end of 1976, or a little more than 10 years' supply. Its future is similar to that of oil, if not worse, since the United States imports less, foreign countries such as Canada will not export any more to the United States, and the price has been held artificially low by the government over the past decade. As we all may know, Congress has recently agreed to lift price controls on natural gas over the next 7 years. Lifting price controls, compounded by a diminishing supply, will guarantee a skyrocketing price on a commodity now relatively inexpensive. I would suggest not counting on natural gas beyond 1985.

Coal

Next, I would like to speak about coal, particularly since the Carter energy plan seems to place such a high value on this resource and what it can do for our energy future. There is general agreement among geologists that accessible deposits of coal will last another 400 to 600 years, domestically and worldwide, if consumed at current rates. Thus, the coal situation is different from oil and natural gas. The problems lie with utilizing coal for transportation uses, 25% of our energy budget, and the second difficulty is the effect and use of coal on environmental quality and health. A third problem rests with the nature of man wanting more. If the price of other energy products skyrocket, as oil and gas will, coal will follow. An excellent example of this theory was the 3-month long coal strike we all observed this last winter. That strike was on the verge of crippling major industries in the midwestern United States, as well as closing down most of the public utility companies which use coal to provide heat and electricity to the population.

An examination of the wage demand problem indicates that the plight of an underground coal miner is sad. Those people who spend a great deal of their working life in underground shafts are faced with threats to life and limb on a daily basis as well as on a long-term basis through the deterioration of their physical condition. What is the price of imposing such dangers upon an individual? This is the question that will continue to drive up the miners' salaries; and this, also, is the reason why fewer and fewer Americans will accept such type of work in the future, regardless of the pay. Jimmy Carter may have learned a lesson from this long and bitter strike—coal will not be a cheap energy source for the years to come.

What about western coal? For the most part, the vast reserves of western coal are strip mined, not tunneled out of the ground. Well, strip mining has its problems, and they obviously lie with the destruction of the land, proper techniques of recovery, and the costs thereof. If there were no governmental controls on strip mining, this nation would be assured that vast portions of western United States would be a barren wasteland. If you do not believe it, take a close look at Aspen, and the result of uncontrolled mining at the turn of the century. Proper reclamation of strip mined areas could cost upward of $15,000 per acre. This is a cost that is now required by law; and as our nation's open lands become less and less, you can rest assured that increasing pressure will be put upon miners for better and better revegetation plans, more in accord with the demands of professional biologists and ecologists. Much of today's reclamation is not consistent with the natural ecosystem that existed prior to strip mining, and Congress always seems to eventually discover.

The environmental tradeoffs regarding coal in this nation are eastern lungs or western deserts. You can bet that the people of this country will no longer stand for either; and, thus, the end result is escalating costs for coal production.

One more environmental point to be discussed about coal is its effects on air quality. If this country were to expand its utilization of coal substantially, the effect on our nation's air would be drastic, or the cost of containing the pollution would be drastic. The cost of this potential problem, to my knowledge, has not yet been accurately gauged. It is essential that this factor be included in the formula which recommends the expansion of coal for future energy.

Since we are in the neighborhood of mining, and since oil shale hits so close to home, I would like to make mention of its potential. Many claims and high hopes are held for oil shale here in Western Colorado, and some have estimated that there is more energy available in Colorado's oil shale than in all the oil reserves of Saudi Arabia. To me, that is like saying there is more sand in the Sahara than there is oil in Saudi Arabia. It might cost a little less to get oil from shale than from sand, but neither of these two commodities is oil, nor can they be created into an energy product than can compete with oil.

The current state of the art of mining shale is a Modified in Situ (MIS) retorting method, whereby underground explosions create rubblization of the inplace shale, and the high temperatures allow the kerogen (the oil like element in shale) to flow, since kerogen is a solid until heated above 900° F. Once the kerogen is brought to the surface, it must be converted and refined to extract oil products. The 1973 costs of this process was estimated at $26 per barrel, compared to domestic oil production at $8 per barrel and Arabian oil at $13 per barrel. Some oil companies now feel that the price might be brought down to as low as $16 per barrel; however, that is based upon estimates, and nobody is willing to invest a great deal to prove out those estimates.

If oil shale were eventually produced, another major environmental problem would crop up—that of inflicting cancer on workers and residents of oil shale areas. Shale oil was proven highly carcinogenic in Scotland in the 1940's, as shale oil was used as a lubricant in certain cotton-spinning operations in England. Between 1920 and 1943, over 1,000 cases of skin cancer were reported among English cotton spinners who were exposed to shale oil—an incidence considerably in excess of rates throughout the rest of that nation.

Nuclear

The early development of nuclear technology was for purposes of warfare—the creation of atomic bombs which when held by a government could be decisive in any war. This was proven by the United States, as its assaults on Nagasaki and Hiroshima abruptly ended the Japanese-American portion of World War II. This all changed in 1953 when President Eisenhower launched an "Atoms for Peace" program which was aimed at hastening the day when the fear of the atom would begin to disappear from the minds of the people, and also to develop commercial nuclear power for peaceful purposes. For the past 25 years the federal government has continually supported the nuclear effort, by diverting much of its research to private corporations and supporting a costly research program over the last quarter century. It is evident to even the most ardent supporter of nuclear power that neither of Eisenhower's objectives has been reached, nor does it appear that they will be attainable.

The proposed Seabrook nuclear power plant in New England and the government of West Germany's proposed nuclear plan of 1977 were met with objections, sit-ins, and active protests by citizens, in an effort to prolong the development of those power plants. Closer to home, we observe the current ongoing active protest at Colorado's Rocky Flats nuclear facility; and we see further evidence of increasing public protestation of nuclear facilities. Even if all the contentions about the unsafeness of nuclear facilities were untrue, it is apparent that the psychological fears on the part of a large portion of our population will play a big role in denying nuclear energy any future.

A look at the economics of nuclear power plants indicates that they have yet to be able to compete with coal-fired plants, and the future predictions are that the costs of nuclear power generation will rise even faster than those of coal. This is due largely to additional safeguards (environmental and health) being required; the rising costs of mining, transporting, and handling radioactive materials; and the limited supply of high-grade radioactive materials. It has been calculated by Harvard Business School Professor I. C. Bupp that nuclear energy will surpass the unit costs of coal in 1979 and 1980 and will then continue to be more expensive than coal for years to come.

Finally, all these problems appear to be small when compared to that of the storage of ever increasing amounts of radioactive waste materials. The wastes produced by a typically sized nuclear power plant today produce enough radioactive waste material in 1 year to kill 100 times the number of people-years of energy supplied. And, there is nobody out there in the world with any workable plan that can do anything but perpetually store these wastes. Certainly technology always poses the possibility of overcoming this problem; however, no solution is in sight today.

Sun

Now, we move onto a much brighter prospect for the future—the sun. The sun offers the only potential source of energy that can provide a large extent of today's world's insatiable demand for energy, in a manner that is environmentally safe, and of which the supply is unlimited. Surprisingly, the U. S. government has largely neglected this potential energy source, and President Carter is one of few national political figures to endorse solar propects, albeit his financial commitment to solar research is still far below his campaign promises. Solar energy is delivered to the Earth in pure form-radiation, lacking the encumbrance of physical matter, thus lacking the polluting effects of matter and allowing for a greater potential flexibility of usage. Sounds like a dream or some sort of unbelievable miracle, doesn't it?

Because of the uncomplicated manner in which solar energy can be engineered into existing electric and heat producing systems, solar energy is practical to take care of our nation's requirements for space heat; hot water; and, if built on a large scale, electric power—approximately 38% of our nation's total energy budget.

We have also to look at the solar potential for creation of hydrogen composed of hydrogen and oxygen molecules, for use as a nonpolluting form of fuel for transportation and industrial fuel. Hydrogen conversion of gasoline-fueled automobiles can be done without major component changes to the internal combustion engine. In fact, automobiles have been converted which can operate on either hydrogen or gasoline, simply by the flip of a switch. Hydrogen can be produced from water through electrolysis for which the initial energy requirement could be provided by the sun. Hydrogen holds the possibility of being piped great distances, as natural gas now is, and being an inexpensive source of fuel for many of our needs, including transportation, which is 25% of our national demand. Thus, including hydrogen by solar, it is possible to provide over 60% of our nation's energy requirements by use of the sun, and within a reasonable period of time, say 10 to 20 years, rather than solar energy being something of the 22nd century, as popular opinion largely believes.

Another potential device to be exploited by solar energy is the fuel cell. The fuel cell has no moving parts, is simply constructed, and is the most efficient means of converting fuel energy (hydrogen included) into electricity. Conventional systems using diesel engines or turbines attain a first law of thermodynamics efficiency of some 38%. The fuel cell can attain a 60% efficiency. There are many other alternative ways to store solar energy; all that are needed are time and research to develop the perfect things such as pumped and elevated water; compression of air and other gaseous materials; and, of course, massive storage of low-temperature heat through the use of rock bins or water tanks. My comments on the possibilities of solar energy are limited, as I am sure you will be much better informed through other speakers at this forum.

CURRENT USES OF ENERGY

Now that we have covered the alternative sources of energy, I would like to briefly discuss the major areas of production where energy is consumed, so as to get a feel for a history of how we got where we are, and what we can do to overcome the problems. The areas to be discussed will be agriculture, petrochemicals, and transportation.

Agriculture

Agriculture is an industry that grew from a family farm type situation in the 1930's to a predominantly capital/energy intensive, low-labor usage industry in the 1970's. For such a conversion to occur, farms consolidated, farming interests borrowed to purchase improved technological devices such as machinery and fertilizers (petroleum based), and the consequence was a drop in real income of the U. S. farms from $18 billion in 1950 to $13 billion in 1971—both 1967 adjusted dollars. Although income per farmer increased, due to consolidation, less total income was the result. Also, total mortgage debt increased from $8 billion in 1950 to $24 billion in 1971.

Common theory about the plight of the farmer is that the middleman takes all the profit and that because farmers are too independent to organize, they suffer economically. Of far more significance is the modern farmer's dependence upon heavy equipment purchases, and an activity that relies heavily upon petroleum for fuel and fertilizer. Despite the more logical crop rotation farming process, which over a period of years produces as much as highly fertilized farmland, the short-term financial mirage of highly fertilized, low-labor farms put many farms in a deficit situation. The recent agriculture movement, which originated here in Colorado, has as its purpose 100% of parity, or a guarantee that farmers get paid for all their costs, regardless of how high they might be. This would be the final blow to that industry, and maybe even to our economy as a whole, if we as a people were to begin subsidizing a capital/energy intensive industry through 100% of parity. You can be assured that the costs of food would escalate greatly in a no-lose situation for the farmer.

Farm activities that I am concerned about are high power fertilizers, insecticides, and herbicides; gasoline and diesel fuel for tractors and other machinery; propane to fuel grain driers—formerly a solar process; and electricity to power milking machines, grain driers, and other stationary equipment. Although agriculture consumes only 4% of energy demands, it is a "picture-perfect" of conversion of a labor/solar intensive industry to a capital/energy intensive industry and the resultant problems and energy dependence thus created.

Petrochemicals

The second area where energy intensity has prevailed and has been used inefficiently is the petrochemical industry, a product of World War II innovation. This industry uses 28% of all industrial energy, or 9% of the total national energy budget. The petrochemical industry was created by joining the petroleum refining industry with the chemical industry, to create through industrial processes, many modern day products such as plastics, synthetic clothing materials, detergents, and pesticides, and disposable everythings at amazingly increasing rates. In 1946 total production stood at 300 million pounds, whereas in 1974 the output was at 39 billion pounds. It is not only the environmental problems that are to be concerned with in this industry, as they are evident to most all of us, and I will not discuss them. In the realm of economics, once again we have an industry that utilizes inexpensive energy to the exclusion of labor for the mass production of products whose costs are due almost totally to capital and energy. In the economy of the 1960's, when labor was costly relative to capital and energy, this industry boomed. Granted, the cost of labor is not decreasing; however, the cost of petroleum is about to go through the roof, just as the increasing cost of capital is being reflected in higher and higher interest rates. Furthermore, the scarcity of capital is rapidly getting to the point where it may not be accessible no matter what the price. This nation's addiction to the wonderful world of plastics is likely to be shocked into a situation closer to that of pre-World War II when most of our products originated from natural resources such as leather, natural rubber, natural fabrics, and recyclable containers and food serving devices.

Transportation

The third area which needs to be addressed is that of transportation, which consumes 25% of the U. S. energy budget. An inventory of the range of transportation options viewed from a thermodynamic efficiency/energy productivity view is as follows:

- Electrified intercity railroad,
- Electrified urban railroad,
- Diesel operated railroad,
- Diesel operated bus,
- Diesel operated truck,
- Private car, and
- Airlines.

How does this list compare with current use and trends? Less than 1% of U. S. railroad locomotives are electrified. Rail usage as a whole is declining. In 1945, 69% of all ton miles of freight was carried by rail; whereas in 1970, it has declined to 40%, and the trend is continuing in the 1970's. Passenger cars have grown in use 5% annually since World War II, and they along with airlines have almost totally eliminated rail passenger traffic. It is evident that the trend has been toward more energy inefficient transportation forms over the past 30 years, which at the same time are greater polluting and environmentally inefficient—all for the sake of sometime convenience, and at a very high capital cost to individuals.

While President Carter is still pressing for a national energy bill, the highway trust fund continues. Past President Eisenhower introduced the Interstate Highway System, for national defense purposes, back in the late 1950's. Although the Interstate System's then stated purpose is now not the real use, the program is pushing through to completion to support the most inefficient form of ground transportation—the private auto. President Carter has yet to take action against an incredible national energy policy working contrary to our best interests—the Interstate Highway System. A glaring example of the negative environmental and economic effects of that system exists right here in Colorado's Glenwood Canyon. The State of Colorado is considering some $240 million to bring 13 miles of highway through the Canyon up to Interstate standards, or some $18 million per mile. At the same time, viaduct segments over the Colorado River and up on the Canyon walls would echo noise and visually destroy a natural masterpiece—all for the sake of the energy inefficient automobile. A further fear is that, historically, federal public works projects cost many times more than estimated by the time they are completed. The 1973 estimated cost for the project including Glenwood Canyon plus an additional adjacent 14.5 miles of Interstate was $65 million. Now it is four times as expensive for half the distance. It is likely that if it ever gets built as currently envisioned, it will cost from $300 to 400 million in 1978 value dollars. The problem with all this is that it reflects the federal government's "blank check" mentality whereby the costs are not controlled or accounted for, and the result is deficit federal budgets and the government using a lot of capital resources which otherwise would be available for private uses. The kicker on Glenwood Canyon is that a proposed divided two-lane alternative, which would be as safe as the four-lane, although at times maybe slightly slower to travel, costing maybe two more minutes to the traveler, could be built for 40% of the cost of the four-lane project, and with no environmental damage beyond that which currently exists.

CONCLUSION

In conclusion, I would like to say that the current status of this nation's energy picture and economic status can and most likely will result in good. This nation has been isolationist regarding its own economic welfare; and once we as a nation begin to wake up and get in stride with the economic and energy consumptive realities of the rest of the globe, we will begin to resolve our widening dilemma. Current national and international events indicate that the United States is beginning to awaken and understand the international world we live in and the hows and whys of external effects upon us.

This nation will be eventually forced to recognize some long forgotten practices, given up largely by the gross material wealth of this nation during the 1960's. These practices are a return to the conservation ethic as opposed to the current consumption ethic being practiced throughout our nation. Secondly, the federal government will learn to balance the federal checkbook year by year, rather than incurring increasing debt levels, which will guarantee fewer services at high costs in future years.

Finally, it will be that future energy choices will be made in a more humanistic manner, considering not only the short-term economic aspect, but rather the long-term economic and environmental aspects. This humanistic approach will direct our nation and the world to energy choices such as solar, which will finally spell doom for the wide array of negative, life-threatening energy choices that exist in today's world.

THROUGH THE LOOKING GLASS— NET ENERGY ANALYSIS AND HUMANISTIC CHOICES

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Looking into the future is a difficult, frustrating, risky, and absolutely essential endeavor which must be undertaken if we wish to have any choice about the shape of that future and if we care to live in a humane society. The current national dilemma concerning energy springs from our past reluctance to take a longer view. If we do not soon begin this arduous task, many of our options may be closed out later on down the road, leaving us with the kind of crisis in which humanistic choices are no longer possible—in which mere survival under a tyrannical regime is the only choice.

It is becoming increasingly clear that our dependence upon nonrenewable energy resources, if continued, will place us on a pathway toward ultimate resource depletion and economic collapse. Gradual transition to a steady-state economy based upon sustainable energy flow must begin soon and among the first steps required is adoption of a widespread system of total energy accounting.

A growth economy—like an early successional forest ecosystem—directs surplus energies toward rapid expansion in a nonsustainable way. In contrast, a steady-state economy—like a climax forest ecosystem—allocates energies more efficiently in patterns that can be sustained through time. Unless we are fully aware of the true long-range energy implications of our decisions, well-meaning programs and policies are capable of contributing to a crash rather than leading to a steady-state.

The value of energy to society is the net energy which remains after the energy expended to get and concentrate that energy has been subtracted. If it requires two units of energy to bring another two units to the point of consumption, then there is no net gain. Care must be taken to account for both direct and indirect energy consumption. Although our total energy production continues to increase, we are expending ever larger amounts of energy in the very process of extracting energy, so that net energy may decrease. Some alternate energy systems—which are widely believed to be net energy producers—may even turn out to be net losers when subjected to careful analysis of the fossil fuel subsidies used to produce them if their lifetime is not long enough.

The advantage of net energy analysis over traditional energy accounting methods is the inclusion of indirect as well as direct energy inputs. "Direct energy" consumption is the use of such items as gasoline, natural gas, heating oil, and electricity. "Indirect energy" is the energy required to support nonenergy purchases. For example, the indirect energy consumed by purchasing an appliance includes the energy required to manufacture the appliance as well as an appropriate fraction of the energy required to build the appliance factory and so on. Ignoring indirect energy costs leads to a distorted view since the average American consumer uses more energy indirectly than directly. According to the Center for Advanced Computation at the University of Illinois, in 1967 Americans used 16.9 quadrillion Btu directly and 31.5 quadrillion Btu indirectly [1].

Four methodologies have been developed to calculate the total direct and indirect energy inputs to a product: process analysis, input-output analysis, hybrid analysis, and ecoenergetic analysis. "Process analysis" finds all direct energy inputs and all material inputs. Each material input is researched to discover its direct energy and material inputs. Each succeeding set of material inputs is broken down until the energy inputs become "small."

The Community Energy Network of Ithaca, New York, has used process analysis to find the total energy use of insulation [2]. Their study considers four first-order indirect energy inputs processing the insulation, heating and lighting the plant, transportation, and installation. In addition, two second-order energy inputs are examined: manufacture of plant equipment and processing of raw materials. The results of the study are summarized in Table 1. The last line shows that large differences in energy inputs are required to produce the same energy savings in a building.

To reduce the time required to perform each net energy analysis and to increase accuracy, an "input-output" table of the U. S. energy flow has been created. This table lists energy inputs to all sectors of the U. S. economy from all other sectors. Using matrix algebra, the total direct and indirect energy inputs to each sector are calculated. Energy intensity coefficients of Btu per dollar or Btu per physical unit can then be calculated for each sector. With a list of energy intensity coefficients, it is straightforward to calculate the total energy use of any product.

The U. S. energy input-output table was assembled from Department of Commerce data by the Center for Advanced Computation at the University of Illinois (CAC) [3]. The large amount of data required to generate the table takes time to develop so the most recent

Table 1. ENERGY COSTS OF THREE TYPES OF INSULATION

in million Btu per ton

	Fiberglass	Expanded Polystyrene Board	Cellulose
Raw Materials	15.33	141.77	0.585
Production Equipment	0.157	0.027	0.011
Processing and Plant	0.815	8.05	0.25
Transportation	3.419	26.0	0.52
Installation	Negligible	0.050	0.04
	19.721	175.897	1.406
Total Energy Use in million Btu per R- value:	0.36	2.87	0.054

Source: G. Klein, et al., "A Feasibility Study on Development of a Small Scale Cellulose Insulation Industry in Tompkins County, New York," The Community Energy Network, Ithaca, New York, 1978, pp. 53 and 56.

data are for 1967. CAC computed energy intensity coefficients (in Btu per 1967 dollar) for 357 sectors of the U. S. economy. Several studies have taken some of the Btu per dollar coefficients and converted them to Btu per physical unit coefficients [4,5,6].

Although input-output data are very convenient to use, most products or systems that are analyzed do not conveniently fit into one of the 357 sectors. For these systems, process analysis is used until items are obtained that fit into the input-output data. Such a "hybrid" analysis was done by the Institute for Energy Analysis at Oak Ridge Laboratory on a wind-electric generating station [7]. Table 2 shows the components that the wind station was broken into and the energy required for each that was obtained from the input-output intensities. In addition to the 15.497 x 10^9 Btu required to build the system, 51.66 x 10^7 Btu per year are required to operate it. However, the output is 2.06 x10^{10} Btu per year so, clearly, this wind station is a net energy gainer. Also, the high quality energy produced makes it a potential energy breeder. Energy quality and breeders will be discussed later.

Table 2. ENERGY REQUIRED TO BUILD A 1500 kW WIND ELECTRIC GENERATING STATION

Component	Total Primary Energy (10^9 Btu)
Wind Turbine	
Blades	0.658
Hub	1.550
Structure	
Tower	2.956
Foundation	0.225
Pintle	0.999
Yaw	0.366
Nacelle	0.073
Transmission	4.373
Electrical	0.736
Construction, miscellaneous	1.688
Construction, direct	1.477
Professional service	0.106
Transport	0.320
Grand Total	15.527

Source: A. M. Perry, et al., Net Energy Analysis of Five Energy Systems, Institute for Energy Analysis, Oak Ridge Associated Universities, ORAU /IEA (R)-77-12, Sept. 1977.

"Ecoenergetics," the final net energy calculation method we discuss, extends the boundaries of the problem [8]. Natural energy inputs such as solar or biomass are included along with fossil fuel inputs. The environmental disruption of natural energy flows caused by a system or facility is taken into consideration. Finally, energy quality factors are used to compare different energy sources. These quality factors are used to compare different energy sources. These quality factors are very controversial as one study has estimated a Btu of solar energy to be 2,000 times less useful than a Btu of coal [9].

These four net energy methodologies have been developed in part to discover if new energy producing ideas are in fact energy gainers when indirect energies are considered. In addition, net energy analysis can be used to compare different energy alternatives.

The United States is currently searching for alternatives to its depleting fossil fuel reserves. It is important that the alternatives consume as little fossil fuel as possible both directly and indirectly. A recent study by Wilcox and Brown [10] compared the energy resource inputs for residential heating and cooling systems employing (1) conventional electric, (2) heat pump, and (3) an active liquid solar collector system with conventional electric backup. Among the conclusions were:

- Considering all energy resource inputs from a multiple-fuel based economy, the solar option consumed only 44% of the coal resource input needed for the conventional electric option each year. An additional 0.8 barrel of crude oil resources and

2.8 MCSF of natural gas were consumed on an annual basis by the solar option (mostly as energy associated with fabrication and installation of solar equipment).

- The solar option collected about 124 million Btu annually, yet drained society of considerably more energy—an apparent net energy loss.

Thus this complex solar system saves a considerable amount of energy but does not produce more energy than it uses.

Comparing different systems on the basis of total energy use can be valuable to the policymaker. Usually the results of two different studies cannot be compared because the assumptions are different. However, if one is careful to keep the same assumptions for all systems, useful comparisons can be made. One such study is currently underway at the New Mexico Solar Energy Association [11]. Seven conceptual houses were designed to be identical except for different heating systems: electric baseboard, gas furnace, active solar system with concentrating collectors, active solar system with liquid flat-plate collectors, greenhouse, Trombe wall, and direct gain. All solar systems were sized to provide 90% of the heating load in Santa Fe, New Mexico. Using the hybrid method and data from the Center for Advanced Computation at the University of Illinois, the direct and indirect energy inputs to build and operate each system were found. (See Table 3.) The results allow for some interesting comparisons:

- The fossil fuel systems require considerably less energy to install but more than make up for this in annual energy requirements. As a result, the fossil fuel systems use 2.5 to 9 times as much energy as the solar systems (including auxiliary heating) over 20 years.

- Active solar systems require two to six times as much energy to build as passive systems. In addition, a conservative calculation shows active systems require at least 7 million Btu per year to operate the pumps and controls (18%-20% of total energy use over 20 years). Thus a considerable energy savings can be realized by using passive solar systems.

- Both active and passive solar systems are net energy gainers assuming a 20-year life. However, the payback period varies from less than 2 years (for the direct gain house) to almost 15 years (for the flat-plate collectors) as shown in Table 4.

  Notice that the active systems may pay back financially before they do energetically.

We need to resolve this current dilemma—in which dollar costs fail to reflect energy costs accurately—by making energy impacts paramount. Enactment of appropriate tax incentives, elimination of planned obsolescence, curtailment of tax rewards for wasting energy, inversion of utility and other fuel supplier rates, and energy quota legislation are some measures that could conceivably be employed to modify energy consumption in this direction.

Solar technologies which offer a viable alternative as a primary energy resource can be developed within the context of solar breeder systems. There is evidence in the scientific literature of some early efforts to consider designs of "solar breeder" systems. A solar breeder can be defined as any solar conversion device that delivers in its lifetime more energy of sufficient quality or grade than needed to maintain and rebuild itself [12]. Quality needs to be high enough so that all processes involved in production of the original are available to produce a replica; clearly, a hot water heater, for example, could not produce temperatures necessary for making the metal, glass, etc., of which it is composed.

A recent study [13] attempts to quantify the total energy use in the production of silicon solar cells from raw silicon dioxide in the earth to finished product. The study found that the energy required to fabricate the final solar cell was small (9%) when compared to the energy tied up in the final polycrystalline semiconductor material—due both to a low yield in fabricating wafers

Table 3. TOTAL ENERGY USE OF 7 HOME-HEATING OPTIONS

Option	Energy Embodied in Heating System (Million Btu)	Annual Energy Use of Solar System (Million Btu/yr)		Annual Auxiliary Energy Use (Million Btu/yr)	Total Energy Use in 20 yrs (Million Btu)
Electric Baseboard	6.0			194.0	3886.0
Gas Furnace	10.7			105.0	2110.7
Active Solar					
Concentrating Collectors	205.9	7.2	with electric auxiliary	19.4	737.5
Flat-Plate Collectors	241.4	7.1		19.4	771.4
Passive Solar					
Greenhouse	98.3	-0-		19.4	486.3
Trombe Wall	71.0	-0-		19.4	459.0
Direct Gain	41.6	-0-		19.4	429.6

NOTE: Auxiliary for solar systems is electricity. Both auxiliary and total energy use would be substantially reduced if gas, oil, or wood were used.

Source: Sherwood, "Total Energy Cost of Home Heating Options," New Mexico Solar Energy Association, forthcoming.

Table 4. ENERGY PAYBACK TIMES FOR SOLAR HEATING SYSTEMS

System	Energy Payback Time Including Auxiliary (years)
Liquid Flat-Plate Collectors	14.7
Liquid Concentrating Collectors	12.6
Greenhouse	4.2
Trombe Wall	3.0
Direct Gain	1.8

Source: L. Sherwood, "Total Energy Cost of Home Heating Options," New Mexico Solar Energy Association, forthcoming.

and to the energy intensiveness of the high-temperature refining process itself. An energy payback time of about 12 years was calculated for terrestrial solar cells using current production techniques. However, significant energy-cost reduction appears feasible in the future, according to Hunt, so that this type of passive solar system is a potential candidate for solar breeding due to the high grade of its energy output.

Although the above studies differ widely in scope and implications, they do serve as useful prototypes for solar system designers and consumers alike. Most important, they emphasize the need for understanding net energy concepts before systems are designed and commercially manufactured. In particular, they suggest the need for immediate net energy analyses of functional solar systems which employ materials of low-energy content and long lifetimes.

Not everything, of course, needs to show a net energy gain, but it is absolutely critical to be able to distinguish net losers from gainers, as well as relative net energy advantages of competitive systems when comparing alternative primary energy options, in order to predict future directions and avoid false expectations. Clearly, critical decisions regarding social values that are not quantifiable in energy terms must be faced in order that a net energy policy not unnecessarily intrude upon areas that are appropriately reserved for individual choice.

While any national energy policy scenario would have broad impact on humanistic choices in its wake, so could the postponement of major energy strategy decisions. Planning now for an eventual steady-state economy allows us to anticipate the enormous social transitions that lie ahead—in a manner that can preserve vital human freedoms rather than see them dissolve in the throes of energy crises.

Net energy conclusions, properly deployed to reveal energy circuits within our society that too often lie unseen and unaccounted for, can point us toward energetically realistic paths. Such foresight could help prepare us for the high quality of life that could potentially accompany a future steady-state economy.

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A.S.E.—NETWORKING

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Colorado Contact
Alternative Sources of Energy Magazine
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One of the key building blocks for a more humanistic future is a vital communications system. The rapid pace of renewable energy development along with the decentralized base of much of the most meaningful work being done makes this link even more crucial. Sharing our dreams and devices through gatherings such as the Energy Forum hastens the emergence of "human" technologies.

Most of my experience with energy communication has been gained through acting as Colorado Contact and New Products Editor for Alternative Sources of Energy. A description of where we were and are illustrates our experience with networking.

A.S.E. has been active in networking among people interested in using clean alternate energy sources since its beginning seven years ago. In fact, the publication started as a newsletter meant primarily to circulate data within the A.S.E. communications network. The group was made up of students, professionals, scientists, tradesmen, inventors, and imbeciles with a common interest in energy and a knack for doing things. Most of the material embraced in the occasional issues was reports on completed projects undertaken by participants in the network. The whole thing was powered by a tremendous amount of time and money donated by those involved.

Typing and layout for each issue were done on a dozen different (usually worn-out) typewriters on a dozen different kitchen tables across the country. Things were normally lost or late, but a lot of valuable learning was passed along in the process. The small size and dedication of the group involved at that time helped to make the whole thing work.

Since then, A.S.E. has evolved from a relatively small national communications network to a larger, looser group, involved mostly with putting out the magazine. Emphasis has changed from internal reporting among participants to the publication of material for anyone interested. While some of the advantages of the more intimate net have been lost with growth, a chance to have more effect has resulted.

Articles, still coming largely from readers, are paid for now. Subscription income along with grant money (NCAT and CETA) is helping to set up a more efficient office with much more information available. The quality of articles and printing is vastly improved. The publication has become more useful to more people.

While enabling A.S.E. to reach more people with more information, growth has simultaneously crippled our networking capability. Staying alive in the publishing business today isn't easy, especially for a bunch of technologists. Most of the dollars and effort seems to go into production and just keeping things (almost) up-to-date. Keeping the mailing lists current, handling the overwhelming amount of information and mail that is coming in, and keeping abreast of developing technologies are about all the office staff can do. Clearly, the communications net aspect can't receive the attention it deserves.

The fact that A.S.E., a networking group at heart, is being forced to neglect communications due to size is significant, I believe. There are lots of local and/or fairly small groups that are doing a tremendous job of developing appropriate technologies. There are very few larger groups that are very effective in stimulating people through information exchange. This is unfortunate since the comparing of notes among small groups and individuals acts as a catalyst.

It is my opinion that this information exchange process is more important and effective than any single development in hardware could be. There are people doing some very effective work with networking, but it deserves much more emphasis overall. If a self-sufficient, energy-balanced way of living is to grow from the rich compost of our industrial society, more effective networking will help the seed to grow.

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COLORADO SOLAR OPTIONS OR MESA VERDE REVISITED

Peggy Wrenn
Colorado State Solar Energy Coordinator
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Colorado is nationally and even internationally known as a leading solar energy center. Why? Colorado has one of the earliest passive solar structures in the Long House of Mesa Verde. Why does Colorado have so many solar solutions, from low-cost, low-technology, home-built air systems to passive solar greenhouses to high-tech, big commercial HUD demonstrations?

Why was Colorado's bid for the National Solar Energy Research Institute selected over 19 competitive proposals from other states? Why did Colorado legislators pass some of the earliest solar bills? Colorado is often looked to as a model for solar-related public policy decisions. Why?

The answer to these questions is an evolving enigma that I've been exploring for 3 years, as a volunteer workshop organizer, as a learner and a teacher, as a private citizen, and, in the past year, as a professional working in state government.

I believe the reason Colorado is internationally associated with solar energy is, in two words, public involvement.

That answer sounds very simple, but I believe it has broad and far-reaching implications for all of us, especially those of us here today, as we make individual choices about how we spend our time and our personal, human energy. Just as we have many choices about which type of solar system to use, we have many options as to how we go about building and using those systems. We can choose how we spend our time and our personal energy.

Communities and neighborhoods in Colorado have rallied around solar advocacy in an almost unprecedented way. There are at least a dozen nonprofit groups of people like the Roaring Forks Resource Center in Colorado today. There are over 300 business people, professionals, and educators who have made individual choices to spend their time designing, building, promoting, installing, and servicing solar systems in Colorado.

Why have all these people, from literally all walks of life, organized themselves to become solar-dedicated? It can't be for the money; most of them are volunteers or small business people who are struggling to survive financially. Why have we (and I mean many of you here in the audience), collectively spent thousands, maybe millions, of hours pasting labels on envelopes, writing articles, giving free lectures and free estimates, taking time to educate people from square one just to get them interested?

Now the answer doesn't sound so simple. In my own personal life I've had to answer that question—why have I spent so much of my personal time on solar energy? The answer that I've found has totally colored my perspective as I've made choices about Colorado solar energy policy from a governmental, or "public policy" (if you will) point of view.

Since I got involved in solar as a house-builder and volunteer, I've brought that perspective to the job I'm doing now. Though I intended to talk about the content of the Colorado Solar Action Plan, it seems more meaningful, in light of the theme of the forum this year, to address the humanistic choices that underlie the philosophy of the plan.

The unique feature of the Colorado Solar Action Plan is not that it proposes to authorize funds for accelerating solar use, but that it proposes to almost totally decentralize the expenditure of those funds. It's based on belief in the power of public involvement to create social change and recognition that meaningful public involvement can only take place on a local, community, or neighborhood scale. Colorado's "grassroots" solar reputation is a case in point.

Perhaps I can best explain why I think the moment for public involvement has arrived by explaining how I found myself totally immersed in solar public involvement, to the point that it changed the whole direction of my life.

In 1970 I bought a piece of land 13 miles west of Boulder in the mountains, and in 1975 I was still working on the house I'd started building with my partner in the spring of '71. We started out thinking we were in for a 1- or 2-year project, and we found ourselves buying an old 1930 sawmill for $100, completely rebuilding it, scrapping together some dollars for nails and tools, and spending 7 years milling our own lumber from local beetle kill pine to build a house that still isn't finished. (And I should be home this weekend fixing the leak in the porch over the kitchen.)

Why did I take time out from this already over-extended building project to help organize a conference in 1975 that resulted in the formation of the Colorado Solar Energy Association? And why have I lived in an unfinished house ever since, getting continually more and more sucked into expending all my energy toward the sun?

Personally, I did it because it was the first opportunity in my life to pull everything together. I'm a 20th century child, as fragmented and disenchanted as any. I need to integrate all the apparently disconnected forces that seem to govern my life. I need to think integratively, or holistically, to stay healthy. Solar energy has helped keep me healthy by helping me pull things together and see a whole picture.

Let me explain how solar did this for me. I first got interested in solar energy because I wanted to put a hot water system on my house to free myself of the hassles and expense of getting a propane truck to come up a mile of the main road in the snow. All of a sudden I found myself involved in the first positive public involvement of my lifetime. In fact, I got so involved that I still haven't found the time to put that water heater on my roof.

I'd been involved in volunteer movements before, from anti-war and anti-establishment commune movements to anti-pollution and anti-nuclear environmentalist movements. And I'd seen a little positive light in the pro-integration, pro-Black, and pro-Indian movements . . . and, though "movement" is an unsatisfactory word for these odd social happenings of public involvement, I'll call it the feminist movement, which was sort of half pro-woman and half anti-man.

Then the solar energy movement captured me and has been driving me ever since. Why?

Because it brought everything together. It brought together the minority and employment issues of the early '60s and the anti-war, living in communes energy of the late '60s, and the environmentalist, anti-nuke energy of the early '70s. And for me, it brought together all the personal energy of the mid-'70s that I spent building a house and learning about American Indians and holistic healing techniques.

Now if that sounds all very unlikely and hopelessly fragmented to you, then you too qualify as a 20th century child. Solar brings it all together because it's not about fragmented and centralized systems that we depend on without understanding them; it's not about being angry and frustrated by enormous social machines that destroy and oppress. Instead it's about decentralized, local support systems that we can not only understand and control, but also become responsible for, as families and neighbors and friends in natural social units. Since you're here, you're probably like me in that you've probably made a commitment to solar energy and realized there's no going back.

Why? For me, it's because solar gives me an opportunity to become responsible for my own life support systems. That is a very broad and far-reaching responsibility. It gives my life a meaning that I never felt before. If I build and use systems to supply the food and energy that sustain me, then I'm accountable and responsible to the Mother Earth and the Father Sun and to the products of that union, the children of the Earth. This means you, me, and black and brown people, and the plants, and the animals. Solar energy, by bringing my personal energies to bear on a kind of positive public involvement, has taught me to be responsible for something bigger than myself by forcing me to realize that energy is the common denominator of all life.

Solar energy has made me realize that public policy is only the sum of the people, and that responsibility for the systems we depend on lies with each and every one of us, not with Public Service Company or a few politicians and bureaucrats. From both a personal and a professional point of view, I've learned that lesson.

Struggling with the issues of solar legislation, performance standards, and consumer protection and pushing for a state policy that recognizes solar as an alternative to oil shale, coal, and nuclear power has taught me that the people of Colorado are the only ones with the answers. We are the ones who must be responsible for what we choose to do collectively as a state. We are the ones with a vested interest in our own welfare.

In the same way, we're all responsible, as a community, for what becomes of the Earth and the natural systems that we depend on.

In case the interconnectedness of independent, personal volunteerism and public policy and solar energy is still not entirely clear to you, I'd like to quote two people to try to illustrate my point. First I'd like to quote Chief Sealth of the Duwamish Tribe of the State of Washington, from a letter he wrote to President Franklin Pierce in 1855 (as reprinted in the 1973 issue of the Aquarian ESP). The second person whose words I'd like to share with you is Governor Jerry Brown of California, from an article about his recent visit to a California mental hospital in the latest issue of Co-Evolutionary Quarterly.

Chief Sealth wrote a letter to the President of the United States in 1855 about the proposed purchase of the tribe's land. He wrote:

> What Chief Sealth says, the great chief in Washington can count on as truly as our white brothers can count on the return of the seasons. My words are like the stars—they do not set.
>
> How can you buy or sell the sky—the warmth of the land? The idea is strange to us. Yet we do not own the freshness of the air or the sparkle of the water. How can you buy them from us? We will decide in our time. Every part of this earth is sacred to my people. Every shining pine needle, every sandy shore, every mist in the dark woods, every clearing and humming insect is holy in the memory and experience of my people.
>
> If I decide to accept, I will make one condition. The white man must treat the beasts of this land as his brothers. I am a savage and I do not understand any other way. I have seen a thousand rotting buffaloes on the prairies left by the white man who shot them from a passing train. I am a savage and I do not understand how the smoking iron horse can be more important than the buffalo that we kill only to stay alive. What is man without the beasts? If all the beasts were gone, men would die from great loneliness of spirit, for whatever happens to the beast also happens to man. All things

> are connected. Whatever befalls the earth befalls the sons of the earth.
>
> One thing we know which the white man may one day discover. Our God is the same God. You may think now that you own him as you wish to own our land. But you cannot. He is the body of man. And his compassion is equal for the redman and the white. The earth is precious to him. And to harm the earth is to heap contempt on its creator. The white, too, shall pass—perhaps sooner than other tribes. Continue to contaminate your bed, and you will one night suffocate in your own waste. When the buffalo are all slaughtered, the wild horses all tamed, the secret corners of the forest heavy with the scent of many men, and the view of the ripe hills blotted by talking wires, where is the thicket? Gone. Where is the eagle? Gone. And what is it to say goodbye to the swift and the hunt, the end of living and beginning of survival.
>
> We might understand if we knew what it was that the white man dreams, what hopes he describes to his children on long winter nights, what visions he burns into their minds, so they will wish for tomorrow. But we are savages. The white man's dreams are hidden from us. And because they are hidden, we will go our own way. If we agree, it will be to secure your reservation you have promised. There perhaps we may live out our days as we wish. When the last redman has vanished from the earth, and the memory is only the shadow of a cloud moving across the prairie, these shores and forests will still hold the spirits of my people, for they love this earth as the newborn loves its mother's heartbeat. If we sell you our land, love it as we've loved it. Care for it, as we've cared for it. Hold in your mind the memory of the land, as it is when you take it. And with all your strength, with all your might, love it as God loves us all. One thing we know—our God is the same. This earth is precious to him. Even the white man cannot be exempt from the common destiny.

Well, Chief Sealth said this long, long before we discovered Spaceship Earth. What visions are we burning into our children's minds so that they may wish for tomorrow? Will these shores and forests still hold the spirits of our people or will we suffocate in our own bed? In a funny, roundabout way, Governor Jerry Brown spoke to these questions at a recent visit to a mental hospital. He said:

> So I think we have to ask ourselves—and I'm not raising this as a political question, but as just a way to understand the nature of reality that we all face—why is it that, despite the public philosophy of those in key positions, government gets bigger and bigger, more complex, more involved, and your taxes keep going up?
>
> The very simple reason is that it takes more than words to put some limit on that growth. There are certain needs and obligations in the community that just have to be taken care of, and if you don't do it—through some volunteer movement, some other arrangement outside of the public sector—then inevitably government will take the task and assume those obligations.
>
> There is no substitute for neighborhoods, for mutual-support systems in the private sector. Whether it be neighbors who know each other, who have some responsibility for someone other than themselves and their family—you can't get away from it. The idea that you can put it on government if you want to is going to triple your taxes, because then you have to hire a full-time person who doesn't have the commitment involved in it that you would to do that kind of work.
>
> That's my simple message: that voluntarism is not a luxury; it is a necessity for a civilized society that wants to truly meet its human needs. And we have to expand it in a dramatic way across a broad front of government and human activity. We have to find some way to re-create the spirit of neighborliness and mutual self-support that existed before the mobility and the anonymity and increasing information flow that has been the product of this very prosperous society.
>
> We're institutionalizing everybody. And I'd like to deinstitutionalize everybody, I'd like to have a community that has a more human spirit to it . . . I accept a large measure of responsibility for making it better, but I can't do it alone.

This human community that Brown is talking about rings, at least in my ear, of Chief Sealth's words about his tribe. And though I started out, when I began writing this speech, to talk about the Colorado Solar Action Plan that we've written as a first cut at defining the state's solar policies and programs, I found I couldn't talk about the plan without talking about the public involvement premise that it's based on.

It is a particularly appropriate time for me to express this message because the Aspen Energy Forum marks the anniversary of my beginning public involvement in solar at the 1975 Forum. I've come back every year because, in a way, I feel that the people who gather here every year almost ritualistically are a tribe. We are a community of carers who've voluntarily taken on a certain measure of responsibility for our life support systems.

Anyway, about the Colorado Solar Action Plan, which I though was the subject of my talk when I sat down to write it . . . the first and most basic assumption of the plan is that people and public involvement have gotten us this far, and we have to trust them to get us even further. The proposed programs in the plan are designed to support what's already happening in the private sector. The kind of thing that's going on here today, and things like the low-cost solar collector workshops that go on in the Chicano communities of the San Luis Valley in southern Colorado, and the meetings and activities of all the many Coloradans who've chosen to spend their energies on solar because they believe in it. I should mention that many of these people were directly involved in conceiving and writing the Colorado Solar Action Plan.

A colleague of mine (and cogovernment worker, whose name I won't mention for obvious reasons) recently told me that the only thing government can do is give out money. In a very real sense I believe he's right. Government can redistribute wealth according to some amorphous consensus about what's best for everybody. Really, people have to do the rest.

So the Colorado Solar Action Plan puts most of the money and responsibility for accelerating the use of solar in Colorado in the hands of the people. Basically, the plan proposes four programs, which are, in decreasing importance: education and training; technical assistance, including matching funds for solar systems on public buildings; and data development to monitor both the success of different types of solar systems and the success of educational and technical assistance programs. The fourth program, key to the whole plan, is legislation, which will be required to commit state funds for solar to supplement the federal dollars which may come down from the Department of Energy through the western region.

The western region is one of four regions that received planning grants from the Department of Energy last summer to plan mechanisms for accelerating the use of solar (including wind and biofuels). DOE may follow up with some limited funding to implement the plans that were developed. The whole question of how the regions should relate to the National Solar Energy Research Institute and to DOE has become so political that the level of funding to states through the regions will probably remain quite low. Regardless of the regional funding, Colorado could very profitably spend some of its own state funds by supporting the extraordinary grassroots solar activity that has already made it the number one solar state in the country, second only to California in the total number of solar buildings.

I will be working this summer on the legwork to get a comprehensive solar legislative package ready for the 1979 session, including authorization of funds, improved solar tax incentives, and some consumer protection mechanisms. The way the plan is now written, it would put most of these funds into the hands of the people who will spend them most frugally. The plan proposes to use existing local resources and people to implement all the programs, and to decentralize the planning and delivery of services to the most appropriate local, community, or neighborhood scale.

The people of Colorado who have done so much with so little, using volunteer energy, personal funds, and donated materials in many cases, are probably the only people who can make this plan successful and cause solar to displace a large amount of our energy supply mix in the next 5 years. We are the people who have a vested interest in making it work.

So, without belaboring the point too much further, I'd like to conclude by showing you some of the great variety of solar projects that have collectively made Colorado known as a solar energy center. I didn't spend much time discussing technologies because these are secondary. The nuts and bolts of the technologies, fascinating as they are, are meaningless unless put in the larger context of people, food, energy, and environment. For me, the humanistic choices that solar energy presents us with are the most critical choices we've ever made.

I see solar as the best opportunity we may get for the radical social change that will be required for us to survive in peace. There is no perfect or best solar system because each person must choose the right system for him or her self, for his or her community. We have to participate in our own best solutions.

We have to become responsible for our own life support systems and care for the Earth the way She has cared for us. If we try to let government make our choices for us, we are passing the buck; and we cannot expect to be satisfied with the outcome.

I'd like to leave you with a quote from a friend of mine who is one of the world's unsung wind-energy designers. He says, talking about a wind generator he's completely rebuilt since he installed it in 1973:

> Renewable energy turns your lifestyle in the house into an intelligent system. The system needs an operator who is aware of the total welfare of the system. Consumption of power is keyed to production; when wind is blowing you pump water from the deep well.
>
> I'm down on the industrial attitude and the laziness of people with respect to maintaining their life systems. Thousands of hands were made idle by the Industrial Revolution. Independence is dealing with one's own environment and interacting with it in real time. Independence is stored energy.
>
> It gives you a great amount of peace of mind—our system has intrinsic value as long as the wind blows, as long as the grass grows, and as long as we can get replacement parts.

This is what I mean about taking responsibility. We not only have to build the technological systems; that's the easy part. We also have to build the social fabric and make the choices that will keep us supplied with replacement parts. Thank you for listening.

BUILDINGS AS ORGANISMS

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Imagine an insulating material which is also transparent. It sounds like a contradiction in terms. Such a material would prevent the flow of heat and yet would hardly be visible. We have developed such a material and will be manufacturing it in a totally automated factory in a year or so for less than a dollar per square foot. It may eventually cost less than conventional opaque insulations. It is a coating, about 1,000 atoms thick, that can be put onto any plastic film. Because the coating is so thin, the coated film looks just like the uncoated film, but the materials it is made from and their structure are carefully arranged so the coating reflects heat. That is to say, it reflects thermal or infrared radiation, which is just like light except it has a longer wavelength and is thus invisible to the eye.

Because it is invisible, most people (including many engineers and architects who should know better) don't realize what a large role radiation plays in the movement of heat in everyday life. The recent introduction of infrared cameras is beginning to stimulate awareness of thermal radiation. If you could see it, any energy consuming device such as an oven or an automobile would glow brightly, and any cold place, such as an open icebox or the night sky, would appear black. Anyhow, the coating that we have developed reflects thermal radiation, a property normally possessed only by polished metal surfaces, and this reflectivity makes the coating an effective thermal insulation. Even though the coating is a hundred times thinner than a piece of paper (which is why it is so cheap) it can insulate as well as an inch of plastic foam or glass wool insulation when it is used with a dead air space. This is stepping lightly indeed in the consumption of dollars, energy, and human effort. We call this coating which we have developed "Heat Mirror."

As long as we are imagining things, let's imagine another plastic film—one that is perfectly transparent and indistinguishable from an ordinary plastic film until it is heated above a certain critical temperature, at which point it turns white, an opaque white that reflects light without absorbing it. Imagine also that this temperature induced change is thoroughly reversible; that as soon as the film is cooled below its critical temperature, it becomes transparent again. We have developed such a material and it would also be inexpensive to manufacture. We call this coating "Cloud Gel." It switches from transparent to white and back again instantaneously over a temperature change of only three degrees. This transition temperature can be tuned to any value between 0°C and 100°C by adjusting the proportions of its constituents.

The Cloud Gel is made from plastic molecules which are like long chains. These chains are dissolved in a solvent where they thrash about in a tangled mass much like spaghetti in a pot of boiling water. Since the diameter of these chains is much smaller than a wavelength of light, the light cannot "see" them any more than a large fish swimming in a straight line through a sea of spaghetti could distinguish individual strands of spaghetti. Scientists would call this an example of the uncertainty principle. Thus the plastic solution appears perfectly homogeneous and transparent to the eye in spite of its fine structure. The plastic chains dissolve in the solvent by virtue of their attraction for much smaller and roughly spherical solvent molecules which coat them to form a "cage" much like the insulation around a wire. As the solution is heated, the chains thrash about with more and more violence (thank God we can't hear them) until finally a temperature is reached at which the cage is broken and the solvent molecules are cast off. At this point, the plastic molecules become insoluble in the solvent.

Now an interesting thing happens—without the solvent cage the chains and solvent repel each other and they try to reduce the surface area where they are in contact. The chains accomplish this by curling up from their extended position into balls much like spaghetti wound on a fork. Of course, the diameter of these balls is much greater than the diameter of the chains. In fact, the balls are now large enough to deflect our fish (light particles) from their straight line paths when they bump into them. This change from extended interwoven chains to separate balls is observed on the macroscopic level as a change from transparent to opaque white. The light, like the fish, is scattered randomly from its straight line path and the information contained in the image the light transmits is lost. When the solution is cooled, the whole process is reversed; the balls unfold, reacquire their solvent coating, and the Cloud Gel becomes transparent again. Of course, the plastic and solvent molecules are specially designed to have these relationships.

At this point you are probably bored with imagining plastic films full of fishes, so let's imagine a concrete block—no ordinary concrete block but one that can store 20 times the amount of heat that an ordinary block can and which stores this heat without a change in temperature. How can heat be stored without a change in temperature? Consider a glass of ice water. Since the ice and water co-exist, the temperature must be 0°C, the freezing point of water or the melting point of ice. If heat is added to the ice water, the temperature cannot rise until all the ice has melted. Similarly, if heat is removed, the temperature cannot be lowered until all the water has frozen. A scientist would call this an isothermal situation since large quantities of heat can be exchanged without attendant temperature changes. The temperature of the glass of ice water is self-regulating. Every material has its own melting point, so if we want to store heat (or "cool" which is really another way of looking at the same thing) at some particular temperature, we merely select a material which melts at that temperature. Since the changes in molecular structure and organization are much greater in the solid-liquid transition than they are in simply heating and cooling a material, the quantities of heat involved are similarly greater.

Unfortunately, most materials when cooled a bit below their freezing point do not crystallize but remain liquid unless there is a "seed" crystal around which to form. That is to say, it is easy to make a crystal grow, but hard to create one from a pure liquid by just cooling it. Another problem is that most materials, unlike water, are made from several components which on freezing can form a variety of different solids, each with different proportions of the components. These other solids generally store much less heat and store it at the wrong temperature. A third problem is that like the ice water, which needs a glass, these materials also need a container to prevent things from getting messy. All these problems can be solved by incorporating the heat storage material into the very fine pores in foamed concrete. The concrete initiates crystal growth by acting as a seed; it keeps solid and liquid components from separating by the fineness of its pore structure which insures that the sought after compound is formed on freezing, and the concrete acts as a structural container for the thermal storage material when it is in its liquid state.

We call this material which we are developing "Thermocrete." For a room temperature melting point its main ingredient is calcium chloride—the stuff they throw on streets to melt ice. We can select other salts to store heat at many temperatures between 0°C and 100°C. Laboratory samples have withstood 1,000 freeze-thaw cycles with no measurable loss in the amount of heat stored. The compressive strength of Thermocrete is 1,000/sq in, approaching ordinary concrete.

So now we have three new materials—a material which transmits light but not heat, a material which transmits light when it is cool and reflects it when it is hot, and a material which stores heat and cool without getting warmer or cooler. So what?

Well, suppose one were to lay a stack of these materials out in an open field as is shown in Fig. 1, what would happen? Assuming it is a sunny day, sunshine will pass through the Heat Mirror and Cloud Gel and will be absorbed on the Thermocrete where it will turn into heat. Since the heat cannot escape through the Heat Mirror, it will go into the Thermocrete where it will melt the heat storage material in the Thermocrete. We have thus trapped and stored the sunlight.

When all the heat storage material has melted, and only then, the temperature of the Thermocrete block will start to rise. If we have set the temperature at which the Cloud Gel turns from transparent to white a few degrees above the temperature at which the Thermocrete melts, then only after the Thermocrete is completely charged with heat will the Cloud Gel turn white. Thus the Cloud Gel prevents the sunlight from overheating the Thermocrete by reflecting it. The Cloud Gel does not respond to outside temperatures because it is insulated from them by the Heat Mirror. Nor does it respond to sunlight, being activated solely by temperature. So, during a sunny day, this stack of materials rises to a temperature in the narrow range (70°F to 75°F) between the transition temperature of the Thermocrete and the transition temperature of the Cloud Gel.

What happens at night or during a cloudy day? Heat slowly leaks out of the Thermocrete through the Heat Mirror and the Thermocrete slowly freezes without cooling. Calculations show that if the Thermocrete melts at 70°F and the temperature outside averages 30°F, and we are using two layers of Heat Mirror, then over a 24-hour period a layer of Thermocrete only one-third inch thick will freeze. This is a measure of how good an insulation the Heat Mirror is and how good a storage material Thermocrete is. Calculations also show that on an average January day in Boston, there will be enough sunlight falling through our stack of materials to melt two-thirds inch of the Thermocrete. Thus we see that even in the grips of the Terrible New England Winter, our stack of materials easily maintains a comfortable 70°F by captured and regulated sunlight.

Thermocrete is also useful for cooling in the summer, especially in hot dry climates where the nights are usually below 70°F even when daytime temperatures reach 100°F. This is done as follows: during the night the Thermocrete is cooled by placing it in contact with the cool night air by using either natural convection or fans. If you'll remember our glass of ice water, you'll see that the Thermocrete can store large quantities of "cool" just as it can store heat, and it stores this cool without a temperature change. This is the beauty of storing heat and cool by melting and freezing. Since the Heat Mirror and Cloud Gel isolate the Thermocrete from the heat and sunlight of the day, the cool collected and stored during the night trickles out very slowly during the day. This "ratchet effect" is used most of the time even in hot humid climates, but it won't work all the time in the Deep South because the summer nights are usually above 70°F. When this happens, the Thermocrete can't freeze.

In summary, these three materials can maintain a comfortable year-round climate by utilizing locally available and natural (free) energy sources, sunshine, and cool night air. This remarkable winter and summer performance has been borne out by computer simulations and experiments. This is done with no moving parts except molecules, electrons, and photons, which don't wear out. These materials are also extremely cheap. The simplicity and elegance resulting from the design of building materials on a molecular level is reflected in their cost effectiveness. Other climate control systems requiring energy inputs and active elements will find it difficult to compete with the combination of these materials in the marketplace.

Now we can see where the title of this article came from and what the viewpoint is that unifies these three materials. It is the biological analogy which gave the

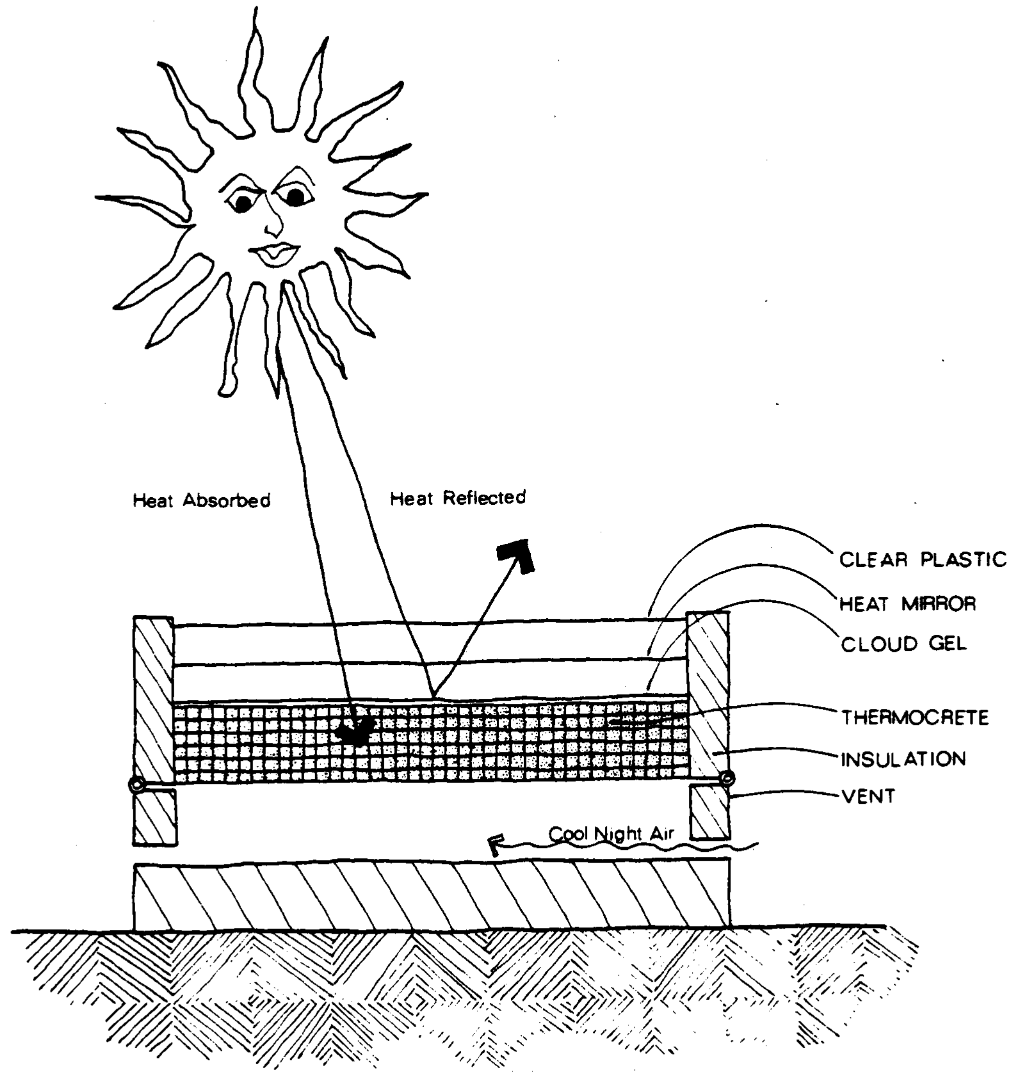

Fig. 1. Passive heating and cooling unit

direction for their development. The building is viewed as a one-celled organism whose environment contains all the necessary nutrients and also some hostile elements. The cell wall (Heat Mirror and Cloud Gel) establishes relations between the inner and outer environments in a way such that the internal environment remains constant when the external environment changes. Through the selective permeability of its roof or walls the building exhibits homeostasis, perhaps the most basic property of living things.

Well, this discussion has all been very abstract, but how will these materials actually affect buildings? In two sorts of ways—first they will allow conventional buildings to use local and renewable rather than centralized one-shot energy sources and thus greatly reduce the cost of running conventional buildings. The sun belongs to everyone—coal, oil, and uranium don't. Secondly, these materials will make it possible to build new types of buildings. For these materials to have an interesting effect on the real world, they must first find large and less imaginative markets to justify financing the building of factories and distribution channels. Unfortunately, these are both subject to the economics of scale, so that our materials will not be cheap until they are popular. Since new buildings replace old buildings about every 40 years, there is a large market in reducing the energy consumed in the heating and cooling of existing buildings.

Although it has been compared with putting sails on tugboats, the use of Heat Mirror on all windows would reduce national energy consumption by about 1.2 million barrels of oil per day and save Captain and Mrs. American almost a dollar per year for each square foot of window they cover with Heat Mirror. The use of Cloud Gel on all windows where sunlight increases air conditioning loads would reduce national energy consumption by roughly 0.5 million barrels of oil per day. Thermocrete could also reduce the amount of fuel used in heating a building by storing the heat from its oil burner and then distributing the heat to the building when needed. Since the oil burner need fire only once per day, it would not waste fuel getting up to operating temperature. A 4-foot cube in the basement next to the oil burner would be large enough for the average home and would pay for itself in 2 or 3 years. Universally installed, these units would save the United States about

1.3 million barrels of oil per day. On the other hand, much smaller Thermocrete cool storage units connected to air conditioners would allow electric power plants to run at night. Although this would not save fuel, it would save money since electric generating stations need not be so large, as they are usually sized for air conditioning peak loads. Adding the effects of all these energy conservation measures together, these three materials could reduce national energy consumption by about 10% and reduce the need for adding nuclear capacity as fossil fuels run out.

For new construction or retrofitting of fairly conventional looking houses with solar heating and night air cooling, we need to turn our stack of materials on end to make the south wall of the house. Figure 2 shows such a house. This wall does many things: it is a load-bearing structural element; it collects solar heat and night air cool; it stores this heat and cool; and it regulates and distributes the flow of heat and cool. Since in new construction it replaces an ordinary south wall, its energy processing functions are purchased for a marginal increase in cost. Structures using these materials which are thermal models of this type of building are being tested at M.I.T. and Los Alamos Labs. Their performance will be put into computers to predict performance in other climates. Our materials should also find wide application in improving the performance and lowering the cost of conventional solar heaters.

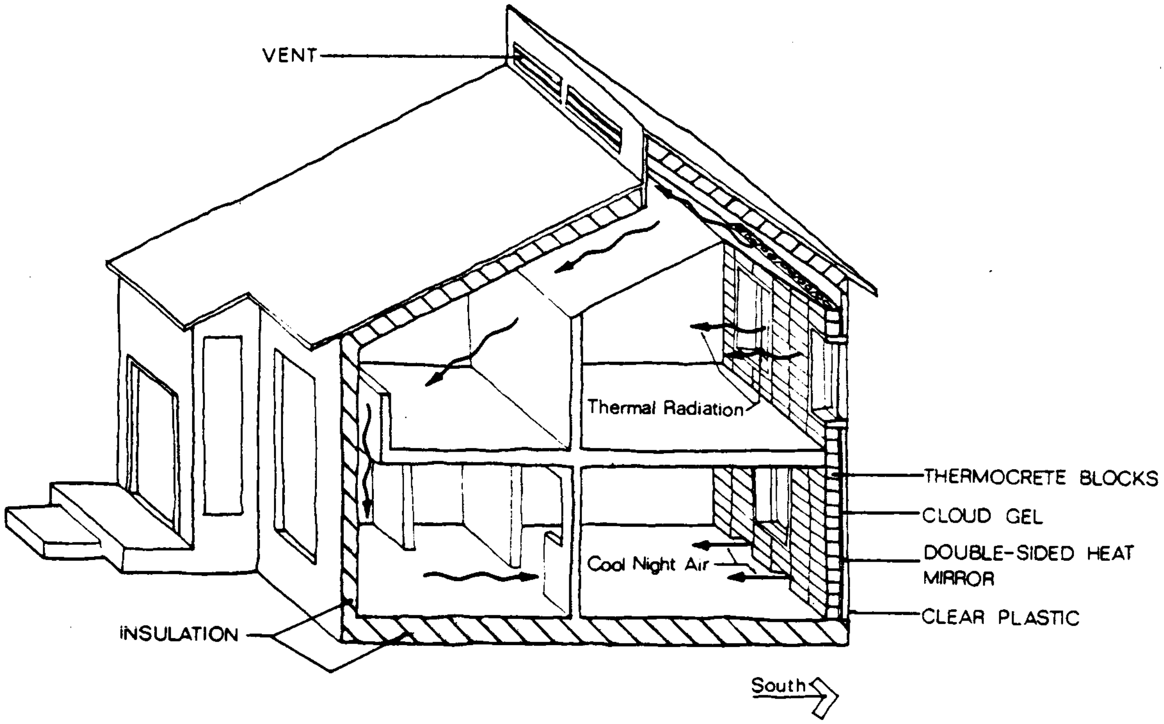

Fig. 2a. Passive heating and cooling wall

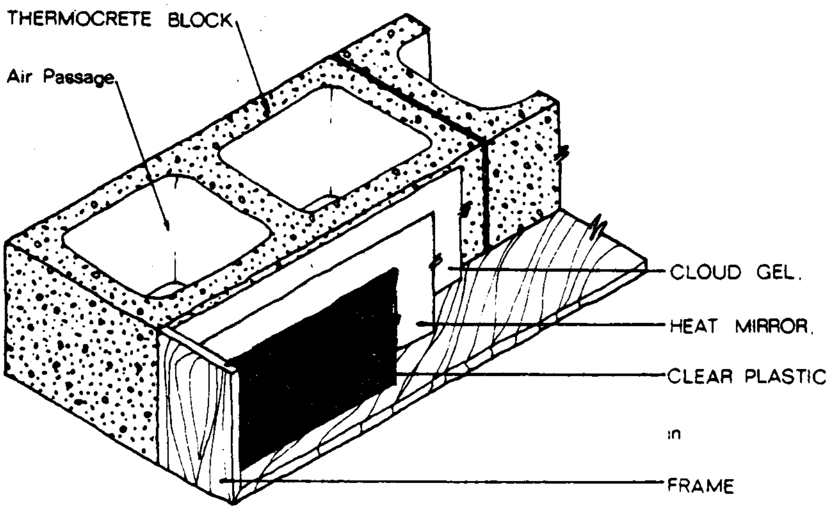

Fig. 2b. Block for passive heating and cooling wall

But much more interesting than energy conservation and solar heating are the entirely new kinds of buildings that can be built using these materials. These include Climatic Envelopes and Biospheres. The Biosphere is a home which feeds, heats, and recycles water and the wastes of its occupants. Its potential social impact is enormous because it makes work, in the sense of the "9 to 5" job, unnecessary. Its core is a solar collecting greenhouse which can be built without our three materials, but which would benefit greatly from them. Also based on the biological analogy, the Biosphere was invented by the author in 1969. Since then the New Alchemists, the Berkeley Solar Group, and the Ouroboros Group have actually built functioning whole systems.

The Climatic Envelope is an old concept, but no one has built one yet because it won't work without the three materials. It is simply the stack of materials from Fig. 1 elaborated into a large bubble of good weather. It is suitable in small spans for a revised version of the home or greenhouse. In large spans it can enclose tropical parks or housing developments with no heating or cooling bills. First use will probably be for covering large commercial buildings such as sports arenas, shopping centers, university campuses, etc., but they also seem to be the most practical solution to the problems of energy for space conditioning the city, where any other kind of retrofitting seems hopeless. The height of large span envelopes will facilitate natural ventilation by wind and the chimney effect, but one could not use present automobiles inside climatic envelopes.

Removing the weather protection and structural restraints from the living areas inside the buildings should produce a corresponding relaxation and personalization of the internal architecture, not to mention a great reduction of first and running costs. The main functions of a home under a climatic envelope are visual and audio privacy and pleasing appearance. These greatly reduced functions are much more within the realm of the amateur homebuilder in both skill and financial resources. Because the shelters inside the climatic envelope have such reduced functions, they can consist largely of movable partitions and soundproof curtains. Activities presently enclosed only for climatic reasons could take place in the "open air." The envelopes could be either one for each family, separated by berms, or could span large areas, with families separated by trees and fences.

Figures 3 and 4 show a typical Climatic Envelope. The building is a transparent roof, shaped to shed snow, placed over a hole dug in the ground. The rooms are placed against the walls of the hole in the form of a horseshoe which is covered with gardens. Fruit trees and vine arbors provide shade. The outer roof is made from Heat Mirror and Cloud Gel, and the leaves of the plants are the absorbing surfaces for sunlight. Thermal radiation and a big lazy fan circulate either heat from the plants or cool night air when appropriate to Thermocrete tiles which are distributed throughout the structure.

So that, in broad strokes, is what Suntek is all about. Who is Suntek and how did we get together to develop these interests? Back in 1968 while traveling through New Mexico, I met Steve Baer, who has a particular design aesthetic about buildings and had organized a company, Zomeworks, to realize this aesthetic which is based on minimal use of materials, energy, and human effort and is directed toward the needs of people in the Third World. Solar energy seemed like a safe field for a physicist and the philosophy was appealing so we worked together for several years with some funding from the Whole Earth Catalog.

In 1973, Blair Hamilton invited me to a conference he had organized that was held in a half acre transparent inflatable bubble that he had built for Antioch College with Charles Tilford, Sean Wellesley-Miller, and Beth Sachs. This building was built with materials like the ones I was working on in mind and was a product of the same design aesthetic so we were naturally quite excited about meeting each other. Sean invited me to work with him at M.I.T., where he was on the Architecture Department faculty. We were able to get a National Science Foundation grant which was 17% of the Nation's then miniscule solar energy budget. At this point, John Brookes, a biochemist from Harvard who had also been working on heat mirrors joined Sean and me.

In 1975 the oil crisis shifted the government's funding emphasis in solar energy from the academic to the private sector, and Suntek was awarded two materials development contracts from the Energy Research and Development Administration—one for Thermocrete through Oak Ridge National Laboratory and one for Heat Mirror and Cloud Gel through Lawrence Berkeley Laboratory. Since these materials had already been invented and patented by Suntek, we were able to retain manufacturing rights. At this time John, Sean, and I moved to our present location in California where we were joined by Charles Tilford, a mechanical engineer, and Blair Hamilton and Beth Sachs, both very competent scientific administrators. After spending a year setting us up and organizing us, Blair and Beth left to help the National Center for Appropriate Technology get organized. Mel Hodge, our president, has filled their role. His considerable talent and business experience should prove instrumental in bringing our materials into the real world.

A venture like Suntek would not exist today were it not for the encouragement, advice, and financial support of a varied group of people whose common denominator is imagination, a vision of a certain kind of future, and confidence in their own judgment. We anticipate that Suntek will remain a research organization committed to translating the philosophy expressed in this article into reality. We expect to work with other companies—either existing or established for the purpose—in transferring this new technology from our research laboratory into production and the marketplace. At this point, none of the materials described in this article is yet available for sale. The exception is Heat Mirror which is being manufactured on a prototype machine in limited quantities 12 inches in width at rather exorbitant prices. We would like to build a climatic envelope like the one illustrated. Again, costs would be high because the structure and materials are experimental.

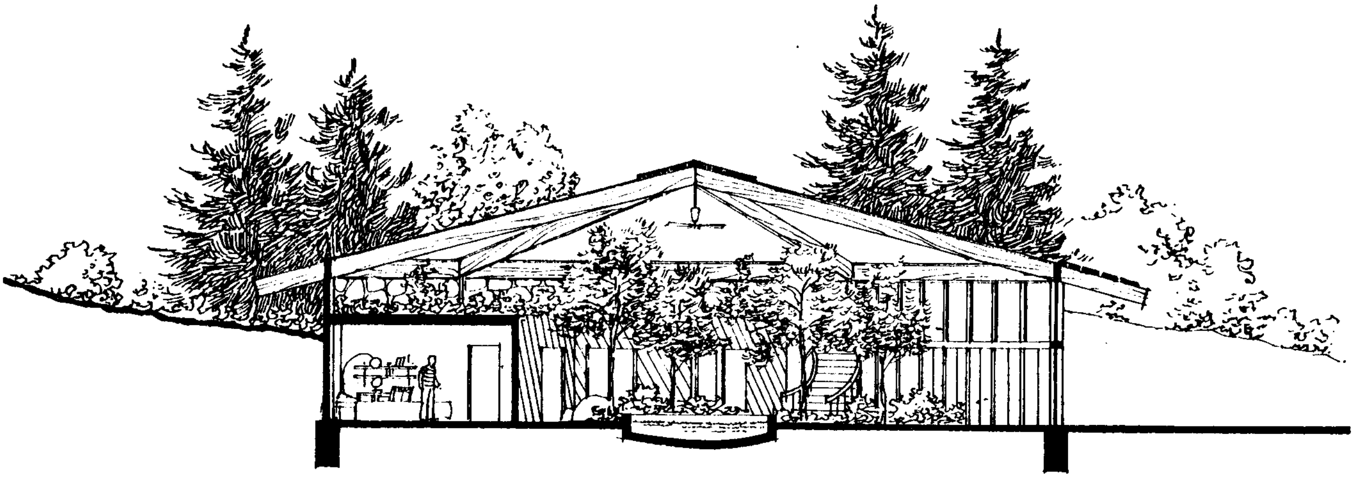

Fig. 3. Typical climatic envelope

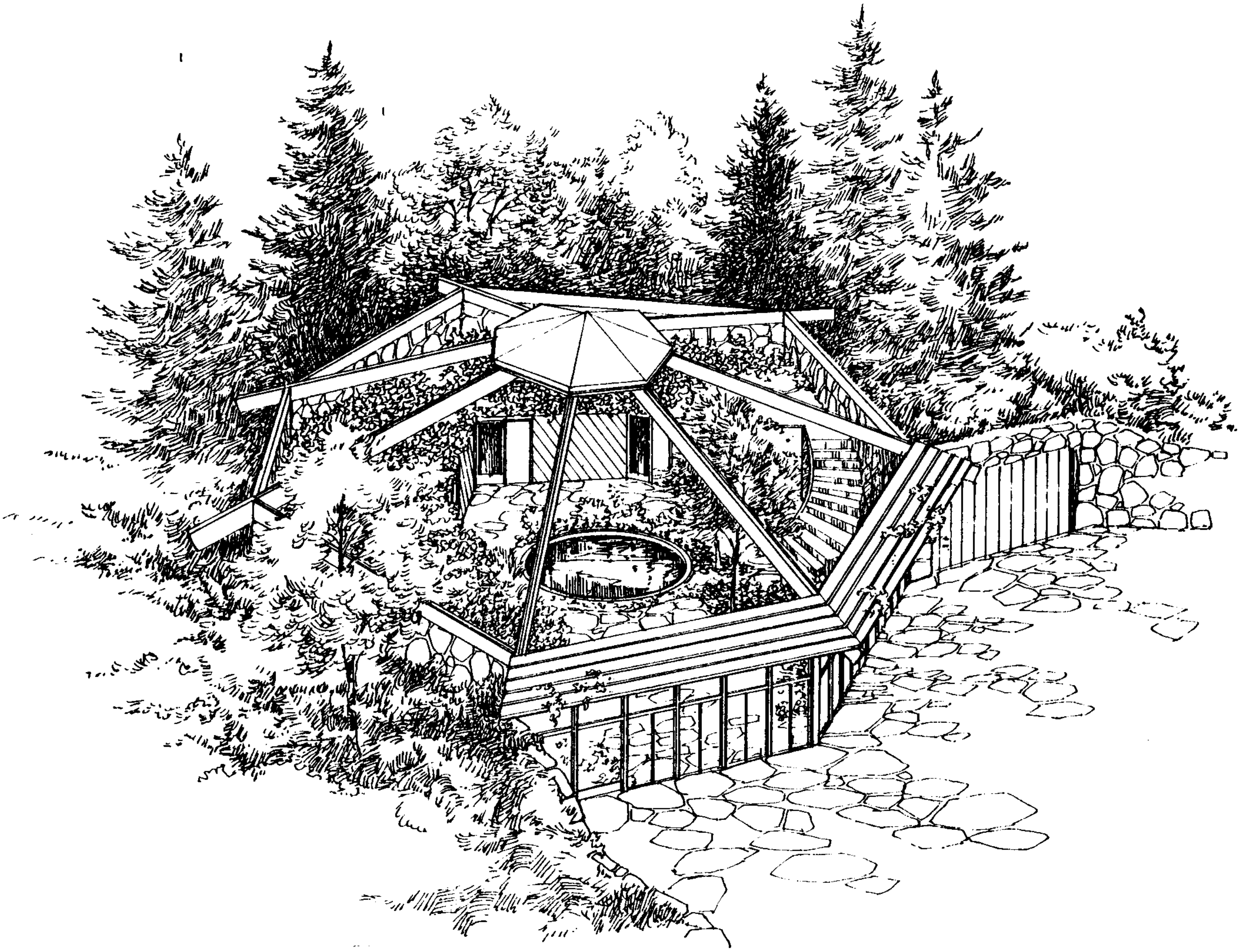

Fig. 4. Typical climatic envelope

A DESIGN SIZING PROCEDURE FOR DIRECT GAIN, THERMAL STORAGE WALL, ATTACHED GREENHOUSE, AND ROOF POND SYSTEMS

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ABSTRACT

Following a two-year research program a design and sizing procedure for passive solar heating systems has been prepared. This procedure contains 28 rules-of-thumb that form a step-by-step process for the integration of passive solar concepts in building design.

To generate data for the formulation of this process, an analytical solution for a simplified model of direct gain, thermal storage wall, and attached greenhouse systems was developed [1]. Each system was simulated by computer and analyzed for various parameters of latitude, weather conditions, collector to floor area ratios, space heat loss, materials, and building configurations. When possible, the results of these simulations were verified by empirical data.

INTRODUCTION

Architecture in the 20th Century is characterized by an emphasis on technology to the exclusion of other values. In the built environment it manifests itself in the materials we build with, such as plastics and synthetics. Also, there is an existing dependence on complete mechanical control of the indoor environment rather than on exploitation of climatic and other natural processes to satisfy our comfort requirements. In a sense, we have become prisoners of complicated mechanical systems, since windows must be inoperable and sealed in order for these systems to work. A minor power or equipment failure makes these buildings uninhabitable. Today, the unique character and variation of local climate and building materials are completely ignored. We can now see essentially the same building from coast to coast.

This paper supports a new orientation toward architecture. It describes a process for designing buildings that is strongly related to site, climate, local building materials, and the sun. It implies a special relationship to natural processes that offer the potential for an inexhaustible supply of vital energy. This relationship provides the basis for the design of passive solar buildings.

At present, information concerning passive systems is overcomplicated; it is dispersed and presented in a format that makes it nearly impossible for people to use. This not only affects the widespread application of these systems but also limits their potential for changing our present methods of building. The following process includes a design and sizing procedure that has been developed to synthesize and simplify technical information so it becomes accessible to a large spectrum of people.

THE PROCESS

All acts of building, no matter how large or small, are based on rules-of-thumb. Architects, contractors, mechanical engineers, and owner-builders design and build buildings based on the rules-of-thumb they have developed through years of their own or other people's experience. For example, a rule-of-thumb to determine the depth of 2-inch floor joists is given as <u>one-half the span of the joists (feet) in inches</u>, or to span a 20-ft space one would need roughly 2 x 10 inch joists. Calculations are used to verify and modify these rules-of-thumb after the building has been designed. We call these rules-of-thumb "patterns" [2]. Each pattern tells us how to perform and combine specific acts of building. We all perceive these patterns in our minds. They are the accumulation of our experiences about the design and construction of buildings. The quality of a building, whether it works well or not, will depend largely upon the patterns we use to create it.

To be useful in a design process, rules-of-thumb must be specific, yet not too specific. For example, if you are required to know the heat loss of a space before applying a rule-of-thumb to size south-facing glass areas, then the rule-of-thumb is too specific and of little use since a building has not yet been defined. If, on the other hand, the rule-of-thumb recommends a rough size of glass needed for each square foot of building floor area, then the glass can be incorporated into the building's design. After a preliminary design is completed, then space heat loss can be calculated and the glazing areas adjusted accordingly.

The patterns give rules-of-thumb for sizing various passive systems. Each system is sized so it supplies enough heat on an average sunny-winter day to maintain a space temperature of 70°F. Because these design-day data are used, the system will not perform as effectively under more severe conditions although the massive nature of passive buildings tends to moderate the effects of weather extremes. After a system has been designed for this optimum comfort condition, the percentage of the annual heating requirement supplied by the system can then be calculated. If a larger annual heating contribution is desired, then the system can be adjusted accordingly; however, it can be expected that, with a larger system, overheating will occur under average clear-day winter conditions. As a space becomes too warm, heated air is vented by opening windows or activating an exhaust fan to maintain comfort. This will reduce the system's efficiency as valuable heat is allowed to escape.

The design and sizing procedure generated for passive systems contains 28 patterns. The patterns are ordered in a rough sequence, from large-scale concerns such as sizing collector areas (glazing), to smaller ones such as the location, thickness, and surface color of a thermal storage mass. Together the patterns form a coherent picture of a step-by-step process for the design of a passive solar heated building.

The following is a list of patterns that make up this procedure. They are divided into three major groups. First are the patterns which give the building its overall shape and fix its position on the site according to the sun, wind, and trees:

1. Building location
2. Building shape and orientation
3. North side
4. Location of indoor spaces
5. Protected entrance
6. Window location

Second are patterns which provide criteria for the selection of a passive system and give specific details for its design.

7. Choosing the system

Direct Gain Systems

8. Solar windows
9. Clerestories and skylights
10. Masonry heat storage
11. Interior water wall

Thermal Storage Wall

12. Sizing the wall
13. Wall details

Attached Greenhouse

14. Sizing the greenhouse
15. Greenhouse connection

Roof Ponds

16. Sizing the roof ponds
17. Roof pond details

Greenhouse

18. South-facing greenhouse
19. Greenhouse details
20. Combining systems
21. Cloudy day storage

Third are the patterns that provide instructions to make the buildings more efficient as a passive system:

22. Movable insulation
23. Reflectors
24. Shading devices
25. Insulation of the outside
26. Location of trees and vegetation
27. Summer cooling
28. Appropriate materials

Each design pattern defines a problem and includes a rule-of-thumb which recommends a specific act of building to solve the problem. For example, the problem statement for Solar Windows states that "direct gain systems are currently characterized by unusually large amounts of south-facing glass." The recommendation gives the following table for sizing south-glazing:

SIZING SOLAR WINDOWS FOR DIFFERENT CLIMATIC CONDITIONS[a]

Average Winter Outdoor Temperature (Degree Days/Month)	Square Feet of Window[b] for Each Square Foot of Floor Area
Cold Climates	
15° F (1500)	0.27 to 0.42[c]
20° F (1350)	0.24 to 0.28[c]
25° F (1200)	0.21 to 0.33
30° F (1050)	0.19 to 0.29
Temperate Climates	
35° F (900)	0.16 to 0.25
40° F (750)	0.13 to 0.21
45° F (600)	0.11 to 0.17

[a] These ratios apply to a residence with a space heat loss of 8 to 10 Btu/day-square foot - °F. If space heat loss is less, lower values can be used. These ratios can also be used for other building types having similar heating requirements. Adjustments should be made for additional heat gains from lights, people, etc.

[b] Within each range, choose a ratio according to your latitude: i.e., 35° NL, use the lower window to floor area ratios; for northern latitudes, i.e., 48° NL, use the higher ratios.

[c] With night insulation over glass.

For example, in Seattle, Washington, at 47° NL with an average January temperature of 38.9° F, a well insulated space needs approximately 0.22 sq ft of south-facing glass for each square foot of building floor area. (A 200 sq ft space needs 44 sq ft of south-facing glass.)

After sizing Solar Windows, a portion of the sunlight (heat) admitted into each space must be stored for use during the evening hours. The pattern Masonry Heat Storage states that "the storage and control of heat in a masonry building is the major problem confronting the designers of a direct gain system." The recommendation gives the following rule-of-thumb:

> To minimize indoor temperature fluctuations, construct interior walls and floors of masonry with a minimum of 4 inches in thickness. Diffuse direct sunlight over the surface area of the masonry by using either a translucent glazing material; by placing a number of small windows so that they admit sunlight in patches; or by reflecting direct sunlight off a light colored interior surface first, thus diffusing it throughout the space. Use the fol-

lowing guidelines for selecting interior surface colors and finishes:

1. Choose a dark color for masonry floors.
2. Masonry walls can be any color.
3. Paint all light-weight construction (little thermal mass) a light color.
4. Avoid direct sunlight on dark colored masonry surfaces for long periods of time.
5. Do not use wall-to-wall carpeting over masonry floors.

Also included in each pattern is a visual description of the recommendation along with all the information available at this time for that particular aspect of the building design.

Patterns can also be used to analyze (diagnosis) existing buildings or proposed designs. It is possible to look at a building pattern by pattern and see which patterns are present and which are missing. In this way changes or repairs necessary to improve the building can readily be seen.

CONCLUSION

Since a building, or some element of it, is the passive system, the use of passive solar energy must be included in every step of a building's design. Whereas the application of conventional or active solar heating systems can be somewhat independent of the conceptual organization of a building, it is extremely difficult to add a passive system to a building once it has been designed. The format outlined here provides a method for including technical information in a way that can be applied by architects, builders, and owner-builders.

NOTES

1. See E. Mazria, M. S. Baker, and F. C. Wessling: "Predicting the Performance of Passive Solar Heated Buildings," Second National Passive Solar Conference, Philadelphia, Pennsylvania, March 17, 1978.
2. A complete definition of a pattern can be found in Christopher Alexander's The Timeless Way of Building, New York, N.Y., Oxford University Press, forthcoming.

Author's Note: Information for this paper is excerpted and condensed from Edward Mazria's book, The Passive Solar Energy Book, Rodale Press, Emmaus, Pennsylvania, October 1978.

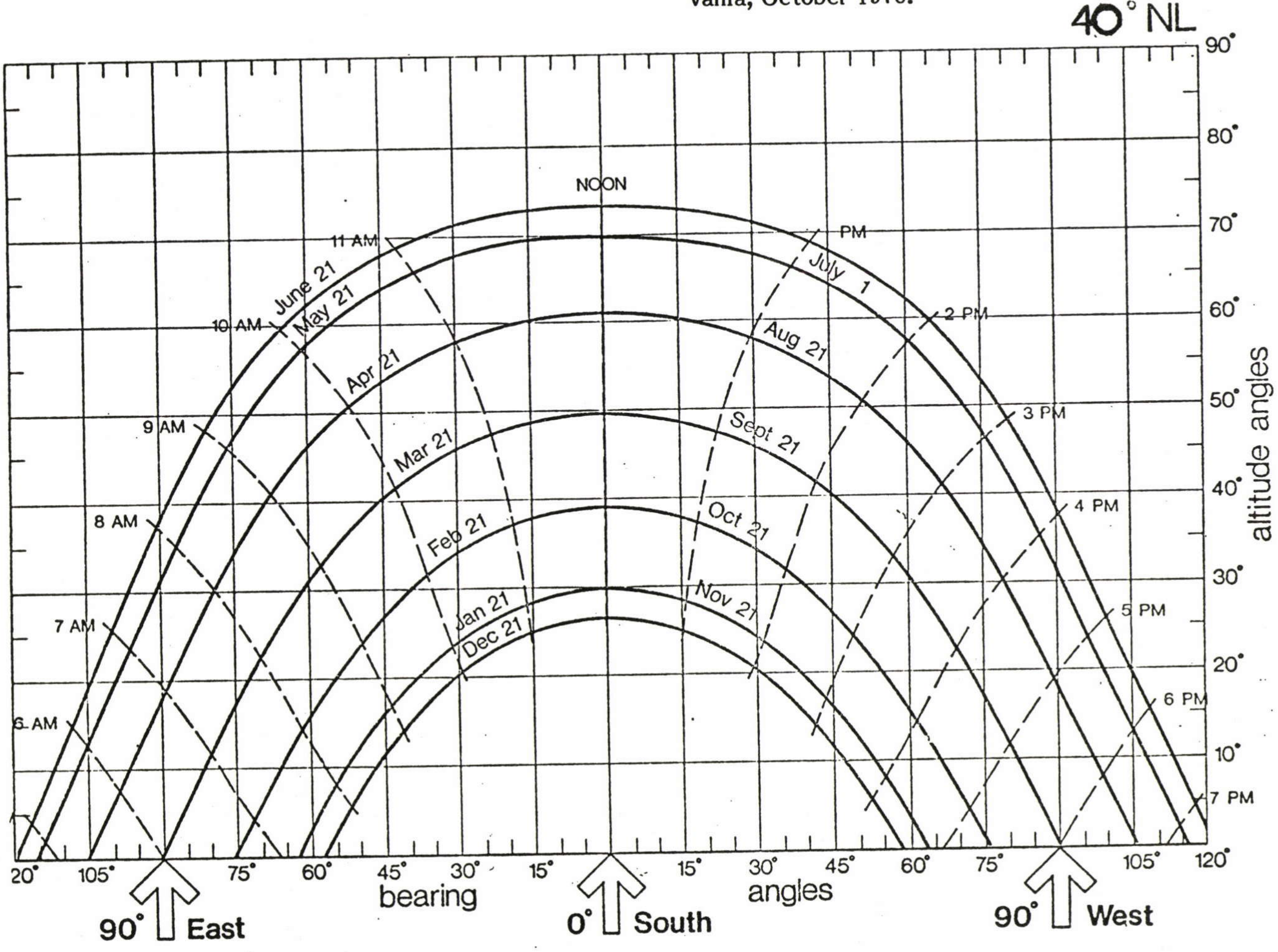

Fig. 1. Completed sun chart

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FENESTRATION AND HEAT FLOW THROUGH WINDOWS

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INTRODUCTION

Fenestration is conventionally defined as "the arrangement and proportioning of windows" but in solar technology it has taken on a much wider meaning. Windows have become the most vital as well as the most vulnerable parts of modern buildings. They admit light and air; maintain contact with the world outside; and, under favorable circumstances, can provide much of the heat needed to keep the building's occupants comfortable. They are also the principal contributors to heat losses when they are not sunlit, and they are almost the only building component which is subject to breakage by natural phenomena or vandalism.

The flow of heat and light through fenestration is determined by its thermal resistance and its solar-optical properties. These have been studied in great detail during the past 30 years by volunteer committees of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and a large amount of fenestration information is readily available in ASHRAE publications [1]. The purpose of this paper is to show where it can be found and how it can be put to work.

FENESTRATION FUNDAMENTALS; HEAT FLOW WITHOUT SUNSHINE

Heat flow through windows is caused by (A) conduction, plus radiation and convection, between the indoor and the outdoor air, and (B) admission of shortwave solar radiation. At night, when there is no solar radiation, the governing equation is very simple:

$$Q = AU(t_i - t_o) = A(t_i - t_o)/R \qquad (1)$$

where Q = heat flow rate, Btuh
(Btuh is ASHRAE's symbol for Btu/hr)

A = area of the glazed surface, ft^2

U = overall coefficient of heat transfer, $Btuh/ft^2F$

R = thermal resistance, $F/(Btuh/ft^2) = 1/U$

t_i, t_o = indoor and outdoor air temperatures

The indoor temperature in Eq. 1 is set by convention, codes, or comfort; it is generally assumed that 72 F is satisfactory in winter (70 F would be just as good, and less costly to maintain) while 78 F to 80 F is acceptable in summer, particularly if there is some air motion. Outdoor temperatures are highly variable, and the building occupant must accept what nature gives him since he has no way to control the weather. What has happened in the past in a specific location, as recorded by the local office of the National Weather Service, is the best indication of what is likely to happen in the future.

Both the U-factor and the thermal resistance, R, include air-to-surface heat transfer both indoors and out. U-factors have been well known to air conditioning engineers for half a century, but the significance of the thermal resistance, R, is not as well recognized. Whereas the U-factor is the rate in Btuh at which heat will flow through 1 sq ft of a particular building component when the temperature difference between the indoor and the outdoor air is 1 F, the thermal resistance R is the temperature difference, in degrees F, required to cause heat to flow through that square foot at the rate of 1.0 Btuh.

Each element in a building component has its own individual resistance which is designated by R with an appropriate subscript. The total resistance R_t is the sum of the individual resistance and the overall coefficient U is simply the reciprocal of R_t. For a single-glazed window, as shown at A in Fig. 1, where t_i is assumed to be higher than t_o, heat is transferred to that window surface by radiation from the other surfaces within the room and by convection from the indoor air. In engineering computations, these two processes are lumped together since it is very difficult to separate them experimentally and combined surface coefficients h_i and h_o are employed:

$$Q = Ah_i(t_i - t_{gi}) = Ah_o(t_{go} - t_o) \qquad (2)$$

where t_{gi} and t_{go} are the temperatures at the indoor and outdoor glazing surfaces. When the rate of heat flow, Q, has been found by the use of Eq. 1, both of the glass surface temperatures can also be found by rearranging Eq. 2:

$$t_{gi} = t_i - Q/(Ah_i); \quad t_{go} = t_o + Q/(Ah_o) \qquad (3)$$

Two values of h_o were adopted many years ago as standard by the ASHRAE Technical Committee on Fenestration. In winter it is assumed that the wind will blow at 15 mph and for that speed, smooth surfaces such as glass have an outer surface combined coefficient of 6.0 $Btuh/(ft^2F)$. In summer, for most parts of the United States, wind speeds are generally lower; and, in recognition of this fact, a wind velocity of 7.5 mph is assumed to prevail. This results in a value of 4.0 $Btuh/(ft^2F)$ for

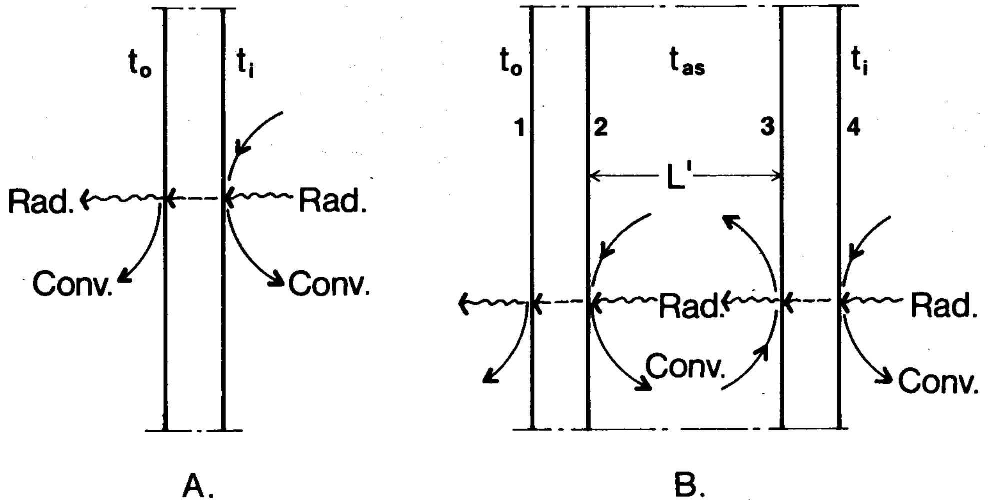

Fig. 1. Single and double glazing, showing methods of heat transfer when the sun is not shining

h_o. The surface resistances, R_o, are thus 1/6 = 0.17 F/(Btuh/ft^2) for winter and 1/4 = 0.25 in summer. For other wind speeds, h_o may be found from:

$$h_o = 2.0 + 0.267 \text{ (wind speed, mph)} \qquad (4)$$

The conventional values of h_o do not pay much attention to the radiation component of the heat flow from or to the window surface, but this is not a serious defect as long as there is some wind. For still air, the effect of the "sky temperature" becomes significant.

For the inner surface coefficient, h_i, the conventional ASHRAE value is 1.46 Btuh/(ft^{2}F), which is actually appropriate for two very different situations. It is correct in winter when t_g is 20 F and t_g is 70 F, and it is correct again in summer when t_g is 90 F and t_i is 75 F. The thermal resistance R_i is 1/1.46 = 0.68 at these conditions, but it can range from 1/1.79 = 0.56 F/(Btuh/ft^2) for very hot glass in summer to 1/1.25 = 0.80 on very cold nights in winter [2].

The thermal resistance of a solid material such as glass is:

$$R_g = \text{thickness/thermal conductivity} \qquad (5)$$

Glazing materials are generally quite thin as compared with other building components, and their thermal conductivity is moderately high, again as compared with other building materials which are good insulators. For double strength window glass, the thickness is 0.125 in. and the thermal conductivity is about 7.5 Btuh/[ft^2(F/in.)], so its thermal resistance is only 0.125/7.5 = 0.017.

The summer U-factor for a window glazed with double strength glass is found from:

$$R_t = R_o + R_g + R_i = 0.25 + 0.017 + 0.68 = 0.947$$

$$U = 1/R = 1/0.947 = 1.06$$

For 1/4 in. architectural glass, R_g = 0.034 and R_t = 0.964, so U = 1/0.964 = 1.037.

The ASHRAE tabulated values of U (see Ref. 1, Table 13, p. 26.10) pay little attention to the glass resistance. If there were indeed a glass with zero thermal resistance, the summer U would become 1.08 and the winter U would be 1.18, which is just about as high as U can get! For glazings other than single uncoated glass, the values in Table 1 apply.

Radiation plays a very important part in heat transfer at the indoor surface of single glazing and at the air space and indoor surfaces of multiple glazing. Uncoated glass has been shown [2] to have a hemispherical emittance of 0.84 at the temperature levels encountered in glazing. At 100 F glass temperature and 80 F indoor temperature, the inner surface coefficient is 1.545 Btuh/(ft^{2}F), and 0.975 Btuh of this, or 63%, is due to radiation. If the glass is coated with a low emittance substance such as gold or silver, the radiation component at this condition could be reduced to about 0.12 Btuh. The combined coefficient, h_i, would be 0.69 and the inner surface resistance would be 1/0.69 = 1.46 F/(Btuh/ft^2), which is more than twice as great as the resistance of the uncoated glass. The total resistance of the coated glass would be (at 1/4 in. thickness) R_t = 0.25 + 0.03 + 1.46 = 1.74; U = 1/1.74 = 0.57, which is about half of the U-factor for uncoated glass.

The drawback to the use of coated glass is the fact that it reduces the capability of the glass to transmit solar radiation by about 20% and that may result in a net loss of heating capability.

The use of reflective coatings on an air-space surface of multiple glazing results in a substantial reduction in its U-factor. Most coatings now available, however, are reflective to solar radiation and thus their transmittance is reduced. This may be desirable when "sun control" is the primary quality which is sought, but it is very undesirable when admission of solar radiation is needed for winter heating requirements.

To summarize the heat transfer situation due to temperature differences between indoor and outdoor air, Eq. 1 gives the hourly rate of heat flux in Btu per square foot for a specified temperature difference. The <u>design</u>

Table 1. U-FACTORS AND RESISTANCE FOR WINDOWS GLAZED WITH GLASS AND ACRYLIC OR POLYCARBONATE SHEET; NO INTERNAL OR EXTERNAL SHADING

	Single Glazing				Double Glazing 1/2-in. air space			
	Summer		Winter		Summer		Winter	
	U	R_t	U	R_t	U	R_t	U	R_t
Glass, any thickness	1.04	0.96	1.10	0.91	0.56	1.79	0.49	2.04
low emittance coating, e = 0.20					0.38	2.63	0.32	3.13
Acrylic or pcb								
1/8 in.	0.98	1.02	1.06	0.94	0.50	2.00	0.47	2.13
1/4 in.	0.89	1.12	0.96	1.04	0.45	2.22	0.43	2.33

heat flow through the glazing is found by using the specified indoor temperature, generally 72 in winter and 78 in summer, and selecting the design temperature from the ASHRAE table [1] which lists both summer and winter values for most of the major cities in the United States and many in foreign countries.

The daylong heat flow is found by using the average outdoor air temperature for the day under consideration and multiplying the hourly heat flow rate by 24 hours/day:

$$Q = 24Au(t_i - t_{ave}) \qquad (6)$$

For windows with movable insulation, Eq. 6 must be modified to recognize the fact that for X hours per day, the coefficient of heat transfer will be U_X, while for (24 - X) hours, there will be a different value of U. The outdoor temperature must be treated in similar manner to obtain consistent results.

U-factors for movable insulation may be calculated readily by employing the resistance concept, and remembering that the resistance of a piece of insulating material is simply its thickness in inches divided by its thermal conductivity. Air space resistances depend upon their width (up to about 1 inch; beyond that there is little change), their average temperature, and the emittance of their surfaces for longwave thermal radiation. The ASHRAE Handbook has an excellent collection of data on this subject.

As an example, consider a double glazed window with 1/2 in. air space, under winter conditions. Its U-factor, from Table 1, is 0.49 so its R_t is $1/0.49 = 2.04$ F/(Btuh/ft^2). If 1 in. of urethane foam insulating board is added, with its surface touching the glass, its additional resistance will be:

$$R_u = 1.0/0.16 = 6.25 \text{ and}$$

$$R_t = 2.04 + 6.25 = 8.29 F/Btuh/ft^2)$$

$$U = 1/R_{total} = 1/8.29 = 0.12 \text{ Btuh/ft}^2$$

A fourfold reduction in heat loss would result!

If an air space is left between the urethane slab and the glass, it would add about one unit of resistance and so U would be 1/9.29 = 0.11. If the urethane is clad with highly reflective aluminum foil, the air space resistance would go up to about 2.63 and R_t would rise to 10.92, giving a U-factor of 0.09, which compares favorably with a good opaque wall.

The most widely used movable internal insulation is a shade, a drape, or a venetian blind. If these are tightly drawn, with little edge air leakage, they will add about 0.29 unit of resistance [1]. The U-factor for single glazing in summer will fall from 1.04 Btuh/(ft^{2}F) to about 0.80. Miniature louvered sun screens, in close proximity to the window, will add about 0.24 F/Btuh/ft^2) of resistance to an existing window, in addition to making a drastic reduction in the solar heat gain. This is desirable in summer, but it may well be very undesirable in winter.

WHEN SUNSHINE FALLS ON WINDOWS AND WALLS

When the sun comes up and begins to shine on walls and windows, the heat transfer situation changes abruptly. The conduction gains or losses continue, but the solar radiation begins to make itself felt immediately. The nature of solar and thermal (longwave) radiation is shown in Fig. 2, in which the relative intensity of these two heat sources is plotted against the wavelength of the radiation. It is seen immediately that solar radiation extends from about 0.2 μm in the ultraviolet to a little beyond 3.0 μm in the near infrared, with maximum intensity near 0.5 μm in the green region of the visible spectrum. The response characteristic or "visibility function" of the average human eye is also shown; only the small portion of the spectrum between 0.4 and 0.7 μm excites the sensation of vision in the human eye, so only this radiation is properly called "sunlight."

The radiation emitted by a sun-heated surface has such long wavelength that there is no overlapping of solar

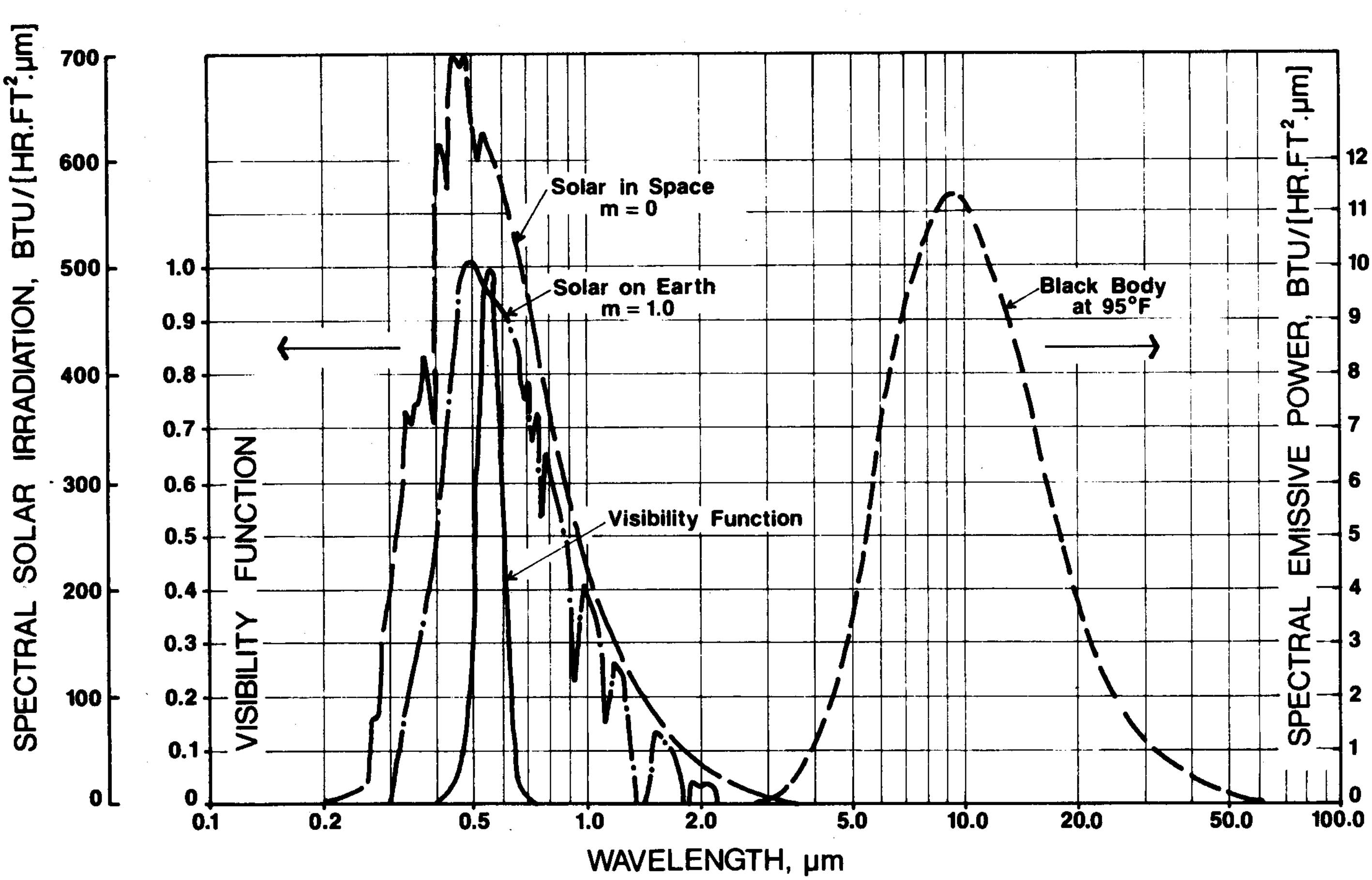

Fig. 2. Spectral distribution of solar radiation in space, air mass = 0, and on Earth at sea level, air mass = 1; the response of the human eye is shown as the "Visibility Function"; spectral distribution of infrared radiation from a sun-heated blackbody at 95 F

and thermal radiation. The energy emitted by a blackbody at 95 F has its peak intensity near 10 μm. Glass possesses the remarkable property of transmitting only shortwave radiation and there is no transmittance at all for wavelengths beyond 4 μm, as shown by the spectral transmittance curves of Fig. 3. A few of the many transparent plastic films and sheets resemble glass in this characteristic, but most of them have some "windows" in their spectral transmittance curves which allow some longwave radiation to be transmitted. It is for this reason that glass is such an effective "heat trap." It allows most of the shortwave solar radiation to enter the glazed space quite freely, but it does not allow any longwave radiation to escape by transmission.

When solar radiation falls upon a sheet of polished window glass, some of the radiation is transmitted, some is reflected, and some is absorbed. The three properties which control these phenomena—transmittance, reflectance, and absorptance—are called "solar-optical," because they are optical in nature; but they apply only to the solar portion of the radiation spectrum. They vary in magnitude with the thickness and surface treatment of the glazing; but, most of all, they vary as the incident angle θ changes. Figure 4 shows the angles which are used in quantitative solar technology, with the sun in the southwest quadrant of the sky and a vertical window receiving the solar radiation on its south-facing surface.

In Figure 4, line OQ is the earth-sun line, and OP is a line in the horizontal plane that is perpendicular (normal) to the glazed vertical surface. The angle of incidence θ is ∠QOP, between the earth-sun line and the normal to the surface. The solar altitude is ∠QOH and the solar azimuth is ∠HOS. The surface-solar azimuth, needed in some computations, is ∠HOP. Equations are readily available by which values of the incident angle may be calculated when the solar position angles and the surface azimuth are known [1], and tabulated values are also available in several ASHRAE publications [3] for both vertical and tilted surfaces for a wide variety of surface orientations.

The incident angle θ is particularly important because it controls the ability of the glazing material to transmit, reflect, and absorb the incoming solar radiation. Figure 5 shows the variation with incident angle of the solar-optical properties of three kinds of glass. Transmittance and reflectance remain nearly constant with rising θ until the 30° mark is exceeded and then the reflectance rises sharply to reach 100% at θ = 90°. At that point both transmittance and absorptance have dropped off to zero because none of the solar radiation is actually entering the glass. The absorptance rises somewhat beyond θ = 30°, primarily because the length of path through the glass goes up; beyond 60°, however, the absorptance falls off to zero, too.

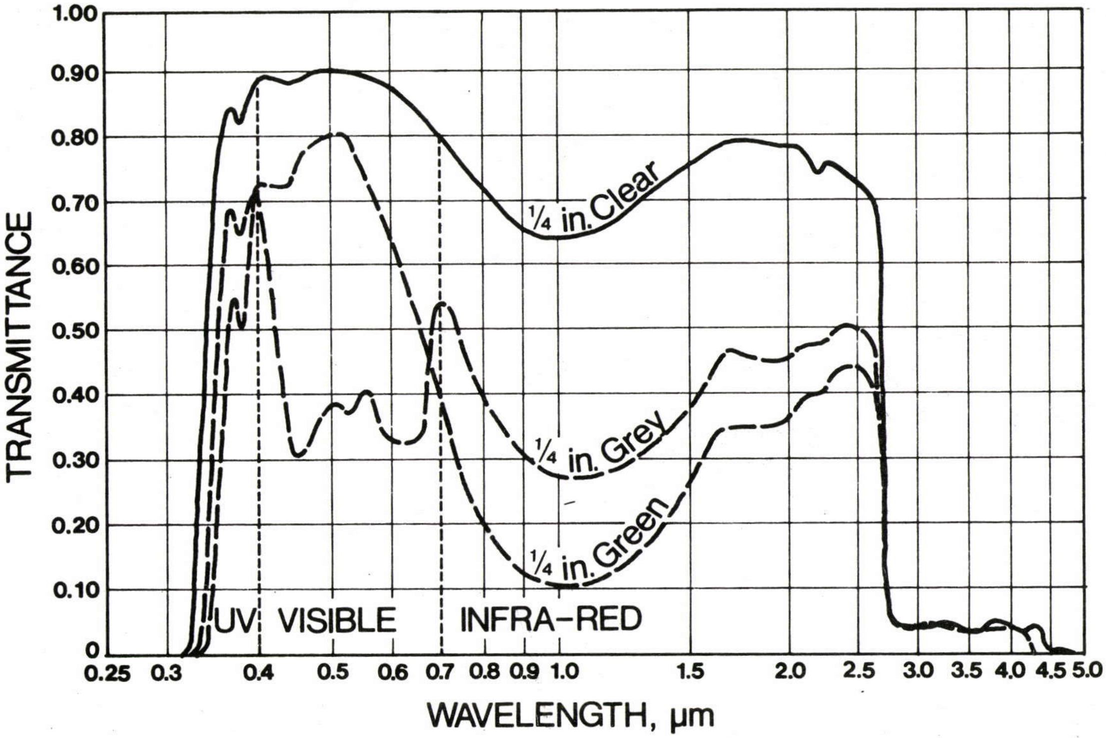

Fig. 3. Spectral variation of transmittance for three kinds of architectural glass; upper curve applies to 1/4 in. clear float glass, lower curves apply to 1/4 in. heat-absorbing grey and green float glass

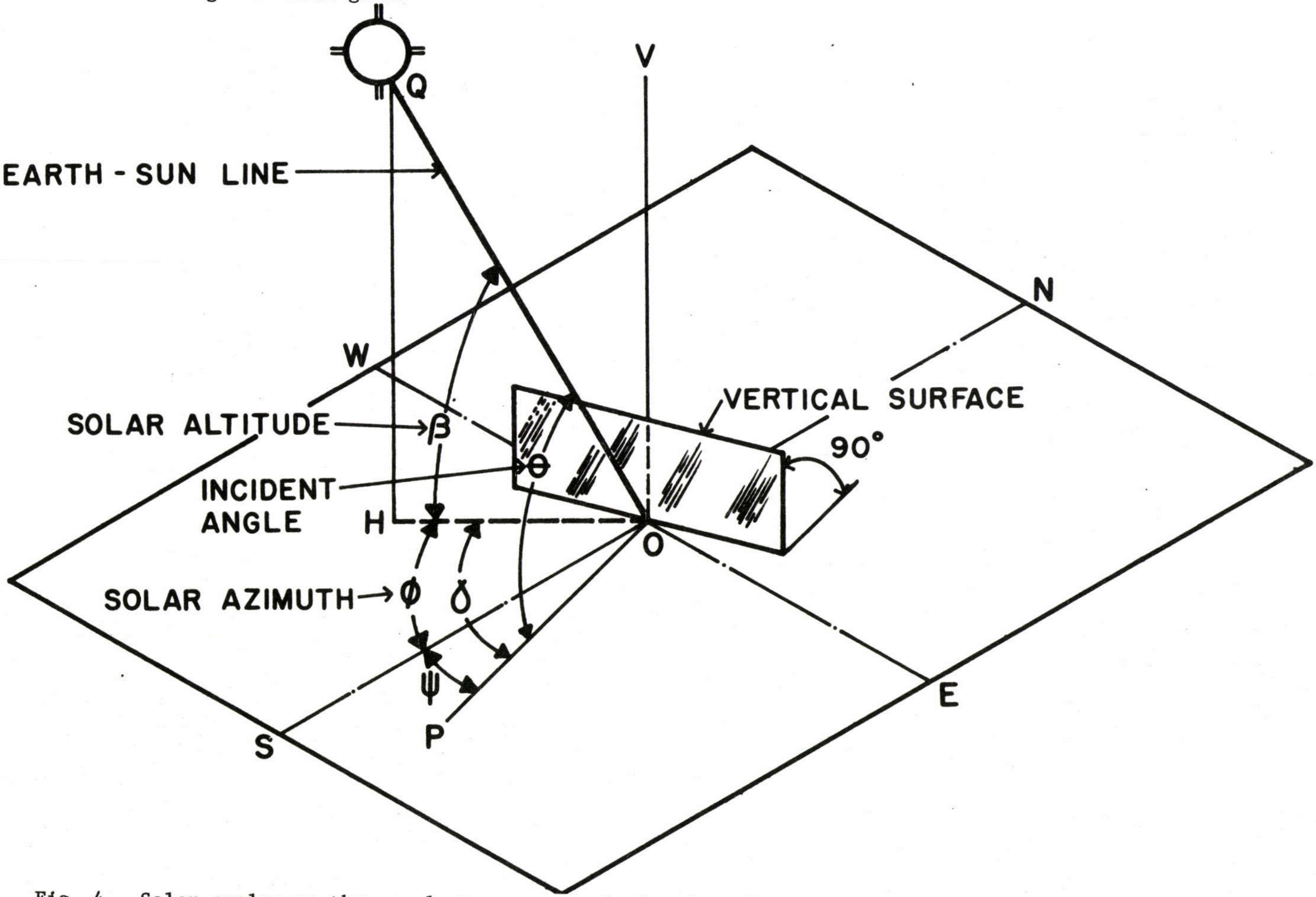

Fig. 4. Solar angles as they apply to a vertical glazed surface facing south southeast, ∠QOP is the incident angle, θ, between the earth-sun line, OQ, and the normal to the surface, OP

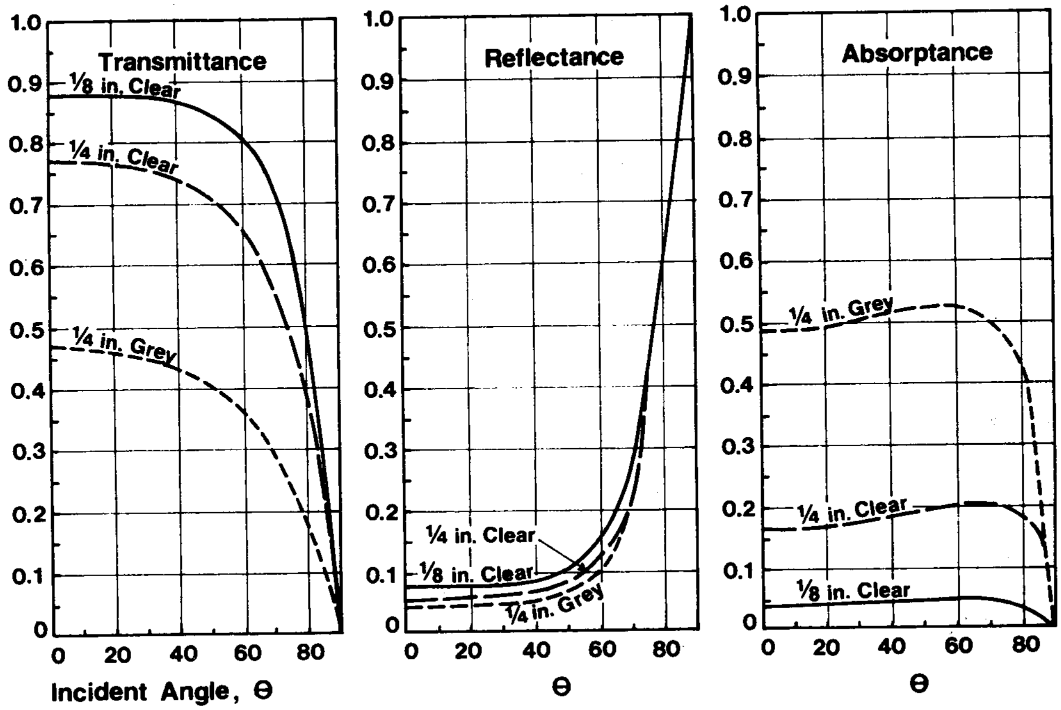

Fig. 5. Variation with incident angle of the solar-optical properties: transmittance, reflectance and absorptance for 1/8 and 1/4 in. clear glass and 1/4 in. heat-absorbing glass

The apparatus with which these measurements were made is shown in Fig. 6. It uses a silicon cell solar radiometer to measure the transmittance of glass or other polished materials at normal incidence and then, as the incident angle is increased by rotating the sample, the reflectance can also be measured by swinging the sensor arm around to allow it to "look at" the front of the sample and thus detect the reflected radiation. Called the TRA-Scope for obvious reasons, this instrument can determine all of the solar-optical properties for a sample in a matter of minutes.

The intensity of the sun's radiation depends primarily upon its altitude and that is a matter of latitude, date, and time of day. Tabulated values of clear day solar irradiance, incident angles, and solar position angles are given in ASHRAE publications [3] for latitudes from 0° to 64° N, by 8° increments, for the daylight hours of the 21st day of each month. These are average values for each date for the entire United States, and Clearness Numbers are provided to enable corrections to be made for locations which have exceptionally high or low atmospheric moisture contents.

When the incident angle and the total solar irradiance are known, the amount of solar radiation being admitted through sunlit glass can be estimated quickly by using Eq. 7:

$$\begin{array}{lllll} \text{Solar} & \text{Solar} & \text{Solar} & \text{Inward Flow} & \\ \text{Heat} = & \text{Radiation, x} & \text{Transmittance +} & \text{of Absorbed} & \\ \text{Gain} & \text{Btuh/ft}^2 & \text{at Angle } \theta & \text{Solar} & (7) \\ & \text{Radiation} & & & \end{array}$$

Using the conventional symbols, this becomes:

$$QS = (I_{t\theta})(\tau_\theta) + N_i(I_{t\theta})(\alpha_\theta) \qquad (8)$$

where I_t = total solar irradiance, Btuh/ft^2

$\tau_\theta, \alpha_\theta$ = transmittance and absorptance of glazing for solar radiation at incident angle θ

N_i = fraction of absorbed solar radiation that flows inward

Equation 8 can be solved readily for unshaded single glazing, but the addition of shading devices, double glazing, etc. complicates the situation to such an extent that another approach must be used, based on Eq. 8 and using the Shading Coefficient concept.

In 1963, D. J. Vild of LOF Glass Co. proposed that a new procedure be adopted by ASHRAE for estimating solar heat gains. He suggested that 1/8 in. clear window glass, with a normal incidence transmittance of 0.86, be used as the standard reference glass and that its Solar Heat Gain be calculated for a wide variety of latitudes, dates, and times of day. He had previously determined that the ratio of Solar Heat Gain through any kind of fenestration to the Solar Heat Gain through the reference glass was essentially constant. He gave the name "Shading Coefficient" to that ratio, and the calculated solar gain through the reference glass was called the "Solar Heat Gain Factor." The total heat gain through sunlit glass then became:

$$Q = (SC)(SHGF) + U(t_o - t_i) \qquad (9)$$

Shading Coefficients are now available for virtually every widely used combination of glass and shading

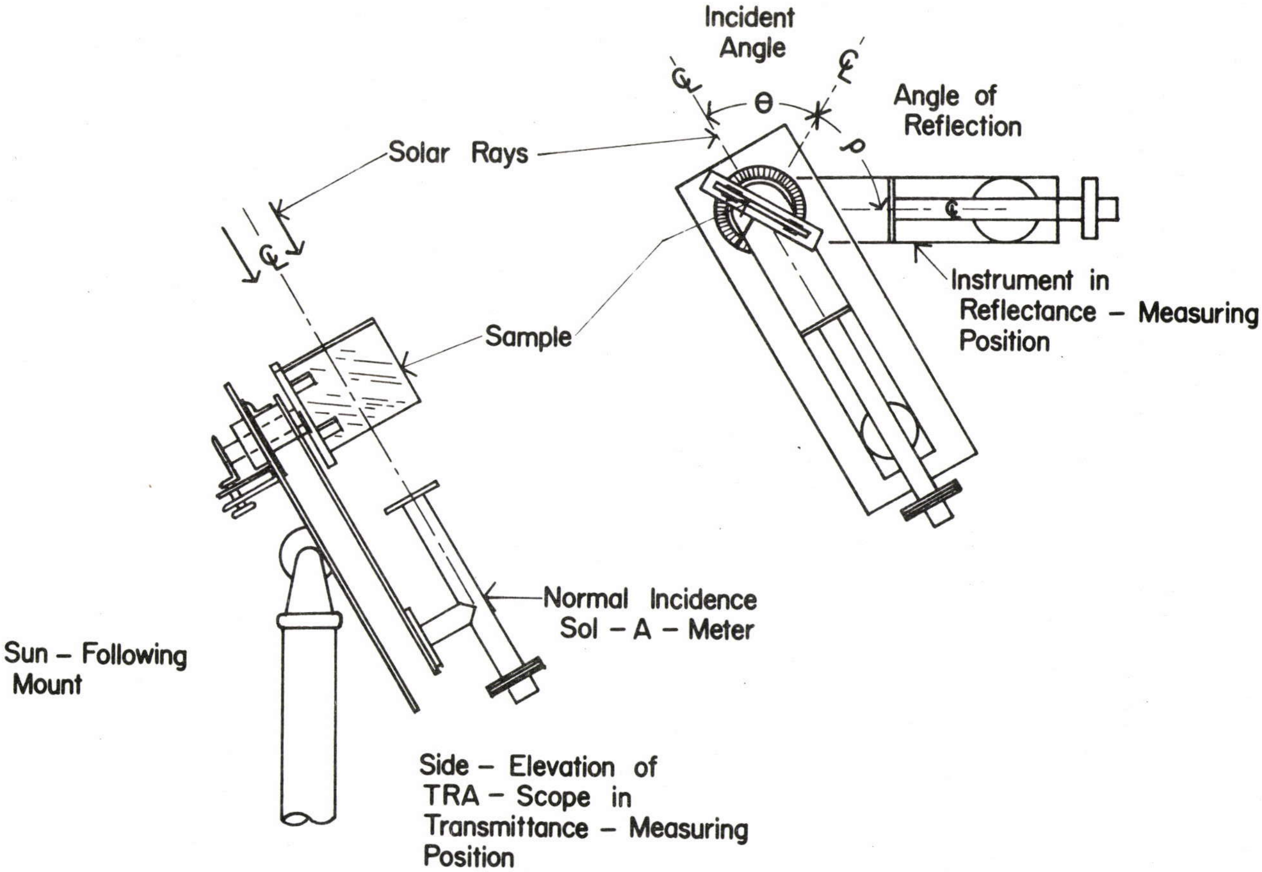

Fig. 6. The TRA-scope, an instrument for measuring transmittance and reflectance for polished glass. Absorptance is found from the equation: Absorptance = 1.00 - (Transmittance + Reflectance)

device, while Solar Heat Gain Factors are tabulated for vertical glazing with orientations at 22.5° intervals all around the compass, from North to North Northwest. These factors are available both for each hour of the day, when the sun is above the horizon, and in the form of integrated half-day totals. This format is needed because what happens to an east-facing surface at two hours before solar noon also happens to a west-facing surface at two hours after solar noon. To show how this information may be used, let us first consider the Shading Coefficients (Table 2) for commonly used glazing materials and then we will apply these to some typical problems.

EXAMPLES OF SOLAR HEAT GAIN CALCULATIONS

Using Denver as the location because it is at 40° N latitude and 105° W longitude and selecting January 21 with a daylong average temperature of 30 F as a good date for sample calculations, Table 3 shows the data for a vertical south-facing window.

Remembering that, from Table 2, SC = 0.94 for single 1/4-in. clear glass and 0.81 for double 1/4-in. clear glass, it is evident that the north-facing window will lose heat very rapidly if it is glazed with 1/4-in. glass and it will still lose heat, but less rapidly, if double glazing is used.

The east-facing window will gain heat until noon and then lose with both single and double glazing because, although the latter cuts the heat loss rate in half, it also reduces the Solar Heat Gain. The west-facing window loses in the morning and gains in the afternoon.

The south-facing window gains heat as long as the sun is in the sky. The net gain for the 8-hour period is:

Single-glazing: $0.94 \times 1626 - 8 \times 1.10 \times (72 - 32)$
$= 1528 - 352 = 1176$ Btu/ft^2

Double-glazing: $0.81 \times 1626 - 8 \times 0.49 \times (72 - 32)$
$= 1317 - 157 = 1160$ Btu/ft^2

For the entire day, assuming a 24-hour average temperature of 30 F, we would have:

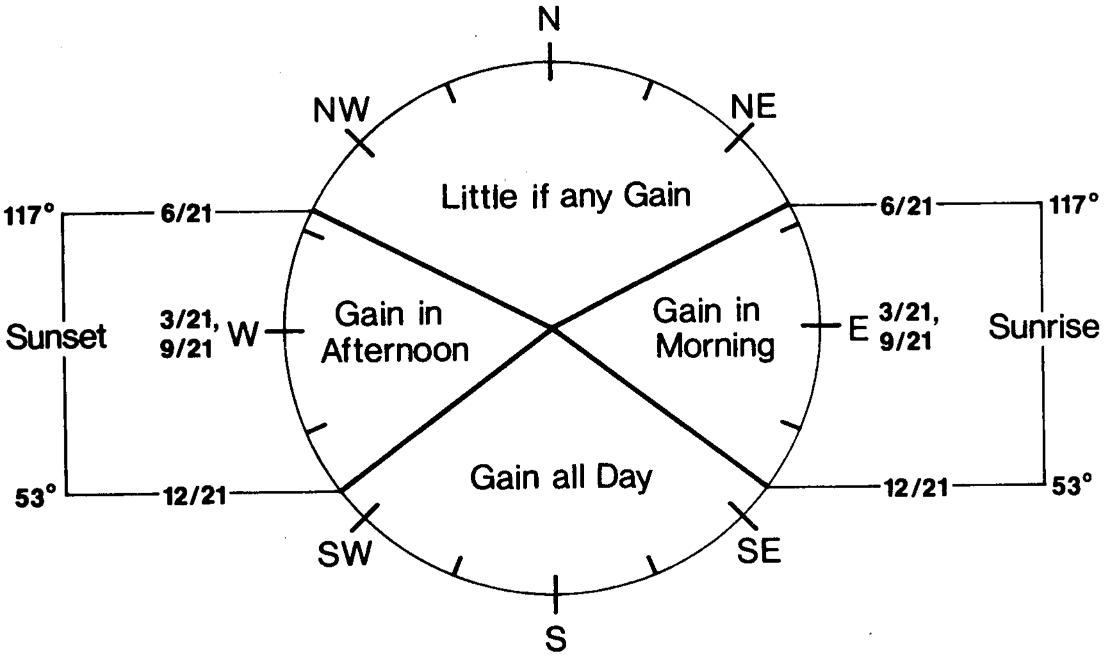

Fig. 7. The solar azimuth circle, showing solar position at sunrise and sunset on June 21 and December 21 for 40° N latitude. In winter, south-facing windows gain heat all day.

Table 2. SHADING COEFFICIENTS FOR TYPICAL GLAZING MATERIALS

Material, Thickness		Solar Trans. at normal incidence	Shading Coefficient, $h_o = 4.0$	3.0
Glass, clear	1/8 in.	0.86	1.00	1.00
" "	1/4 in.	0.78	0.94	0.95
Glass, Heat Abs.	1/4 in.	0.46	0.69	0.73
Acrylic, clear	1/8 in.	0.85	0.98	—
Polycarbonate, clear	1/8 in.	0.82	0.98	—
Glass, 1/4 +	1/4 in.	0.61	0.81	—

Table 3. SOLAR HEAT FACTORS FOR VERTICAL WINDOWS IN DENVER, JAN. 21, ESTIMATED AMBIENT AIR TEMPERATURES, F, AND HEAT LOSS RATES FOR SINGLE AND DOUBLE GLAZING

Time, 24 hr clock	08	09	10	11	12	13	14	15	16	
Temp., F., estimated	15	18	22	28	34	38	42	45	42	
Solar Heat Gain Factors, SHGF, Btu/(hr. ft^2)										Daylong Total, Btu/ft^2
North	5	12	16	19	20	19	16	15	5	(61 + 61 =122)
East	111	154	124	61	21	19	16	12	5	(452 + 62 = 514)
South	75	160	213	244	254	244	213	160	75	(813 + 813 = 1626)
West	5	12	16	19	21	61	124	154	111	(62 + 452 = 514)
Heat Loss Rate, Btuh/ft^2										
Single, (U = 1.10)	63	59	55	40	42	37	33	30	33	
Double, (U = 0.49)	28	26	25	18	19	16	15	13	15	

Single-glazing: 1528 Btu/ft^2 gain - 1.10 x 24 x (72 - 30) = 419 gain

Double-glazing: 1317 Btu/ft^2 gain - 0.49 x 24 x42 = 823 gain

It is apparent that movable insulation will be needed to make the south-facing windows pay dividends and that the double glazing will pay off primarily because of its reduced heat loss, as compared with the single glazing, on cloudy days.

CONCLUSIONS

Simplified methods are available in the ASHRAE Handbook of Fundamentals by which heat gains and losses through fenestration may be estimated with good accuracy. During the hours when fenestration is sunlit by direct irradiation, the heat gains more than offset the losses, but during the hours when the glazing receives only diffuse radiation because it is in the shade, the losses may exceed the gains. Movable insulation is virtually a necessity in cold climates if the heat gain during the day is to remain significantly greater than the heat lost at night.

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POTENTIAL OF UPFLOW STORAGE SYSTEMS FOR NATURAL CONVECTION COLLECTORS

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Figure 1 illustrates a natural convection solar heating system utilizing a rock bed storage [1]. As the air picks up heat in the collector, it rises. As the air gives off its heat to the rock, it falls. Thus a continuous convective flow is established which puts the solar energy into storage. During nongain periods, dampers are used to close the collector-storage loop (to prevent reverse convection through the cold collector), and other dampers between the storage and house are opened to establish a second convective loop which heats the house. This arrangement has been used in several homes and has proved very satisfactory.

Because the efficiency of any collector is relative to its flow-rates and because the flow-rate in a convection system is wholly dependent on the difference in density, or weight of the air between the two sides of the loop, it is wise to place the storage mass as high as possible relative to the collector [2]. Placing the storage mass entirely above the collector also offers the possibility of having a self-damping system.

Figure 2 shows schematics of two natural convection systems with the storage above the collectors. Drawing A shows a similar flow pattern to Fig. 1 with the air giving off its heat to the storage on the downflow. But having the storage entirely above the collectors suggests the possibility of channeling the hot air upward through the storage as in drawing B (to keep the storage orientation the same as in 2-A, 2-B is illustrated with a center-glazed collector that flows counterclockwise instead of clockwise but with nearly identical performance characteristics) [3]. On a purely conceptual level, where it is assumed that both the collectors and storages will function equally in A and B, the overall system performance of the two different geometries should be equal. Although A has a longer travel of hot air in the system, B has a longer travel of cold air, and the overall average ΔT between the two sides of the loop, which provides the driving force for the flow and hence regulates efficiencies, should be the same.

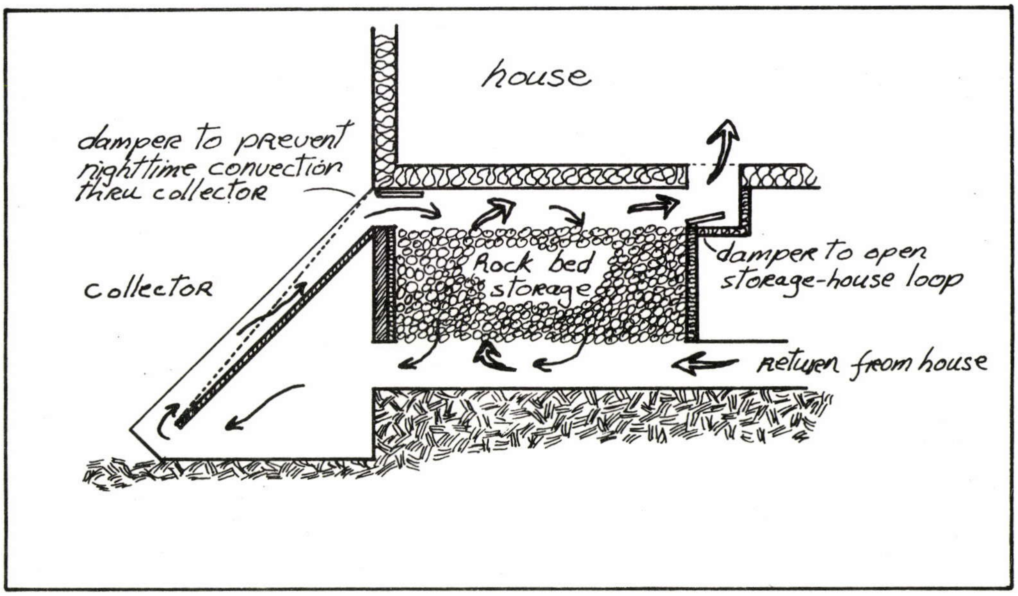

Fig. 1. Natural convection collector with rock bed storage

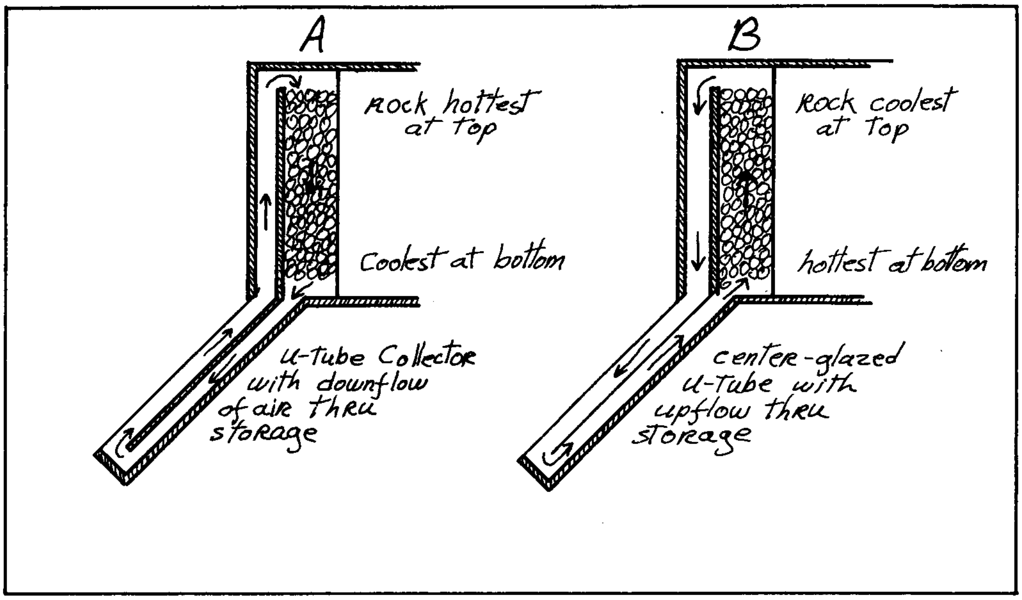

Fig. 2. Downflow and upflow storage systems

Generally, an upflow of hot air through rock storage is avoided for two reasons. First, in a downflow system the air cannot fall until it has lost some of its heat to storage, so the air will seek the coolest parts of storage, and good even transfer is almost assured. In an upflow situation, however, the hot air would prefer to bypass storage altogether or to follow "hot-spots" on its upward path. If this occurs, transfer into storage is poor, and the air going back to the collector will be hotter, thus reducing the collector efficiency. This problem is minimal in tall storage beds but remains a major consideration.

Second, upflow systems put more heat into the bottom of storage than into the top. If the heat is then being recovered from storage by convection, some of the heat removed by the air from the lower portion of storage goes into heating the upper portion of storage before entering the room. If natural convection is used for this recovery, it may be that the increased flow rates due to immediate heating of the lower air in storage will offset the cooler outlet temperatures. This deserves more study.

If, however, the heat from storage is recovered by radiation rather than by convection, this inverted heat stratification becomes an asset. Having the warmest portion of a radiant wall at the bottom tends to reduce the stratification of air within the room (cold feet syndrome) and provides a more comfortable environment. In order to recover this heat easily by radiation, the storage system must take a different geometry. Instead of compact beds of rock, we would want tall, flat wall areas or multiple tubes of rock, to expose as much surface area as possible.

The net result of such a radiant heating design would be similar to that of a Trombe-type wall. Although more difficult to construct, it does have two distinct advantages. First, because the storage is isolated from the collector, the glazing is not a source of heat loss at night. In some designs, simple backdraft dampers would have to be installed, but this is considerably easier and less expensive than nighttime insulation on Trombe-type walls.

Second, the storage wall does not have to be placed in direct sunlight. Within the geometric constraints of a natural convection system, the storage wall may be located in any portion of the building.

Figure 3 illustrates one possible design for this type of system. The mass wall is placed in the center of the building (which allows direct gain from the south wall if wanted) and provides radiant heat to a north room. Ducts under the floor (perhaps using the space between floor joists) carry the air between collector and storage wall. Use of either a standard U-tube collector (Fig. 2A) or the center-glazed U-tube (Fig. 2B) allows a great deal of flexibility in the overall design.

Figure 4 illustrates the north wall of a building being used as the storage wall coupled to a standard U-tube collector. Either type of collector could also be used with a storage wall designed to provide radiant heat to both sides (Fig. 5).

Figures 3, 4, and 5 are all closed loops between collector and storage. In an actual system, it would be useful to install dampers at appropriate points to enable the inhabitant to "short circuit" the loop and heat the building directly with hot air from the collectors. Another possible design uses the building itself as part of the loop (Fig. 6). Here the air exiting from storage passes through the building before re-entering the collector. The ductwork is minimized, the collector will function at somewhat higher efficiencies because it is heating the coolest air in the building, and it becomes easy to design a "double-faced" radiant storage wall. Two problems may be encountered in such a scheme. If the storage to collector ratio is undersized or the transfer in the storage is poor, the air traveling through the building may cause overheating. Also, such a system will have a slight tendency to draw air through the collec

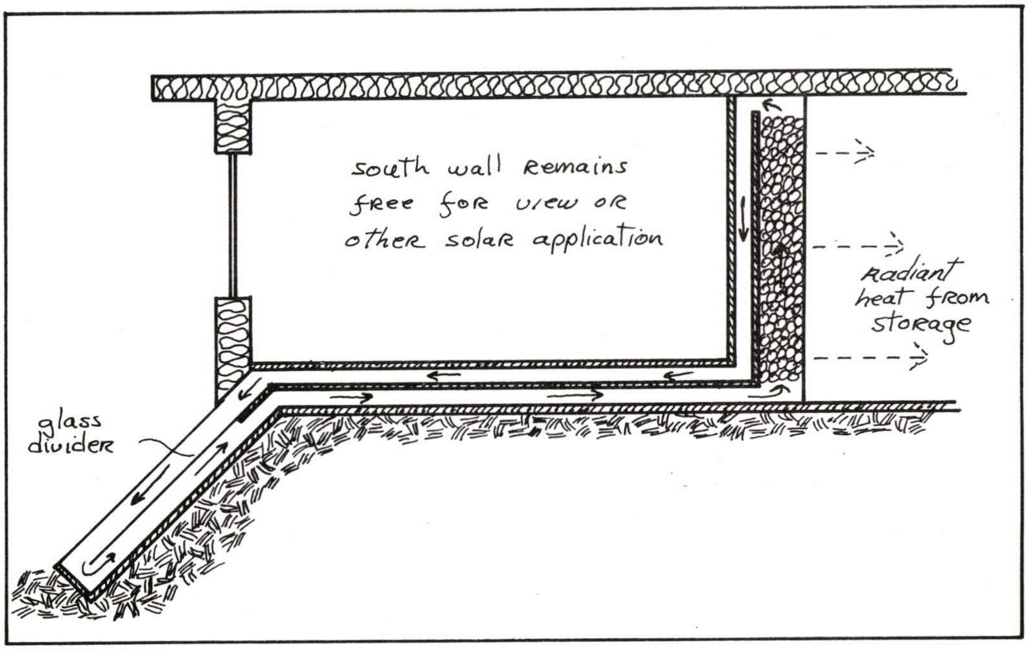

Fig. 3. Center-glazed U-tube collector with upflow storage. Designed to provide radiant wall heat to north room.

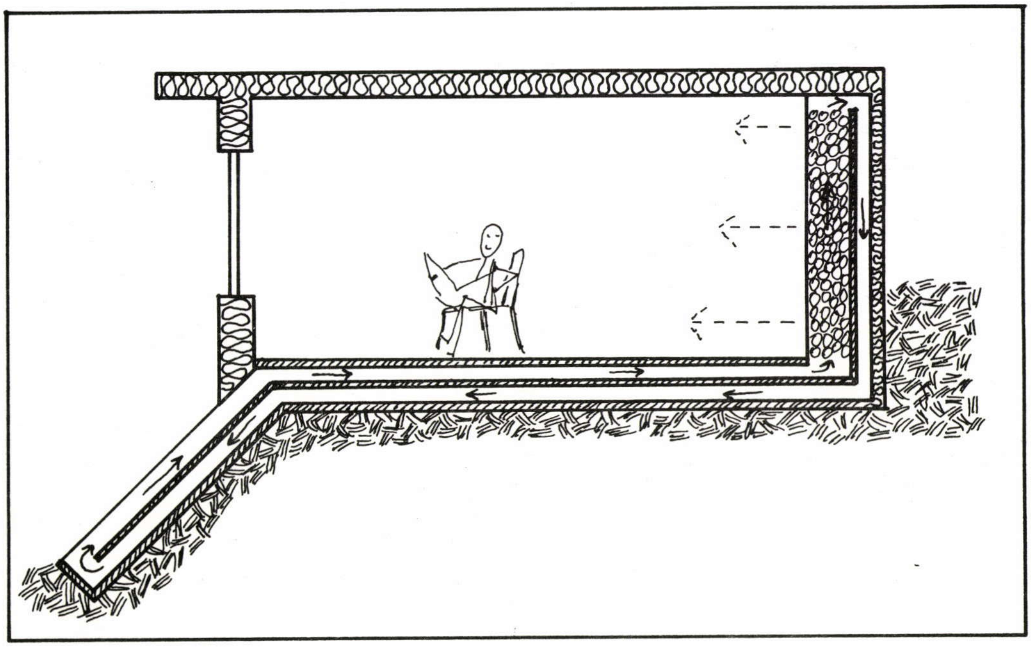

Fig. 4. Standard U-tube collector with north wall storage

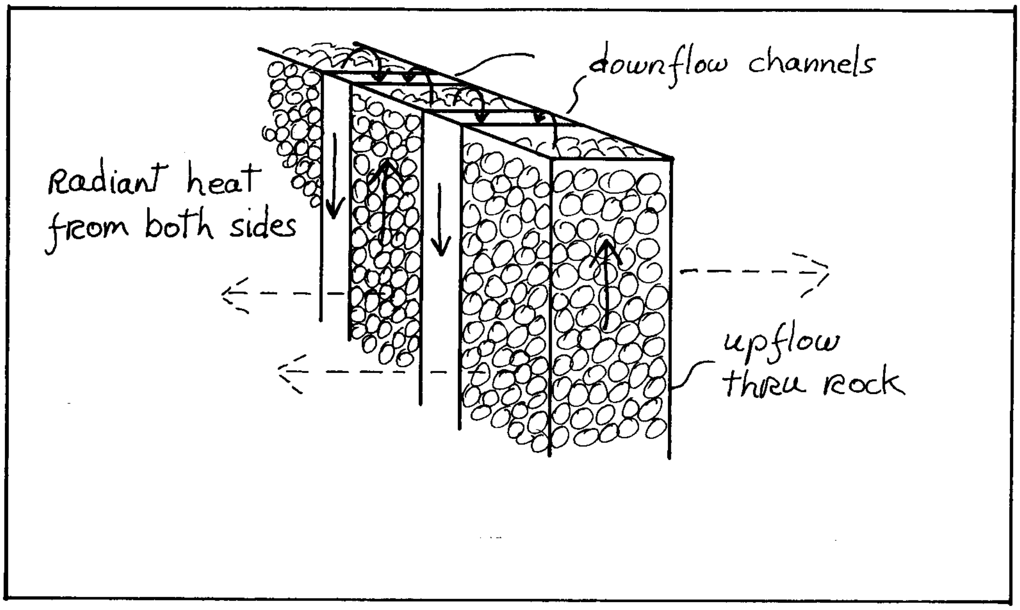

Fig. 5. Alternate upflow and downflow channels in wall

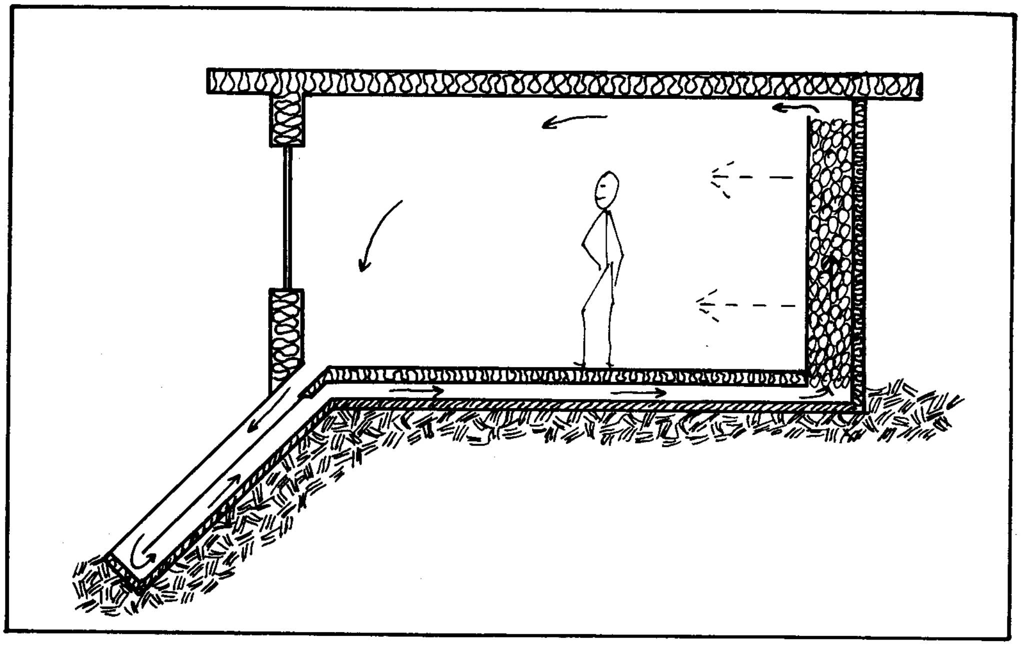

Fig. 6. An "open" system that uses the building as part of the loop

tors at night, because of the difference in temperature (thus weight) between the air in the storage wall and the air in the room. This unwanted convection may be prevented with dampers. Interestingly enough, the unwanted convection in this case will flow in the same direction as the charging cycle, and light plastic "backdraft dampers" would be useless.

The potential of such convection-charged, radiant heating storage walls prompted some simple experimentation with upflow storage systems, and the results were encouraging.

Figure 7 shows a standard U-tube type collector connected to two storage boxes, both containing the same storage mass. The storage in this case was 1-gallon water bottles with a generous flow area between each bottle. Despite the open invitation to bypass the bottles in the upflow mode, the storage picked up 80% as much heat as the downflow unit. It is believed that a rock-bed storage which forces the air into closer contact with the rock (about 2-in. to 3-in. diameter rock for a storage wall 6 ft to 8 ft high) would show at least 90% to 95% the gains of a similar downflow storage system, and any minor difference would be offset by the advantage of the reverse stratification for radiant heating. The actual efficiency of the radiant heating mode will depend on the surface area exposed to the building as well as the temperature. Numerous designs are possible with both concrete block and cast concrete as well as

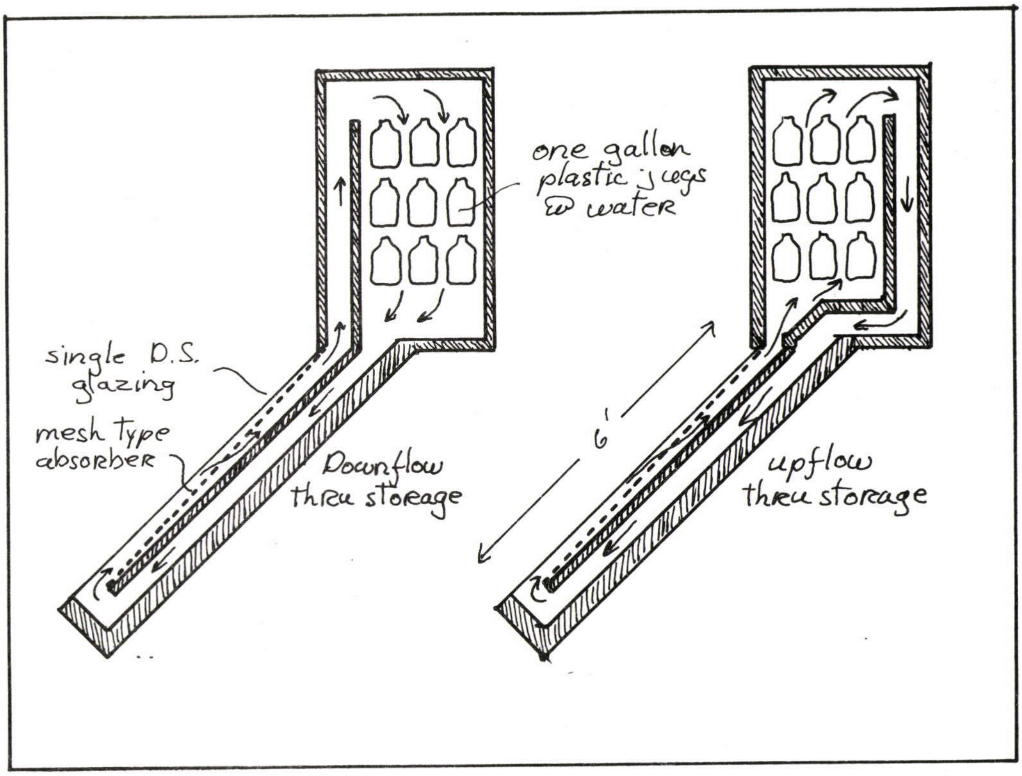

Fig. 7. Experimental units

metal or fiberboard tubes filled with rock and perhaps even containerized water walls.

Although such convection-charged storage walls are somewhat more complex than direct gain storage walls, properly designed convection systems are extremely reliable and generally operate at high efficiencies [4]. The potential of eliminating backlosses through the glazing and putting the storage in the center, or north wall, of the building, and of having the whole system work naturally, often with no moving parts, is certainly worth developing.

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A SELF-INFLATING MOVABLE INSULATION SYSTEM*

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ABSTRACT

In a structure having areas of glazing, designed for passive collection, the solar radiation entering will be absorbed, and this energy will be stored by raising the temperature of the enclosed mass. The necessity for providing movable insulation for glazing areas becomes particularly important in cold climates such as the 9,000 degree day climate of the Colorado Rockies where this work was initiated, and when using designs where the storage mass is located adjacent to the glazing as with the Trombe Wall and the Barrel Wall designs.

In some climates during the summer, these glazed areas need to be insulated during the hours when the solar gains exceed energy losses through these same areas, and then need to have insulation removed to allow unwanted energy to be radiated to the clear night sky, or other cooler exterior surroundings, in order to reduce or eliminate the use of nonrenewable energy sources for cooling purposes.

THE SELF-INFLATING CURTAIN CONCEPT

The Self-Inflating Curtain (Fig. 1) is an automated (yet technically simple) device, capable of providing efficient movable insulation for glazing areas. It automatically covers the glazed areas whenever needed, and self-inflates. Radiation from the mass (in winter mode) or from the sun (in summer mode) is intercepted by the curtain and warms the air in question, causing some increase in pressure and some decrease in density in the upper part of the system. The pressure increase has the effect of pushing the two sheets farther apart—a process accompanied by intake of air via the open bottom of the system. A kind of self-sustaining chain reaction occurs. The space between the sheets can be doubled or tripled in size, although the actual degree of expansion of a given mass of the air on warming is only of the order of, say, 1%. We are dealing with an automatic chain reaction, inhalation process, powered by the energy received from the hot wall, and limited only by the mechanical stiffness, etc. of the sheets and the gravitational forces acting upon them. If the sheets are very thin, very compliant, and very lightweight, the constraints are so small that the thickness of the airspace can increase enormously.

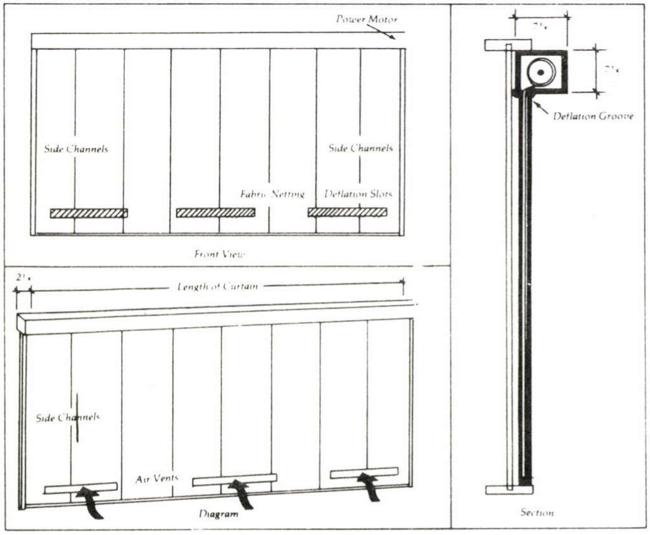

Fig. 1. Illustrated details of curtain system

When the curtain is moved to storage, the air is evacuated through the side channels and bottom deflation slots. The curtain consists of a number of layers of relatively thin, flexible material of high reflectivity and low emissivity. When bounded by air spaces, these reflective materials with metallic coatings make it possible to significantly reduce heat transfer by radiation and convection. Storage space and power consumption of an automated curtain are minimal. A curtain 24 ft long by 16 ft high can be stored in a 6-inch diameter roll. Another important design parameter is the ability to cover large glass areas with a single curtain while keeping the linear crackage (infiltration leakage) to a bare minimum.

MODEL TESTING

For test purposes, two identical thermal aquariums were built. They were constructed of 2-inch thick DOW SM foam and 3/8-inch plywood. Each aquarium had two open sides on which glass and the material to be tested were placed. When the tests were run, a 5-gallon drum of hot water was placed within each box. The rate of temperature decline was charted over a 10-hour time period. Sensors monitored the temperatures of the water and air on both sides of the insulation materials

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*Patent pending.

being tested. In all tests, the most effective insulation tested created the following conditions in the aquarium: highest water and interior air temperatures, and lowest temperatures between the insulation and the glass. In each test some form of multilayered curtain was compared to a material with a "known" "R" value. By testing this way, we could say that one material was better than another in reducing losses from the test module. In the last test, a five-layer curtain proved to be slightly better than 4 inches of fiberglass insulation with an "R" value of 14, which agrees with the value supplied by the ASHRAE Handbook of Fundamentals (1972 tables for air spaces, applying the correct values of emissivity from other tables found in this reference).

The aquarium tests look extremely positive, but anyone familiar with movable insulation knows that the value of a system depends largely on good sealing to reduce system leakage. Therefore, the only true way of assessing the performance of the curtain is to monitor actual installation.

MONITORING OF ASPEN INSTALLATION

To date, 32 completed curtain systems have been installed in residences in the Aspen, Colorado, area. One residential addition which has a Trombe Wall with a 24 ft by 14-1/2 ft curtain was completed in March 1977.

This building provided an excellent opportunity for instrumentation. The addition was thermally isolated from the existing heated residence, and the owners were willing to vacate the space and disconnect all power for auxiliary heating during the 3-1/2 week data collection period.

Instrumentation equipment:

INSTRULAB 2000 Datalogger (15 Type "T" Thermocouples).

MATRIX MK1-G Solar Radiometer (corrected against EPPLY PSP).

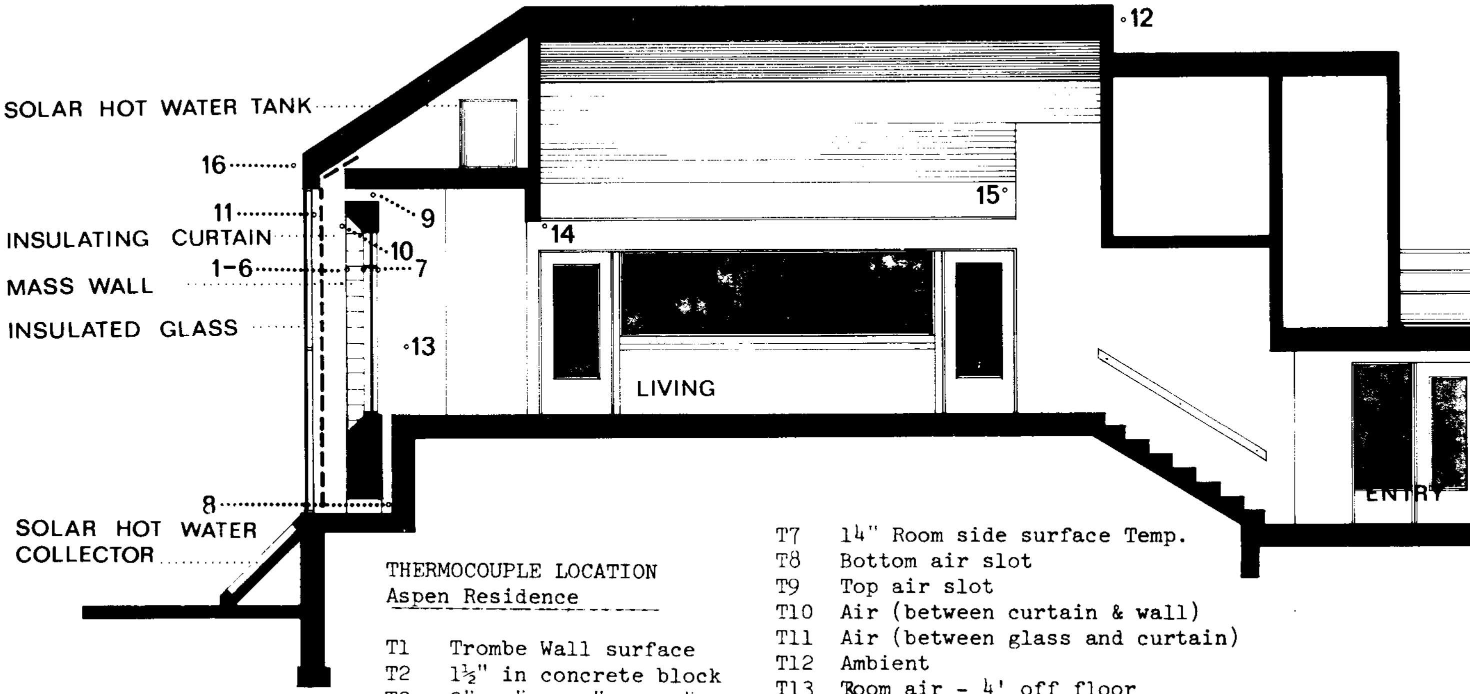
The 16 channels were scanned every 30 minutes from Feb. 10 to Mar. 7, 1978. (See Fig. 2; Building section showing thermocouple and solar radiometer placement.)

From Feb. 18 to Feb. 22 the curtain was fixed in the storage position. During this time the room temperature dropped to a low of 50° F. During the time of curtain operation (Feb. 10-18) (Feb. 23 - Mar. 7) the lowest room temperature recorded was 62.5° F.

Figure 3 shows a very representative week. (Curtain was in storage position from Feb. 20 through Feb. 22.)

Feb. 24 - Feb. 27 Curtain activated. The effects of this piece of movable insulation are dramatically documented.

Figure 4 (Feb. 23) shows the effectiveness of the system for reducing heat gains. It is significant to note the minimal effect on the wall surface temperatures and



THERMOCOUPLE LOCATION
Aspen Residence

T1	Trombe Wall surface
T2	1½" in concrete block
T3	3" " " "
T4	4" " " "
T5	6" " " "
T6	8" in Trombe Wall
T7	14" Room side surface Temp.
T8	Bottom air slot
T9	Top air slot
T10	Air (between curtain & wall)
T11	Air (between glass and curtain)
T12	Ambient
T13	Room air - 4' off floor
T14	Room air - 10' off floor
T15	Room air - 12' off floor
#16	MATRIX MIG Solar Radiometer

Fig. 2. Longitudinal section

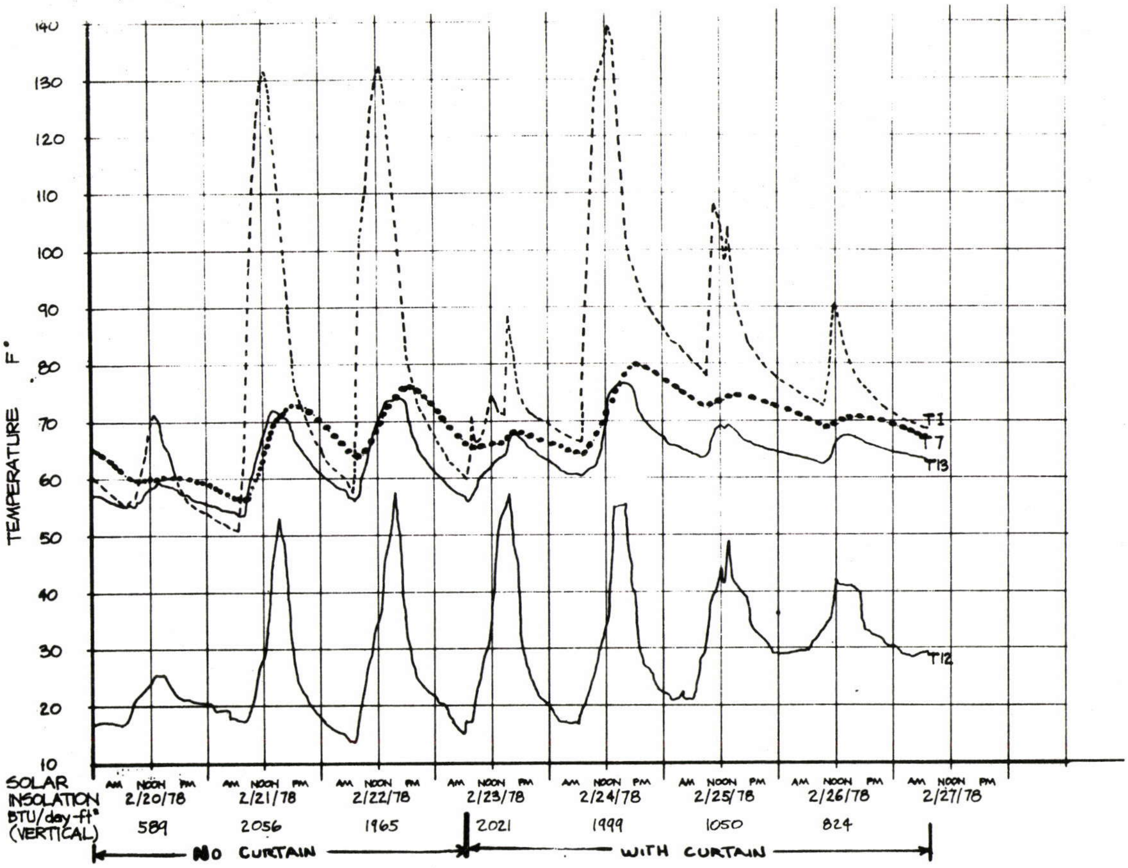
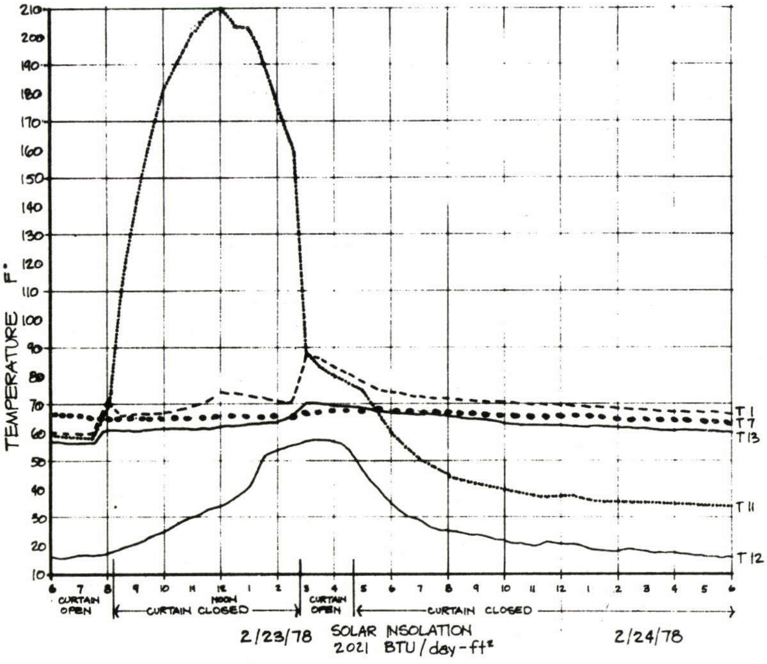


Fig. 3. Example of data dathered during representative week



THERMOCOUPLES
Aspen Residence

T1	Trombe wall surface (outer)
T7	Surface temp. Trombe Wall (room side)
T11	Air temp. (between glass and curtain)
T12	Ambient
T13	Room air temp.

Fig. 4. Effectiveness of curtain system in reducing heat gain

room temperature when the solar insulation value was 2,021 Btu per day per square foot, and the curtain was in the closed position shielding the Trombe Wall. Thermocouple #11 (between glass and curtain) shows the effect of the black anodized mullions, unventilated space, and the 70% reflectivity of the outer gold curtain fabric. (With mirrored outer fabrics, reflectivities of 97% can be expected.)

During the summer of 1977, this effect was minimized by exterior venting at the top of the wall and the high solar incident angles. The room remained cool all summer.

This residence has been the most successful passive structure currently operational in the Aspen, Colorado, area. It is the only passive structure which has been able to provide thermal comfort through the night and into the next afternoon after a sunny day during the peak of the winter heating season.

TESTING AT LOS ALAMOS SCIENTIFIC LABORATORY

A small 4-1/2 ft wide curtain was installed on Dec. 12, 1977, in one of the passive test modules at Los Alamos Scientific Laboratory. The emissivities of the various curtain materials were tested (2 outer layers of gold TG = .373, 3 vacuum deposited inner layers = .073). Mirrored TG also tested had an emissivity of .032; this material is now being used as a replacement for the gold outer layers in our current curtain systems but was not used in the Los Alamos application.

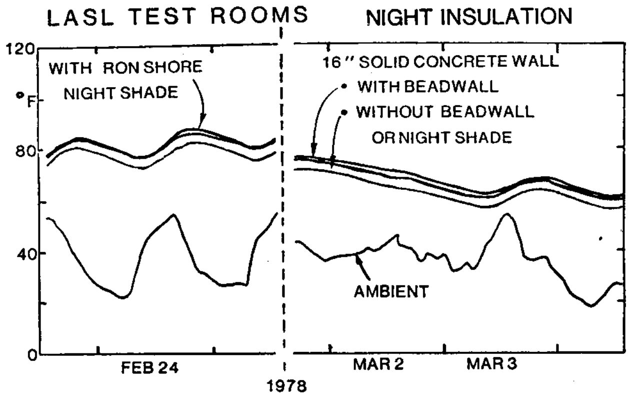


Fig. 5. Results of tests at Los Alamos Scientific Laboratory

The performance curves (Fig. 5) for the curtain test module and Beadwall test module were nearly identical, which would indicate a resistance value of 9 for the curtain system. Curtain systems this small suffer greatly from the effects of edge loss.

The performance curve of the Aspen residence is superior to that of the Los Alamos test module. This is due to the large area of the curtain making edge effects negligible. Conservatively, the resistance value of the larger curtain = 12.

COSTS

The square foot cost of the system is dependent upon size. (Example: 20 ft wide by 17 ft high curtain system = $4 per sq ft FOB Snowmass. Installed cost = $4.28 per sq ft.)

This system in Aspen, Colorado, will have a payback in 4.2 years based on current electricity rates of 3 1/2¢ per kWh, and an increase in the cost of power at 15% per year for the next 5 years. (This rate increase estimate was made by our local utility company.) Note below:

9,000 degree day climate
Assume curtain "R" value = 9
.8 placement factor *

Double Glazing:
Hq = (.56 Btu/hr/sq ft/DD) (9,000 DD) (.8 pf) (24 hr) = 96,768 Btu/yr/sq ft.

Curtain:
Hq = (.11 Btu/hr/sq ft/DD) (9,000 DD) (.8 pf) (24 hr) = 19,009 Btu/yr/sq ft.

Savings per year:
77,760 Btu/yr/sq ft.

Value:
Payback - 4.2 years

The device is truly cost effective, especially when one considers that for view glazing, conventional drapery costs are normally above $2.50 per sq ft.

The curtain system has been shown to be a cost effective, reliable, thermally acceptable, movable insulation system.

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LIVING IN A PASSIVE SOLAR HOME

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Much has been said and written about the mystique of living in a passive solar home. The general impression often left is that this requires a radical change in lifestyle, an accommodation to a decreased comfort standard, or a greal deal of participation and work on the part of the occupant. The purpose of this paper is to relay my experiences in a passive solar home, to dispel some of the myths regarding such homes, and to lend an air of realism to the presentation of the passive concept to a broad section of the public who are generally receptive to the use of solar energy but often skeptical of a system which claims to work with no moving parts.

Living in a passive solar home is indeed a different experience; and if one's goal is a change in lifestyle, then a passive home provides an ideal means toward that end. However, the two are not necessarily wedded and should not be confused. It is entirely possible, perhaps even desirable, to do one without the other.

What a passive home offers its occupants is a delightful new kind of comfort and freedom: freedom from dependence on ever dwindling and ever more costly fossil fuels; freedom to choose whether or not to use those utilities at any given time; freedom from worry about frozen pipes, power outages, temperature extremes, thermostat settings, soaring utility bills. The passive solar home also offers several options. One can live in a direct gain home and be quite involved in the daily operation of the house, always aware of the weather, the intensity of the sunlight, the changing seasons. Or there is a choice of the thermal storage wall, a buffer between the occupants and the elements, eliminating much of the individual involvement in the performance of the house but also, by eliminating much of the direct sunlight from the living spaces, affording a greater choice of furnishings and materials which can be used in the home. And there is the solar greenhouse—or sunspace—which combines some of the better elements of both and provides a year-round garden as well. A combination of some or all of these methods can be used on any one house. The point is that there is no one ultimate passive solar system, and the passive option offers an incredibly broad range of styles and methods from which to choose.

My own solar home is technically a hybrid system. The primary heating and all the cooling are handled passively, but there is an active component. Our home is heated by a 400 sq ft greenhouse which is an integral part of the house. It is two stories high and adjoins all the principal rooms of the house. Heat is stored in a 14"-thick adobe wall which forms the north wall of the greenhouse and the south wall of the living space. (See Fig. 1 and 2.) This wall serves us in several ways. In winter, the sun shines on the wall all day, but transfer of the heat thus stored into the living space is delayed until night when it is most needed. It takes about 10 hours for the heat to move through the wall, and then

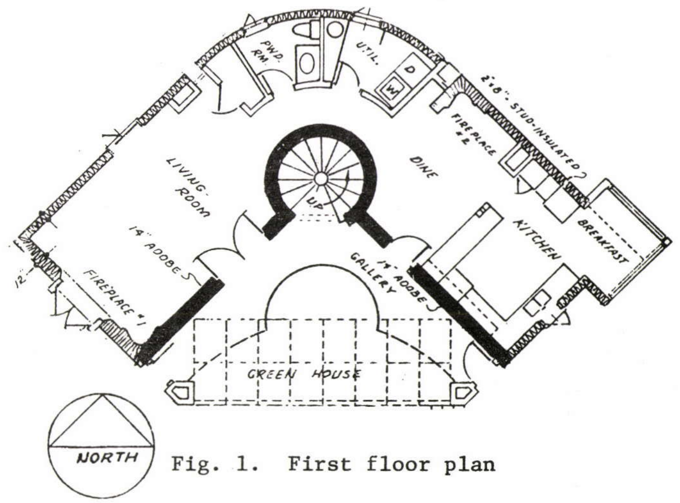

Fig. 1. First floor plan

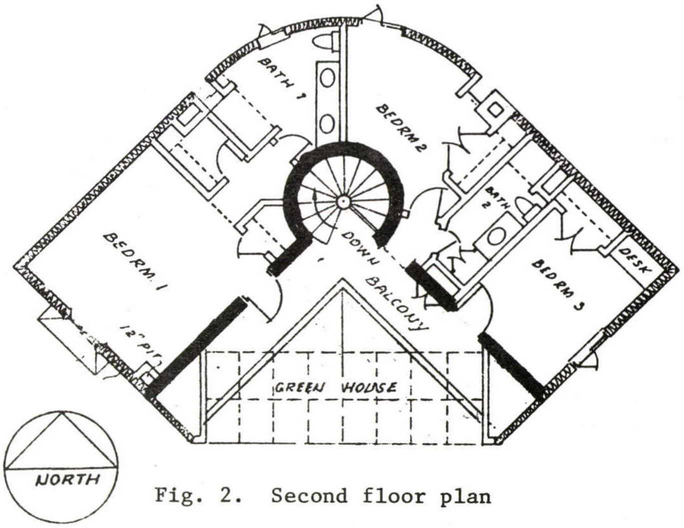

Fig. 2. Second floor plan

we are kept warm through the night by an 80° F wall. Secondly, the wall provides a thermal insolation from the temperature extremes in the greenhouse. In midwinter, it is not unusual for the greenhouse to fluctuate 35 degrees during a 24-hour period (typically from the lower 50s to the mid 80s). These temperatures are fine for plants but not for people, and the mass of the wall combined with its thermopane windows and solid core doors effectively shields us from those temperature swings. Third, the wall and the other mass in the greenhouse provide a thermal inertia which keeps the temperatures in the living areas very stable. It takes at least 2 days for outside weather changes to affect the house. During the entire month of December 1977, the temperatures in the living areas varied only 4 degrees—from 67° F to 71° F—and it is very rare for the house to swing more than 5 degrees in any 24-hour period. The wall, then, is our primary heating system—no buttons to push, nothing to move or alter, no settings to change.

The greenhouse does produce more heat on a sunny winter day than the wall or other mass can absorb directly, and that is where our small active system comes in. At the very top of the greenhouse are two ducts, each with a small (1/3 hp) fan. The hot air is drawn out of the greenhouse and blown through two rock bins located directly under the first floor of each wing of the house. (See Fig. 3.) After passing through the rock bins, the now cooled air is returned to the greenhouse. The fans are operated by differential thermostats and run only when the air in the greenhouse is at least 5 degrees warmer than the rocks—about 4 hours a day. Thus there is an active heat storage system, storing approximately 10,000 Btu/hr, but heat retrieval from the rocks is passive, by simple conduction up through the floors. The performance of this system is not affected by the use of rugs on the floors, and in addition to our 80° F wall, we have 70° F floors to keep us warm.

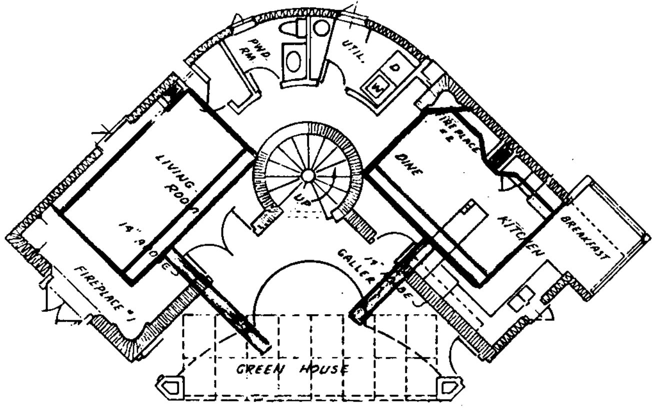

Fig. 3. Rockbeds and ducts

It is difficult but very important to try to describe the quality of the heat we get from our passive system. It is a natural warmth. There are no drafts, no hot spots, no dry air blowing through the house. Many of the standard discomforts usually associated with winter are now things of the past: cold feet, static electricity, dry skin, morning sore throats, all are no longer problems. We have found that we simply take our comfort for granted.

Our home is located in the foothills outside Santa Fe, New Mexico, at an altitude of 7,300 ft. The climate is roughly comparable to that of Denver, with 6,000 degree days, about 70% of possible sunshine, and an average annual snowfall well in excess of 3 ft. We are blessed with a great deal of winter sunshine, but the house has been designed to carry through a period of several cloudy days without the need for auxiliary heating.

We have a complete electric baseboard heating system (gas is not available in our area), with heaters in every room except the greenhouse. Each heater is on a separate thermostat. During the past winter, we simply set each thermostat at 65° F and left it there. The purpose of this was to find out exactly what it would take in the way of extra heat to maintain the comfort level most Americans have come to expect. During the entire 12-month period from February 1977 to February 1978, we used 857 kWh for heating—a total of about $38 at our present rates. We were able to determine the exact number because our power company, in an effort to learn about the performance of solar homes, installed a separate meter which records only the electricity used by the heaters. We have also discovered that nearly all of our auxiliary heating requirements are between midnight and 7 a.m., during the off-peak hours of the electric utility.

Our passive solar home also keeps us cool in the summer. Because the mass wall is shaded all day by the roof and a second floor balcony, and because it can radiate its stored warmth to the greenhouse at night, it stays cool all the time. In addition, there is a large window at the top of the stairwell which is left open all summer. As the air in the greenhouse warms, it rises up the stairs and out the vent—a chimney effect. Fresh outside air is drawn in through large windows in the front of the greenhouse at the ground level. Thus the air in the greenhouse does not get warmer than the outside temperature. This again is fine for the plants, but not comfortable for people, and again it is the mass wall which protects us from the temperature extremes. Temperatures in the greenhouse typically range between 60° F and 90° F on a summer day, with the highest recorded temperature at 98° F. The living areas, however, remain quite cool and stable. The warmest temperature in the living space last summer was 76° F, and that was on a day when the outside temperature was 97° F. A 21-degree temperature difference is hard to achieve even with a conventional air conditioner, but we achieve it naturally, without the use of fans or any other external source, and without the discomfort of icy drafts or hot spots.

As for the greenhouse itself, it is completely self-sufficient thermally. It has no backup heating system, no night insulation, and no shading. Sunlight is admitted through 409 sq ft of double glass (24 standard patio door sized units), and the heat is stored in the two story adobe wall, in the flagstone floor, and in the planting beds and the plants themselves. Temperatures in the space vary widely, swinging an average of 30 degrees every day. Typical winter temperatures are 50° F at night and 80° F during the day. The lowest temperature in the greenhouse during the 2 years since it was built was 45° F. (The lowest outside temperature during that same 2 years was 17° F below zero.) There has not been a day when the greenhouse did not warm up to at least 65° F, even during extended cloudy periods or all-day snowstorms.

We thoroughly enjoy the additional benefits of a solar greenhouse—roses and gardenias in bloom at Christmas, the pleasant smell of fresh greenery, the sound of water splashing in the small fountain, and fresh fruits and vegetables all year long. One need not be a dedicated gardener to enjoy these delights. It takes only about 5 hours a week to keep such a greenhouse producing and running smoothly. Of course, such a sun space might not be used as a greenhouse at all. It could easily function as a play room, a multipurpose room, an old fashioned sun room, almost anything. It is, however, a sun space, an area where the sun really determines the environment and one is somewhat limited by that consideration. It would not, for example, be a good room for a piano, good paintings, antique furniture, or heirloom rugs. The living spaces of the house buffered from the sun space by the mass wall have no such limitations.

There are a number of myths related to living in a passive solar home. A partial list includes:

Myth 1. "Living in a passive home requires a change in lifestyle." This is simply not true. A passive home does tend to make one more aware of the weather, the seasons, all the natural surroundings; but this heightened awareness does not necessarily imply a change in lifestyle any more than, say, getting glasses does for someone who is nearsighted.

Myth 2. "Passive solar homes work well only in the sunny southwest." Again, not true. Admittedly, they work better with more sun than with less, but remember that our greenhouse warms up all by itself to a comfortable temperature even on days when the snow is falling all day. On these same days, our active solar domestic hot water system doesn't even come on, and the collectors may stay snow covered all day long.

Myth 3. "People who live in passive solar homes must become accustomed to cooler temperatures and wear heavy clothes." This one I believed myself until I lived through a winter in a passive home. In this case, it is a matter of choice and can depend either on design or on how much auxiliary one has or is willing to use. The temptation to ride out a spell of bad weather by putting on a sweater instead of turning on the auxiliary becomes very strong, partly because it is a challenge and partly because we passive homedwellers are terrible snobs about our utility bills and delight in being able to say how low they are. The truth is that while some passive homes do see a temperature swing of 15 to 20 degrees during clear weather in winter, most are or can be as stable as any conventionally heated home. In fact, our passive home has never been as cool as our previous, natural gas heated, home was.

Myth 4. "If you live in a passive home you can't have carpets or drapes or upholstered furniture." Indeed, such things never should be in the direct sun, and cannot be placed so as to block storage, but a passive home is not a solar furnace either. If such items are important to your way of life, then there are passive designs in which they can be included just as in a conventionally heated home, without detriment either to your possessions or to the thermal performance of the house.

Myth 5. "Living in a passive solar home takes a lot of time and involvement on the part of the homeowner." Again, this is a matter of choice. If you want to be involved in the workings of your living environment and to take an active part in the operation of your home, fine. There are passive design options which encourage or even require such participation. If, on the other hand, you are, like me, basically lazy, or terribly busy, or unable for whatever reason to become so involved, then there are passive designs which require virtually no active concern on the part of the occupants, but which will still respond to sporadic input. One of the best things about our home is that it conserves energy—my energy. I find that I have to spend much less time and effort and worry running my passive home than I ever did in any conventionally heated home. Most passive home dwellers find that they really enjoy "sailing their solar homes," reacting to the weather and the seasons, but it is again a matter of choice and not a necessity.

So much for the myths; how about the realities? The people of this country have just suffered through two record-breaking winters, with the attendant shortages, shutdowns, blackouts, brownouts, increased heating bills, and other miseries. Comfort, convenience, economy, reliability, along with an aesthetic beauty are the qualities most people want from their home. Mere shelter is insufficient for human needs and the irresponsible use of our resources and technologies in an attempt to enhance our shelter is inexcusable. A well-designed passive solar home is a sophisticated yet incredibly simple answer.

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ROCKY MOUNTAIN GREENROOMS

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Many new and existing Rocky Mountain homes are accommodating the integration of solar greenrooms to provide for food production, solar heat collection and storage, space heat savings, additional living space, and an aesthetically pleasing environment. These greenrooms will play a key role in energy and resource conservation in many Rocky Mountain homes. The development of these food and heat producing solar greenrooms sets examples of socially responsible and environmentally sound applications of solar energy as a viable alternative to the consumption of fossil fuels.

Decentralized food production is essential for long-term survival at the high altitudes in the Colorado Rocky Mountains. Prime agricultural land is scarce, and food production is hampered by the short growing season of less than 90 frost-free days at elevations above 8,000 ft. With few exceptions, the food consumed by people in these areas is trucked in from long distances every week. The availability and cost of energy directly impact the cost of food shipped long distances from farm to market. Possible future restrictions of fuel supplies can result in many areas being faced with food supply reductions and price increases. The feasibility of extending the growing season by conventionally heated greenhouses is also limited by the availability and higher costs of fossil fuels. Residents in these areas are vulnerable to the energy supply and market price fluctuations beyond their control. In addition, the per person farmland is being reduced rapidly as productive lands are lost to urbanization.

DESIGN FUNDAMENTALS

The basic design concept behind the residential integration of solar greenhomes is to use the greenroom as a solar collector with thermal storage. Abundant south-facing glazing allows solar penetration into the space to be directly and passively stored in a thermal mass. Movable insulation over the glazing at night reduces heat loss and increases the efficiency of these passive solar systems. Often, the hot air in the highest part of the space is drawn to storage in an insulated rockbed. After the air has lost much of its heat to the rocks, it returns to the greenroom. This results in a cooling effect of the greenroom space. The stored heat is later used to heat the greenroom or the space of the adjacent residence. A well designed passive/active hybrid solar greenroom can replace the need for a typical active flat-plate solar heating system.

Some "rules of thumb" for the design fundamentals of the attached solar greenroom are:

Orientation: True south or up to 20° of south, when possible. However, greenhouses with sloped roofs of 35° to 60° will only lose 18% to 20% of the daily insolation when oriented 45° east of south [1].

Storage: If directly exposed to the sun, 2 gallons of contained water or 80 pounds of masonry (rocks, bricks, etc.) per square foot of clear glazing [2].

Natural Air Circulation: Use high and low vents on the wall where the greenroom is attached. A 6-ft vertical distance between the high and low vents is minimum. The high vent is one and one half times larger than the low vent. (Example: 160 sq ft greenroom: 4 sq ft for low vent, 6 sq ft for high vent) [3].

Night Insulation: Night insulation over the glazing is recommended to reduce heat loss and improve thermal efficiency during winter months in cold climates.

CASE STUDIES

The Smith-Hite Studio (Fig. 1) is one case study out of hundreds of solar greenrooms in the Rocky Mountains. The Smith-Hite Studio is located near Aspen, Colorado, at an elevation of approximately 7,500 ft. Construction started in October 1977, and should be completed in April 1978. The architect is Gregory Franta, AIA, of Sundesigns; the owners are Debbie Smith and Henry Hite, and the builders are Richard Farizel and Chuck Ravetta.

The design of the Smith-Hite studio integrates a 600 sq ft weaving studio with a 224 sq ft greenroom. The greenroom provides both solar heat collection and space for food production. All exterior walls have a thermal buffer between the ambient air and the interior living/working space (Fig. 2). In general, the primary design parameter of the studio greenroom was energy and resource conservation in addition to the space functions.

The greenroom has 312 sq ft of south-facing glazing (15° E. of S.). Solar heat is passively absorbed and stored in 3,300 pounds of contained water and over

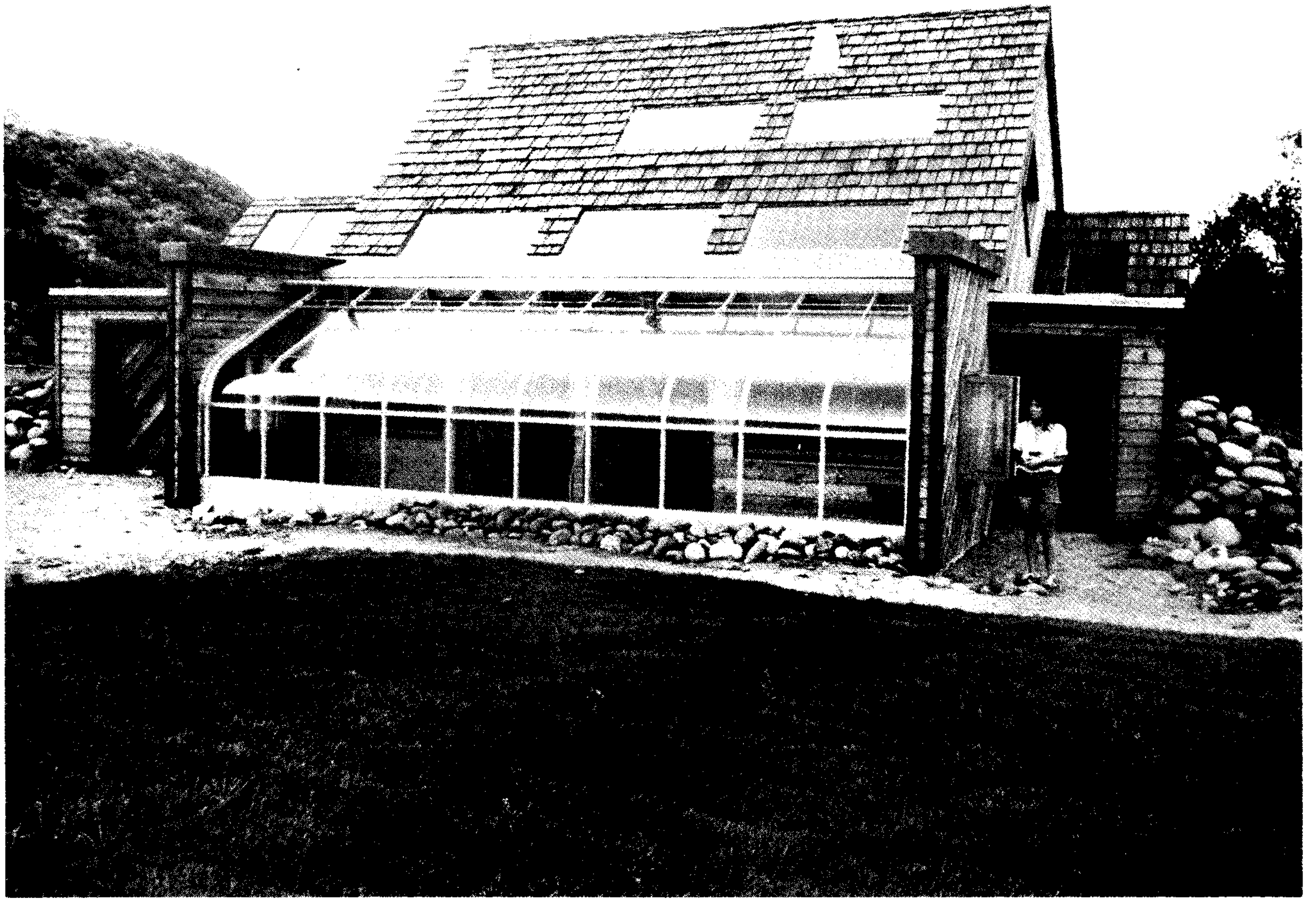

Fig. 1. Smith-Hite studio

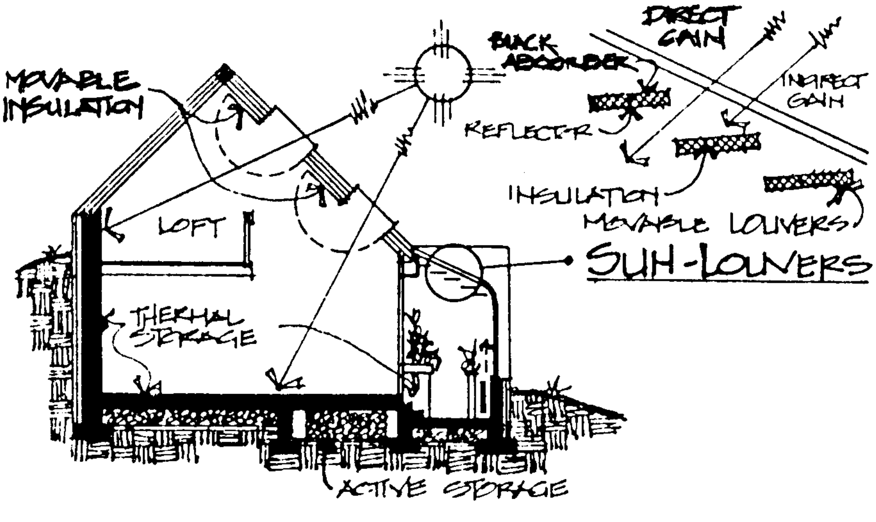

Fig. 2. Smith-Hite studio north/south section

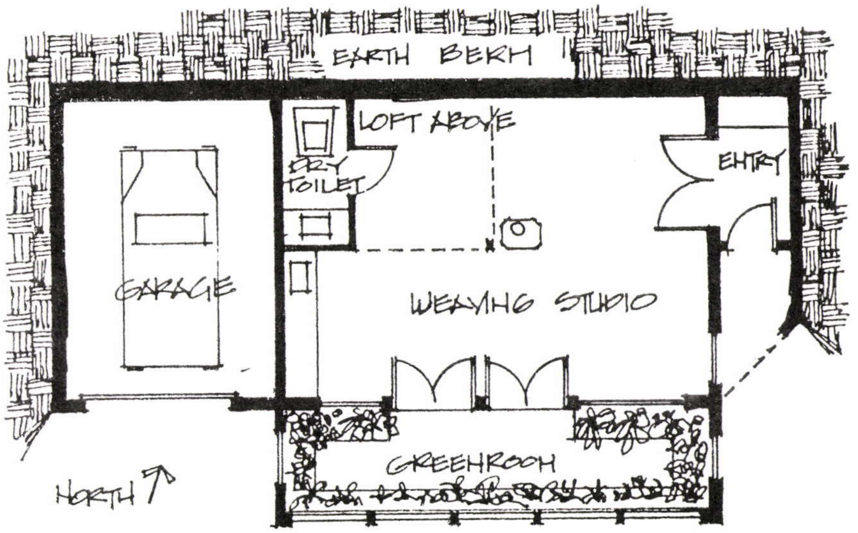

Fig. 3. Smith-Hite studio floor plan

50,000 pounds of gravel and concrete. The water storage is contained in 30 gallon plastic drums located along the north, east, and west walls. The primary portion of the remaining passive storage is located in the floor of the greenroom; a 4-in. concrete slab tops 18 in. of gravel. Styrofoam insulation 2 in. thick is located below the gravel storage to reduce heat loss into the ground.

A system of movable insulating louvers, "Sun-louvers," is incorporated into the roof glazing (Fig. 3). The sun-louvers provide movable insulation at night, act as heat boosters for the hot-air collection system, and provide solar shades when desirable. The sun-louvers have a black heat-absorbing surface on the top side, a reflective surface on the bottom, and insulation in between. In the open position, solar energy is allowed to penetrate into the space as much as desired. At the same time, solar energy is absorbed on the black surface of the louvers to boost the air temperature in the higher portion of the space. The hot air is pulled off the top of the greenroom by a single fan. The air is transported through ducts to thermal storage under the floor of the studio. The air returns to the greenroom after it loses much of its heat to the rocks, cooling the greenroom. During periods of overheating, the sun-louvers are not fully opened in order to allow light to enter the greenroom and increase the amount of heat collected from the sun-louvers. At night, the louvers are in a closed position to reduce heat loss. Movable insulating panels slide up to insulate the vertical glazing. The passive distribution system allows the natural flow of heat from either the storage bed or the greenroom into the studio.

The greenroom not only supplies heat to the studio but also acts as a thermal buffer and reduces heat loss. The glass wall with French doors located between the greenroom and studio allows the greenroom temperatures to fluctuate with little effect on the studio temperatures. This results in the greenroom buffering the south wall of the studio from the ambient weather conditions. The north, east, and west walls of the studio also have thermal buffers: an earth-berm covers most of the north wall; an air-lock entry and mudroom are located on the east wall; and a garage is attached to the west wall.

Other passive and active heating components are incorporated into the studio. Skylights with movable insulating panels provide direct solar gain onto the thermal mass of the floor and north wall. A heat recovery system transports the hot air from the top of the studio into storage. The only auxiliary heat source is a wood burning stove.

In addition to the energy conservation measures, other resource conservation applications have been designed into the studio. A dry organic waste treatment system, "Humus Toilet," is used to conserve water. The other plumbing fixtures are water-conserving fixtures. Recycled doors and windows have been incorporated into the design. Indigenous and nonenergy intensive building materials have been used whenever applicable. The Smith-Hite case study is one of many individual solar greenrooms having impact in the Rocky Mountains.

The Craven residence (Fig. 4) is a contemporary residence designed to utilize active and passive solar heating. The 2,800 sq ft residence was constructed in 1976-77 with a 200 sq ft greenroom. The residence was designed by Dean Moffatt of Sundesigns in Glenwood Springs, Colorado, and the solar consulting was done by Gregory Franta. The 190 sq ft of glazing allows the solar energy to be absorbed into the space, the plants, and the thermal mass. Almost 8,000 gallons of water are located under the planting bench on the north wall for passive solar storage. Heat is passively provided to

Fig. 4. Craven residence

the residence by opening manually operated vents leading to the bedroom on the second floor and windows in the adjacent sewing room on the main level. Movable insulation made of styrofoam panels reduces heat loss through the glazing at night. The temperature is allowed to drop to 50° F at night and rise to 80° F during the day. The hot air in the top of the greenroom is transported through ducts to thermal storage under the greenroom floor. In addition to the greenroom solar system, an active flat plate solar air collector will provide heat for the residence. A separate thermosyphon solar hot water system provides the domestic hot water.

Having a larger impact on energy conservation is a major land-planning project that is in the initial planning stages by Sundesigns in Glenwood Springs, Colorado. Phase I of the 179-unit dwelling complex will consist of 60 multifamily units, each containing a food and heat producing solar greenroom. Of course this does not necessarily mean that each family will grow its own food or even use the solar heating system as efficiently as possible; but the greenhouse will conserve energy for the residence and will encourage and provide space for food production at a residential level.

"Holistic" and responsible planning and architecture of the individual and large-scale projects can reduce the demand on our natural resources for energy and food requirements. The "greenroom" architecture must work with nature, people, and appropriate technology to have an effective impact. The greenrooms are developing rapidly and will be an important factor in energy and resource conservation in many Rocky Mountain homes.

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2. Bill Yanda and Rick Fisher, The Food and Heat Producing Solar Greenhouse. John Muir Publications, Santa Fe, N. Mex., 1976, p. 10.

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INTEGRATED SOLAR GREENHOUSES

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INTRODUCTION

Greenhouses have long been used to extend the favorable growing climate but typically have been great energy users. We are now coming into the age of the "solar greenhouse," an energy efficient growing environment capable of supplying us with food as well as heat, oxygen, and humidity. Greenhouses can be attached to existing structures or integrated into new buildings as a primary function. Regardless, the greenhouse has the potential to become one of the most important rooms in any building. Architecturally, the greenhouse is a natural companion to any room in the house. It provides a continual source of plant growth even in the harshest of climates. The greenhouse is becoming a symbol of our desire to have more direct involvement with nature. Filled with colorful flowers and sprouting seeds, it can fill the soul with warmth even though it may be gray and cold outside. It will provide a pleasant retreat from the busy world, allowing one to escape into a refreshing new world.

By using basic passive design principles, a solar greenhouse can easily be integrated into a living environment. First of all, the greenhouse glazing should be oriented so as to maximize winter solar gain and minimize summer gain. Solar control can be achieved in several ways by using overhangs, louvers, screens, or deciduous vegetation. All other exterior surfaces should be well insulated to minimize heat loss. Next, thermal mass should be added to the floor and back wall surfaces. The effect of a thermal mass is to stabilize interior temperatures by absorbing solar radiation during the daytime, converting it to heat, and releasing it at night when the temperature drops. The mass is beneficial during the summer months, absorbing heat during the daytime and releasing it at night, moderating both daytime and nighttime interior temperatures. Excess heat can be vented into adjacent space to act as a heat source or vented to the outside, depending upon heating demand. Circulating heated greenhouse air throughout a house provides an easy source of oxygen and humidity, raising the comfort level of that environment.

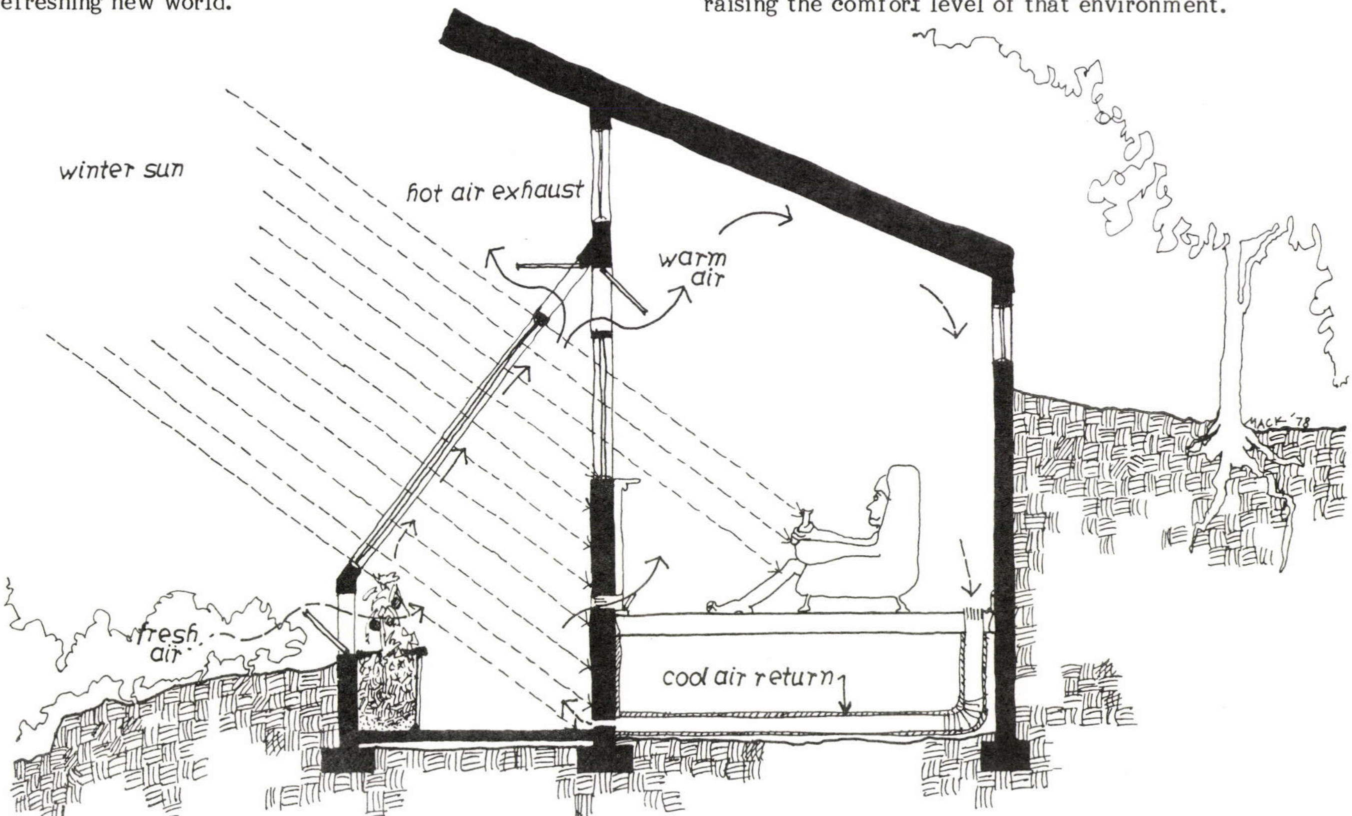

Fig. 1. Typical integrated greenhouse section

The solar greenhouse as a system is an excellent example of the use of appropriate technologies. It is a small-scale, integrated system which is not wholly dependent upon finite natural resources. It serves as a low-energy-cost food production system and a source of heat for attached buildings. It is a high-quality environment in which one may become more directly involved with the life processes, including basic survival.

This presentation will include several case studies of solar heated greenhouses in the mountain/high plains region.

GREENHOUSE EXAMPLES

The Hilary Jones Greenhouse

This greenhouse is located in Sunshine Canyon outside Boulder at 8,000 feet above sea level. The structure contains approximately 250 sq ft of planting beds and is primarily intended for intensive fruit and vegetable growing. The greenhouse is partially sunk below grade and integrated into the south facade of the home to take advantage of the insulating qualities of the earth and house. The northwest wall is primarily solid and heavily insulated to protect the greenhouse from both cold winter storms and the hot summer afternoon sun. The basic structure is framed from 3 x 8 fir beams with a skin of insulated glass. Over 6,000 pounds of brick masonry comprising the planting beds and back wall act as heat storage and help to stabilize the daily temperature swing. Ventilation is achieved by a row of awning windows around the base of the greenhouse with a large single venting door high in the ceiling. This portion of the roof also shades the back masonry wall from hot summer sun. In the winter, surplus heat enters the house by any of several doors, windows, and vents located in the south wall. Specific openings may be opened to provide heat to a particular space. This greenhouse is now completed and is anxiously waiting for the upcoming winter.

The Vollmer Schoolhouse Renovation

The scope of this project called for the renovation of an old schoolhouse located on the plains east of Boulder into a passively heated residence and pottery studio. The passive aspect is characterized by the integration of a greenhouse/dining room addition on the south side of the building. The main passive element is a solar drum integrated into a plant shelf on the south wall of the greenhouse. Heat is collected during sunny hours when an insulated door is lowered, exposing the water-filled drums to the sun. The drums have a glass covering to prevent reradiation. At night the door is closed, storing the day's heat and reradiating it into the greenhouse as the temperature drops. Brick masonry planting beds and wall act as additional storage for the sun's energy. Excess heat is vented into the dining room through a high vent located in the glass and masonry wall separating the two rooms. Low vents bring cool air to be warmed and recirculated. The planting beds along the back wall are intended to grow vegetables throughout the winter.

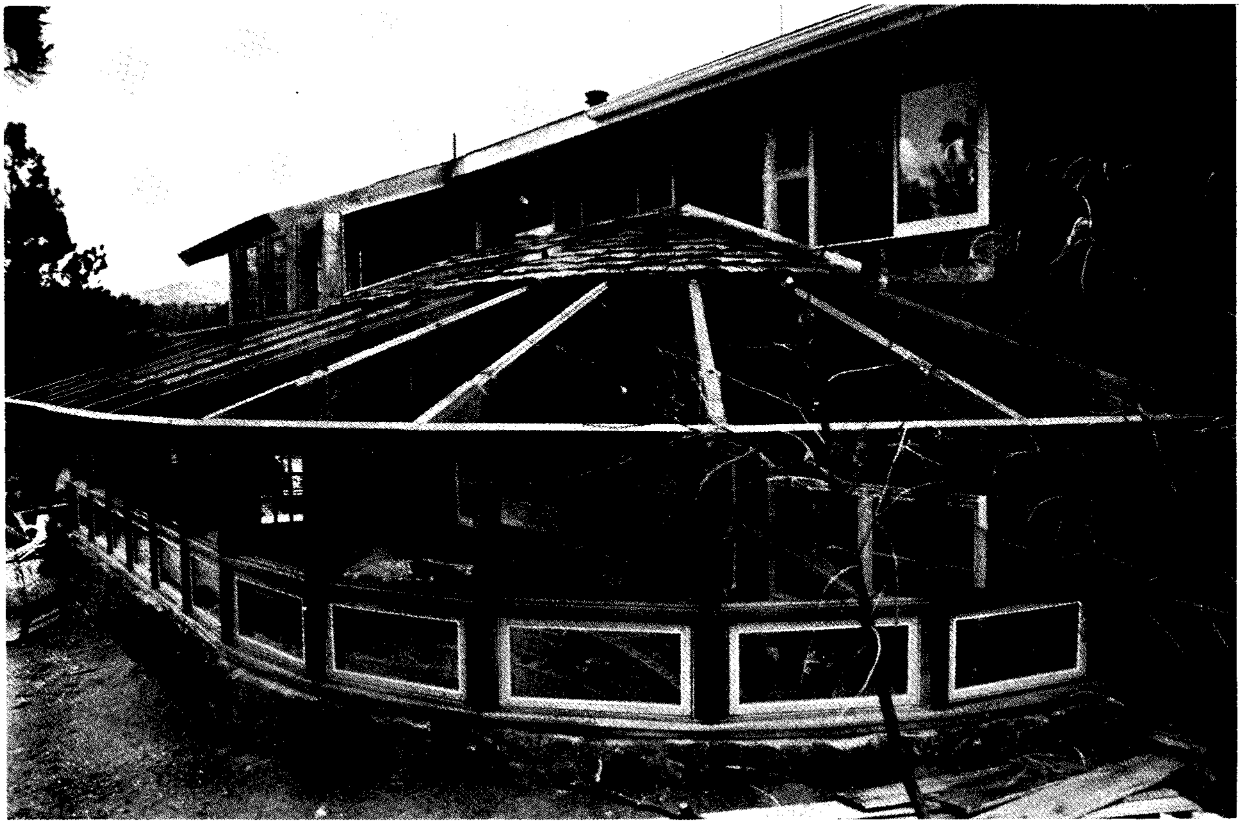

Fig. 2. The Jones greenhouse nearing completion

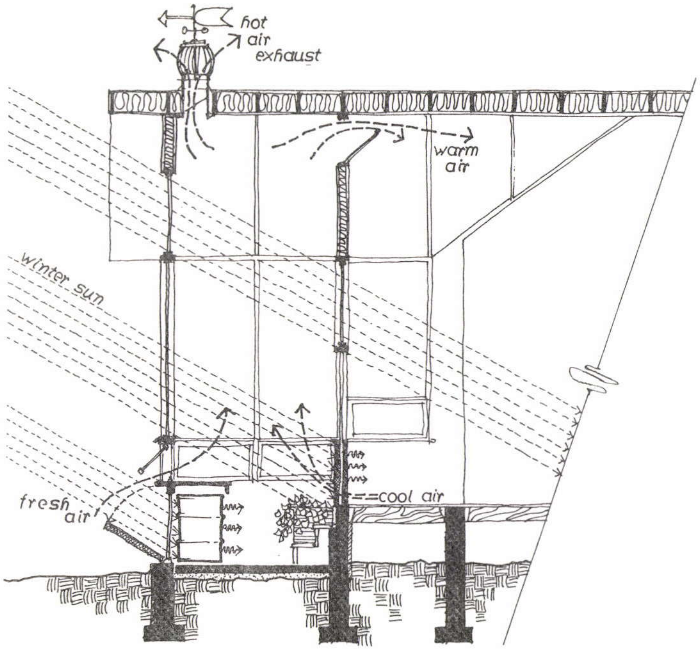

Fig. 3. Greenhouse section, Vollmer Schoolhouse renovation

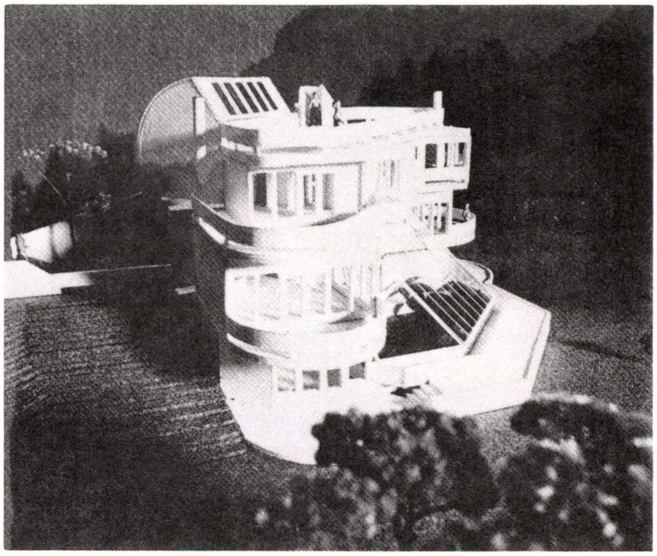

Fig. 4. The Chubb residence

The Chubb Residence

The Chubb residence is an actively and passively heated house presently under construction in the foothills of Boulder. The design attempts to integrate passive, hybrid, and active systems into a balanced whole. The structure is tucked into a south-facing hillside with minimal fenestration on the north and west sides. The active portion of the solar system is four domestic hot water collectors mounted on the upper face of the roof. As a passive-hybrid design aspect, a 700 sq ft solarium-greenhouse is the heart of the residence. The solarium is surrounded on the north, east, and west sides by the building. The south face is primarily glass in a wood beam structure. The floor of the solarium, composed of tile pavers on a 6-inch concrete slab, acts as a passive thermal storage. Excess heat is collected in a ventilation duct in the highest point of the solarium and is distributed directly into the house through the conventional heat-pump air handler. If the house does not require heat, excess heat is pumped by a fan into a 2-foot deep gravel rock bed under the solarium floor where it is stored for later use. The rock bed is insulated from the earth but not from the solarium floor. The floor is directly thermocoupled with the rock storage bed, allowing the low-temperature (70° F-95° F) heat to warm the solarium on cold nights. During the summer, a canvas roll-down awning provides necessary shade with low and high ouside vents providing natural convective ventilation. It is estimated that on a clear January day under design conditions (outside 0° F, inside 65° F) the solarium will supply one-third of the house's energy needs.

CONCLUSION

Every new greenhouse project calls for a fresh approach to passive solar design. There is much yet to be explored and learned. The form which any building takes should be in response to the natural forces of each particular site. By observing these natural forces, the architect can design a structure that conforms to nature and becomes complementary, rather than parasitic, to the natural environment. Each new site with its new set of variables will no doubt bring about improved concepts and new solutions. From this there will emerge a new design ethic based upon our respect for nature and its forces.

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THERMAL PERFORMANCE OF A TOTALLY PASSIVE SOLAR GREENHOUSE IN FLAGSTAFF, ARIZONA

James H. Welch*
Kenneth R. Olson*
David J. MacKinnon**

ABSTRACT

The thermal performance of Rodale's totally passive solar greenhouse in Flagstaff, Arizona, was monitored during the winter and spring of 1978. The results show that the greenhouse interior temperature remained at 30° F to 40° F above ambient in winter and 20° F to 30° F in spring, never dropping below 40° F. Temperatures at plant level stayed between 50° F and 85° F for the majority of the winter and spring. Water storage along the side walls and ground storage, even though not significantly illuminated by the sun, provided 50% of the total stored energy. Relatively small, water-filled containers in a tight fitting wall are shown to be a very effective storage element. And finally, shading within the Flagstaff greenhouse which increases as the sun rises toward a summer position shows no adverse effects on greenhouse temperatures, but creates reduced growth in plants.

INTRODUCTION

Two solar greenhouse projects were undertaken by Dr. David J. MacKinnon for Rodale Press, Inc., publishers of Organic Gardening magazine. One located in Flagstaff, Arizona, has provided a year-round growing environment with 100% passive solar heating. Another, near Allentown, Pennsylvania, had 85% of its heating needs provided by passive solar gain during the severest winter on record (1976-1977). The overall results of this project demonstrate the applicability of solar greenhouses for both a sunny, semi-arid climate with 7,200 degree days of heating as well as for a much more cloudy and wet climate with 5,800 degree days.

The Flagstaff greenhouse has been comprehensively monitored by the authors from mid-February 1978 through mid-April 1978 and is continuing. Its performance is analyzed in this paper.

GREENHOUSE DESCRIPTION (See Figure 1)

The greenhouse has an outside perimeter of 12 ft by 20 ft (long dimension on an east-west axis). The south-facing glazed wall is 200 sq ft in area and is inclined at 56° from horizontal. The north roof is tilted 43° from horizontal. The south and north walls join 9.5 ft above the midpoint of the greenhouse floor.

Only the south wall is glazed. The east and west side walls are opaque and insulated with 3.5 inches of fiberglas batt. Perimeter insulation around the foundation is 1.5 inches of polyurethane foam board. It extends 2.5 ft below the ground surface and continues horizontally beneath the floor at the same level. The perimeter foundation is also surrounded by a rodent barrier of hardware screen.

A movable aluminized curtain is pulled up nightly inside the south glazing as a barrier against radiant heat loss. Primary passive heat storage is provided by 170 water-filled, 5-gallon, square honey tins. Stacked five rows high, there are 550 gallons of storage on the north wall and 150 gallons on each sidewall.

There are three growing beds within the greenhouse. Each is 3-1/2 ft wide by 7 ft long by 1 ft deep. Vents, located on the north knee-wall and east and west sidewalls, are connected to open simultaneously by means of cables and pulleys. "Heatmotors" provide the force to open and close vents passively. A "heatmotor" is a temperature activated device which expands as it warms and contracts as it cools. The greenhouse door on the east sidewall provides significant vent capacity as well.

EXPERIMENTAL SET-UP

To evaluate the thermal performance of the greenhouse, temperatures at 13 different locations were monitored. Air temperatures were measured outdoors, and inside at the floor, midheight, and peak. (All points were shaded from the sun.) Temperature of the water storage was recorded at the bottom, midheight, and top of the north wall, and at the bottom and top on the east wall. Growing bed temperatures were monitored at the front and back of the central bed both at the surface and at a depth of 1 ft.

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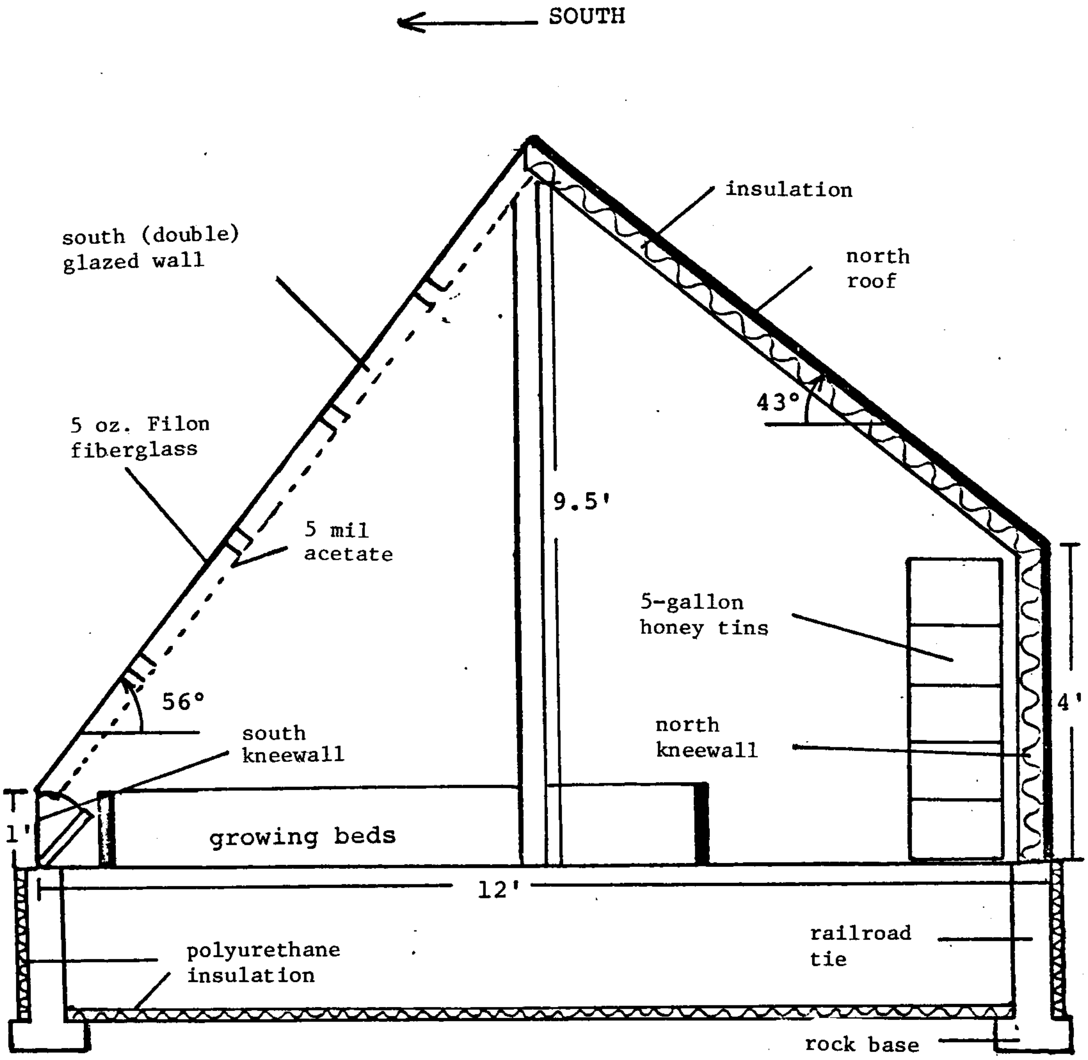

Fig. 1. North-south cross-section of Rodale's Flagstaff solar greenhouse

The temperature at each location was recorded every 2 hours on a Honeywell 24-point recorder, using Type "T" copper constantan thermocouples.

RESULTS

Temperature data were recorded continuously between mid-February and April. Two short intervals were chosen from this period which adequately demonstrated the thermal characteristics of the greenhouse. The intervals are: (1) Winter (February 21 to March 2, 1978) and (2) Spring (April 3 to 12, 1978). Each interval included a sequence of consecutive clear and cloudy days providing the necessary extremes in weather to display variations in the thermal performance of the greenhouse.

Winter - Clear Day

Figure 2 shows temperature readings for a 24-hour period (February 22, 1978) following several consecutive days of clear sunny weather. Greenhouse air temperatures rise rapidly during the daytime with the top of the greenhouse registering 100°F at 4 p.m. After the sun goes down, greenhouse temperatures cool slowly as heat stored in the thermal mass is released. At night the peak of the greenhouse cools slightly below the temperatures at the bottom and midheight of the greenhouse, recording the lowest indoor temperature for the day of 50°F. The close proximity of the thermocouple location at the peak to the south glazing caused recording of the coolest nighttime temperatures.

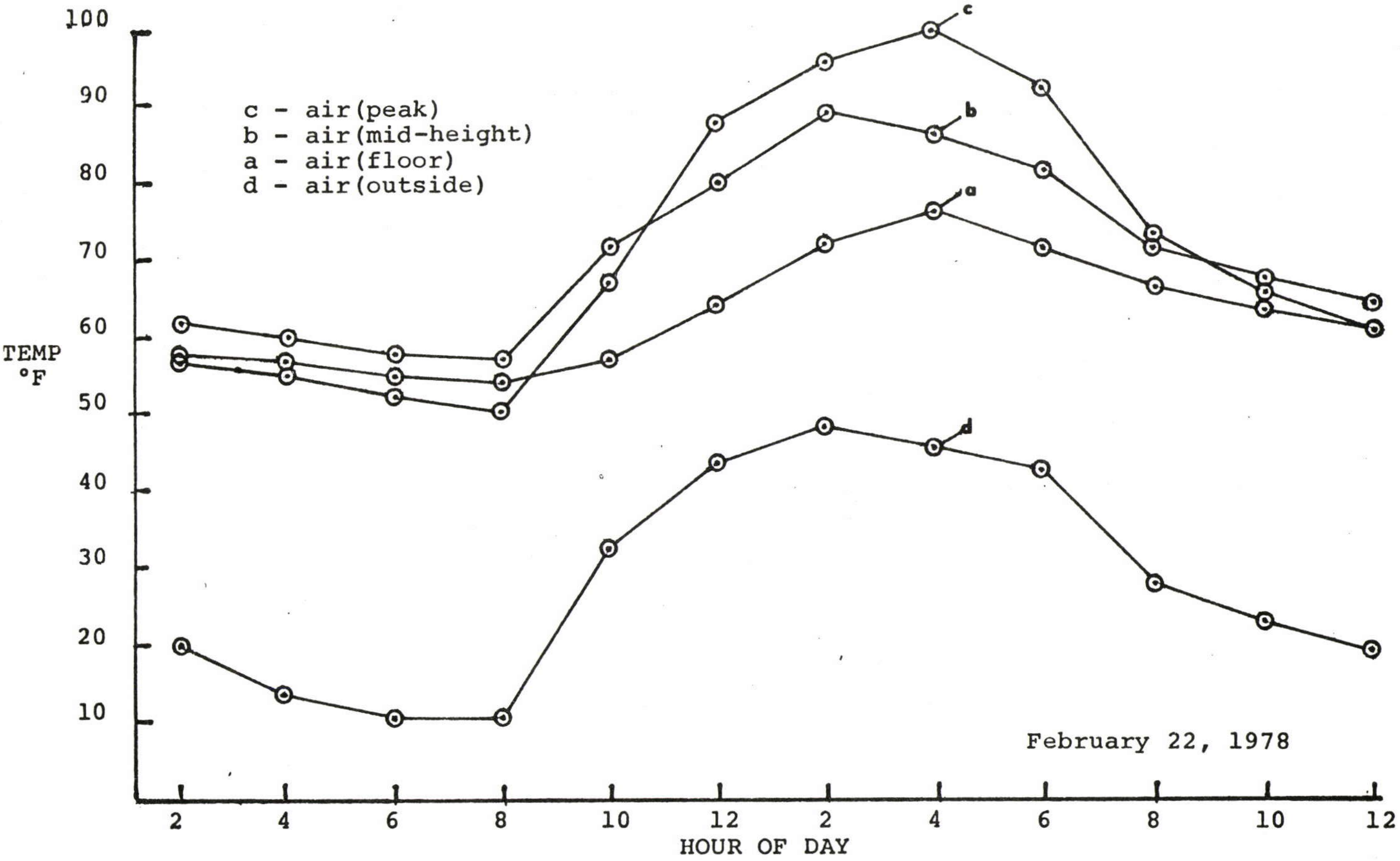

Fig. 2. Greenhouse air temperatures for the clear day of Febr. 22, 1978

Figure 3 displays temperatures in the water storage for the same 24-hour period. The storage on the north wall shows a substantial temperature increase during sunlit hours, registering a 17°F temperature gain on the top and a 7°F gain at the midheight and bottom for the day. Maximum temperature stratification between the top and bottom of storage was 18°F at 4 p.m. This indicates that the containers distribute the heat well vertically, minimizing stratification. Losses at night are slow, averaging 1°F to 2°F per hour.

The storage on the east wall maintains lower overall temperatures than the north wall which sees the sun for longer periods of the day in winter. However, the temperature of the east wall storage increased by 11°F at the top and 8°F at the bottom.

Soil temperatures in the growing beds for the same 24-hour period are recorded in Figure 4. The surface temperatures of the soil undergo dramatic temperature changes, rising 26°F at the back of the beds and 15°F at the front, during the day. At a soil depth of 1 ft, temperature changes are effectively dampened to 3°F to 4°F, respectively. During the winter, temperatures at the front of the growing beds are significantly cooler than at the back of the beds. The front "sees" more cool south glazing and less warm storage than the back, thereby causing the difference. Temperatures at a 1-ft depth average 10°F cooler at the front than at the back of the beds for the 24-hour period.

Winter - Cloudy Day

In contrast to the clear day, 24-hour cycle where greenhouse temperatures undergo wide fluctuations in response to large solar gains, temperatures stabilize during the cloudy day cycle. Figure 5 shows temperature readings at a variety of air, storage, and soil locations during a 24-hour period on March 1 corresponding to the third consecutive day of cloudy weather. While greenhouse air temperatures at midheight increase 10°F indicating some solar gain, temperatures in the north and east wall storage and in the growing beds are stable and relatively isothermal, remaining within 8°F of each other. Temperatures at the end of the day are 1°F lower than the beginning.

Comparison of Spring and Winter Greenhouse Performance

In comparing the winter and spring intervals, the range of air temperatures indoors at midheight was 56°F to 94°F in spring and 42°F to 96°F in winter (data not shown). Outdoor temperature ranges were 23°F to 66°F and 10°F to 48°F, respectively. While average greenhouse air temperatures remained 38°F to 40°F above ambient during sunny periods in winter, spring data indicate only a 20°F to 30°F differential. In contrast to winter, lower light levels within the greenhouse during

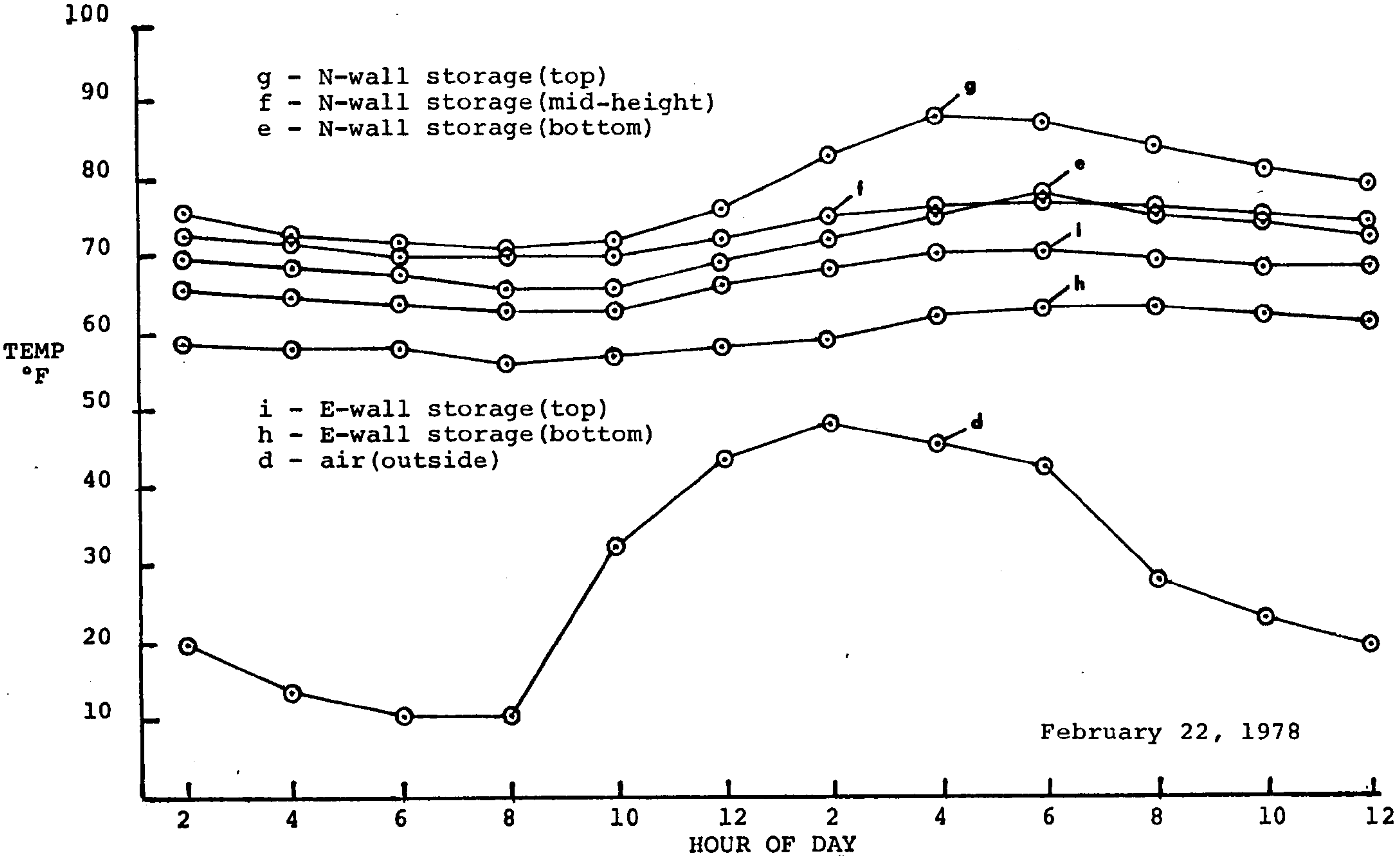

Fig. 3. Temperatures of the water storage for the clear day of Febr. 22, 1978

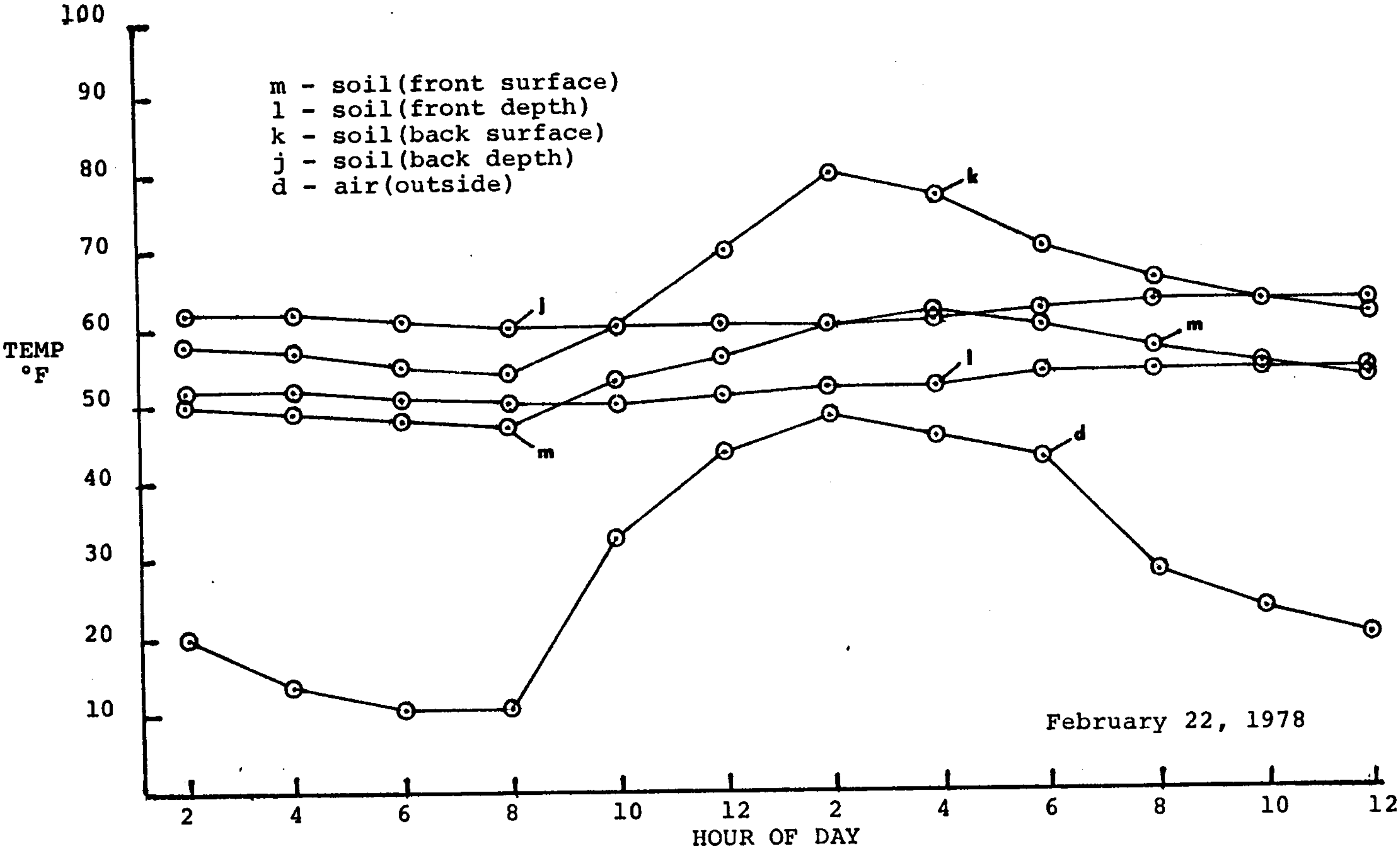

Fig. 4. Soil temperatures for the clear day of Febr. 22, 1978

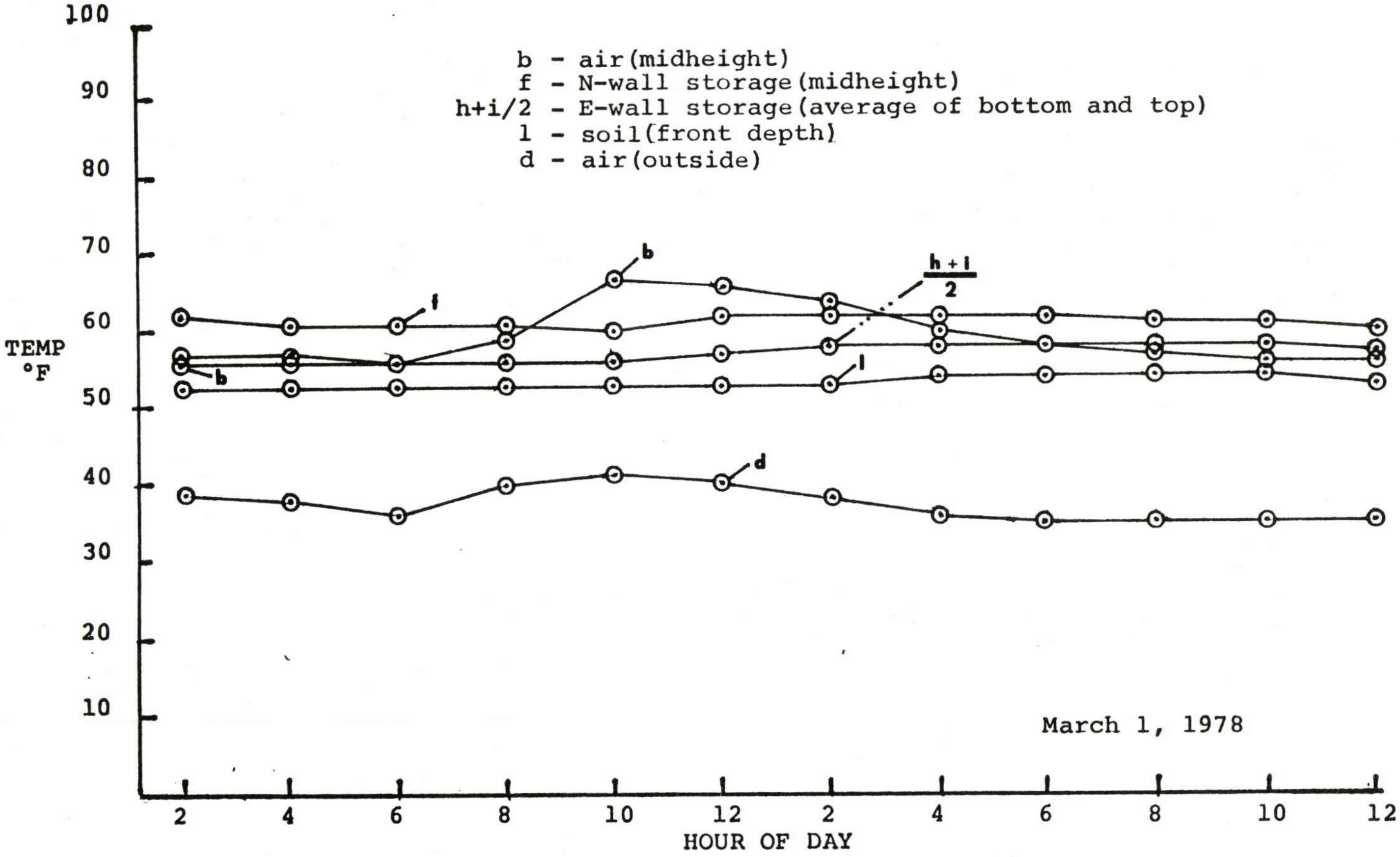

Fig. 5. Temperatures at selected locations for the cloudy day of Mar. 1, 1978

the spring coupled with venting keeps the greenhouse tracking closer to outdoor daytime temperatures.

In spring the increased shading of the greenhouse by the east and west walls in the morning and afternoon is evident. As a result, storage temperatures on the north wall are lower in spring than in winter. They average 60°F to 64°F fluctuating only 4°F to 6°F during a 24-hour period. This contrasts to winter where we observed average storage temperatures of 78°F with large temperature fluctuations. With less direct gain on storage in spring, temperatures are less stratified experiencing a maximum stratification of 9°F, half the amount recorded in winter.

Temperature differences in the beds were substantially colder by 10°F at the front of the greenhouse during winter, while spring data indicate they are within 2°F to 4°F of each other.

A comparison of ground level temperatures between spring and winter produced interesting results. Air temperatures at the plant beds registered a high of 85°F and a low of 50°F for the entire 9-day period in spring, being virtually identical to a 82°F to 50°F range recorded in our 10-day winter period.

CONCLUSIONS

As a result of this study, certain conclusions can be reached on the thermal characteristics of the Rodale solar greenhouse in Flagstaff and solar greenhouses in general.

The Greenhouse as a Solar Collector

During the monitoring period reported here the greenhouse air temperatures never dropped below 40°F and remained 30°F to 40°F above ambient in winter and 20°F to 30°F in spring.

A very rough energy analysis performed on two clear days, one in winter and the other in spring, showed that 34% of all solar irradiation entering the greenhouse was absorbed by the growing beds, the floor, and the water walls.

Even though the greenhouse seemed to collect and store adequate heat in the middle of winter, some excess heat was always vented on a clear day.

The Greenhouse as a Microclimate for Plants

Temperatures at plant level stayed between 50°F and 85°F for the majority of the winter and spring. However, different microclimates within the greenhouse itself were recognized from our study. Soil temperatures are much colder near the south glazing in winter. Although interior air temperatures increased with height during the day, little stratification occurred during the night and cloudy periods. Apparently the radiant heating from the water storage maintained a surprisingly uniform temperature environment.

The Thermal Contribution of East and West Wall Storage and Floor

Water storage along the side walls and earth at floor level provides an important addition to the thermal capacity of the greenhouse. A rough calculation shows that the sidewalls and the floor (including growing beds) each provided roughly 25% of the total stored energy.

Horizontal insulation beneath the greenhouse soil is probably not worth the effort or expense. Perimeter insulation is still recommended.

Proper Placement of Thermal Storage

Our study indicates the importance of proper placement of storage. By stacking 5-gallon honey tins on the east, west, and north walls surrounding the planting beds, there exists a significant radiant exchange from storage to the plant environment, dampening fluctuations and stratification in air temperatures during cold winter nights.

The Use of 5-Gallon Honey Tins as Thermal Storage

Relatively small, water-filled containers in a tight fitting wall seem to make a very effective passive storage system. These containers are small enough to reduce the vertical stratification of heat common in larger storage vessels, such as 55-gallon drums, but large enough to allow convection to rapidly place absorbed heat into the interior of the wall.

Shading of the Greenhouse by East and West Walls

Shading of the greenhouse interior by the east and west walls and north roof becomes increasingly evident as the spring equinox approaches. Although greenhouse light levels remain quite adequate for heating the greenhouse, loss of light to the plants in morning and afternoon limits plant photosynthesis. One solution to this problem might be the use of removable insulating panels on the east and west walls that can be taken off in spring to increase the light to the plant beds. This approach for summer growing would require removal of insulating panels on the north roof as well.

"LIFE BOAT": A DORMITORY FOR THE COLORADO ROCKY MOUNTAIN SCHOOL

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ABSTRACT

"Life Boat" is a dormitory that will be solar heated (passive), that will be extraordinarily conservative of both heat and electrical energy (generated by the wind), and that will recycle its gray water (shower and sink). To our knowledge, there is not another building in the country that stretches current technology so far and offers as much educational potential for those who live in it. It has already won a grant of $42,000 from the Department of Energy for its solar components and was widely acclaimed as a building of unusual significance by a juried panel at the] 978 National Passive Conference.

The uniqueness and importance of the project lie in the intimate ways in which technology is made to serve educational functions in the school and do not result only from its position at the edge of the "start of the art." It has been designed in part by students, will be built in part by students, and will be lived in by students. It is probably the most cost efficient project approved by the Department of Energy to date (dollars per Btu).

GOALS

The goals of Life Boat are of two sorts: educational and technological. At the educational level the project is intended to give those who live in the dormitory a new and different view of what their accustomed styles of living require in the way of energy and materials and to force a confrontation with issues of which they are too often unaware in their personal lives. For example, the temperature of the building will fluctuate rather more than most of us are accustomed to, and each resident will have to take deliberate action to achieve the comfort desired by raising or lowering thermal screens, opening certain doors and apertures, adjusting clothing, or building a fire. In this way residents will be much more aware of their thermal environment and will also have to accept responsibility for it. Important goals, therefore, are to increase students' awareness of, and responsibility for, their environment.

Because electricity will be limited, similarly conscious decisions will have to be made about the use of lights, washing machines, hair dryers, stereos, and other appliances whose use most of us take for granted. There will be power enough for most of these, but their use cannot be simultaneous and, some times, cannot be prolonged. Decisions about priorities will have to be made, and each resident will have to anticipate needs and plan ahead. Each will also have to develop an awareness of just how much power is available at any given time. (Meters will be available in a public place to facilitate this.)

By having to make deliberate decisions about whether or not to use certain appliances at certain times and by having to be assertive in maintaining a comfortable temperature, we hope students will begin to develop a somewhat more realistic view of their impact on the resources of the world. In addition, however, we expect them to appreciate the elegance of the simpler alternatives provided in Life Boat as compared to those with which they have been raised. Ultimately, our goal is to alter students' expectations and sense of personal responsibility so that they will adopt ecologically considerate ways of living.

Other educational goals derive from those already described and relate to social aspects of the school and the larger public. We expect Life Boat to be popular among students, even as it makes unusual demands of them. To a degree they have probably not experienced before, the comfort and convenience each individual feels will be dependent on what others do or on what all agree to do together. Schedules will have to be developed and agreed to by the group and what one individual does or fails to do will be felt by all. The potential for war and strife is obviously there, but it is our conviction that the stronger potential is for the development of an incredibly strong community marked by concern for the commonweal and pride of accomplishment. Our commitment is to make Life Boat a vehicle for responsible citizenship and the realization of the joy and satisfaction that must ensue as that citizenship is expressed in decisions and action by the group and by individuals.

At another level our goals are to advance knowledge: knowledge about the technology of passive solar heating and low voltage, wind generated power, but also knowledge about how to involve young people in the discovery of such knowledge. Given current imperatives relating to the use and discovery of energy in the world, the aggressive pursuit of such knowledge must be awarded a high priority. Equally urgent, at least in the view of those of us who teach at the secondary level, is the active pursuit of such knowledge within the school as part of the normal academic program. We are convinced by our own experience that high school students are fully capable of doing, or at least of participating productively in, original work and that such work is an urgent and essential element in the design of an optimally challenging and effective educational program. Our goal is thus to explore effective ways of teaching by exploring important ways to harness the energy of the sun and the wind.

A DESCRIPTION

Life Boat is a dormitory for fourteen students and one faculty family. With the exception of a second floor bedroom-study in the faculty residence, the building will be one level sunk underground and covered with sod. Only the southern wall will be exposed. Seven rooms for students (two students per room) open onto an east-west hallway interrupted in the center of the building by a living room. The faculty apartment is at the east end of the building and shares a storage and workshop area that separates it from the students' area. The workshop and storage area provides space needed by both students and faculty but also acts as a sound barrier and thus gives a measure of acoustical privacy to the family in residence—something lacking in many dormitory situations.

The building itself is heavily insulated below the floor, in the walls, and in the ceiling. Earth moved up against the three unexposed walls and on the roof further isolates the building from external variations in temperature. The underground design is thus an integral part of the thermal plan; in addition, however, it is also important for achieving harmony with the fields which surround it. Although burying the building increases its cost of construction, the extra cost will be more than compensated for by significantly lowered costs of maintenance, the tradeoff occurring probably by the seventh or eighth year.

Colorado is one of the more suitable locations in which to employ a solar heating system, and we can expect the solar system to provide more than 80% of the building's heating requirements. A wood burning furnace with hot air ducts to the extremities of the building can be used to supplement the solar system during prolonged periods of cloudiness or when we experience unusually low temperatures. The decision to use a wood burning furnace instead of an oil or gas burning one is another deliberate attempt to put students (and faculty) in touch with their environment. Monitoring the temperature, cutting wood, and lighting and stoking the furnace—each is a way to remind ourselves what it takes to be comfortable.

TECHNICAL SYSTEMS

Solar Thermal Performance Summary

Heat. The passive solar heating and cooling system selected for use in the dormitory is one in which thermal energy flows through the building (from collection to storage to distribution) by natural means, enabling the system to function without external power. The operation of this system involves the control of the thermal energy flow and includes the ability to prevent heat and sunlight from escaping or entering the building as desired. It also includes the ability to vary the timing of the energy flows within the building.

The passive solar system features incorporated in the dormitory include integrated south wall solar collection and storage, sunlight reflector monitors, a unique automated movable insulation system powered by photovoltaic cells, and a passive solar tank domestic water heater.

Hot Water. The passive solar preheating system incorporates a slightly concentrating, nontracking symmetric cusp reflector, combined absorber-storage tanks, and a simple form of movable insulation which prevents heat loss from the system during noncollection hours. The reflector design is based upon the work of Ari Rabl at Argonne National Laboratories, where a nontracking reflector geometry has been developed which permits maximal concentration on cylindrial absorbers.

Electric Generating System

A survey of the available wind energy at the proposed site was conducted from February 11, 1978, to March 10, 1978. A telescoping tower for changing the instrument height was used to determine the variations by the site topography.

Result of Survey

Average Windspeed at 40' altitude	4.8 mph
Average Windspeed at 50' altitude	2.4 mph
Average Windspeed at 60' altitude	6.4 mph

Electric power required - estimates of the electrical loads are based on kWh consumed per month.

kWh/Month Student Housing Space

Lighting	74 kWh
Stereo	9
Washing Machine	21
Vacuum Cleaner	6

kWh/Month Faculty Apt. + Workshop

Lighting	38 kWh
Refrigerator/Freezer	80
Stereo	5
Vacuum Cleaner	2
Washing Machine	6
Hot Plate (grill)	3
B&W Television	20

Total Demand 264 kWh/Month

This is an extremely low electrical demand. The conservation ethic was again the overriding design principle minimizing appliances and using energy-conserving fixtures. Beam daylighting from the sun produces a significant reduction in illumination requirements.

Related System Analysis. The building will be wired for low voltage direct current. An abundance of low voltage fixtures are currently available due to the growth of the recreational vehicle industry. There is a major cost savings by instituting low voltage wiring due to the requirements of the State Electrical Code and fire insurance premiums.

The electrical system will be connected to public utility lines via a transformer and rectifier. This allows for economical backup since the winds are not conspicuously high or sustained in the Carbondale area.

Water Conservation - The Use of Recycling Greywater

System Description. The proposed system essentially consists of recycling greywater from wash basins, showers, and washing machines for two major purposes: (a) flushing water for toilets and (b) irrigation water for the greenhouse.

The system will be designed so that greywater from the wash basins and showers in both restrooms in the dormitory will flow to a sump. The sump will act as a storage reservoir from which greywater may be pumped to water closets for use in flushing toilets. Thus, after every toilet use the student would use a handpump to refill the water closet for the next use. The sump will be sized so that it will provide sufficient storage below its overflow for toilet use, but yet not store the greywater for a period long enough for septic conditions to develop. The faculty housing portion of the dormitory will be equipped with a similar sump. All drains from wash basins, showers, and the washing machines will be specifically equipped to remove as much of the suspended matter in the greywater as possible. This will assist in preventing clogging and odor related problems in the sumps.

Greywater entering the greenhouse will pass through a sand filter which will essentially remove all suspended solids and most pathogenic organisms. A gravel bed below the sand filter will act as a storage reservoir. This bed will extend from the center of the greenhouse laterally to an area below the growing beds. Another sand layer will exist above the growing beds which will draw moisture from the gravel and move it up to the topsoil layers by capillary action.

Recycling of Greywater for Greenhouse and Toilet Flushing Use. Typical concentrations of various constituents of greywater are presented below. Heavy metals are present in high enough concentration to be toxic to plants normally grown in the greenhouse. The concentrations of the nutrients nitrogen and phosphorus present in their various forms should greatly enhance plant growth. The concentration of suspended soils requires some removal of the sand filter to prevent soil clogging and hindrance of the upward movement by capillary action in the irrigation process. High BOD_5 levels require that detention time in the sumps be held to a minimum to prevent septic conditions and subsequent odor problems.

Greywater used for greenhouse irrigation:

Total greywater available	8,490 gallons/month
Less toilet flushing	- 6,300 gallons/month
	2,190 gallons/month available for green house irrigation

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THE ARIZONA PORTAL SCHOOL PROJECT

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ALTERING THE IVORY TOWER IMAGE

Eight-year old Sean Collins scrunched his brow in concentration. He was struggling to arrange batteries and wires so they would cause a bulb to light. Try this wire here; attach that wire there. Well, maybe this way instead . . . Finally, success! Sean's face lighted right along with the bulb. He had solved a problem. And incidentally, he'd learned a lot about electrical circuits. Batteries and bulbs or bugs and bees—they are all a part of a child's world and they hold a natural fascination for him. Yet many children rarely encounter much of this "world" in school.

"But if we'd assigned him a chapter to read, or given him a lecture on the subject matter—just forget it." These are the words of Beverly McNamara, a Scottsdale teacher who has had special training in what is known as the "hands-on" approach to learning science concepts. Mrs. McNamara has participated in an Arizona State University sponsored Portal workshop for leadership training in science. She has been a Portal Leader since 1974.

The Arizona Portal School Project is designed to provide teachers with the necessary competencies for directing hands-on investigations of the child's real world—the "things" of science. The Portal School concept was inspired by the need to familiarize teachers with activity-oriented science programs and to prepare them to use the hands-on approach to learning in their classrooms. It is called a Portal Project because it is intended to provide a "portal" between the resources of the university and the needs of a school district. The Project is conducted in two phases: Local, master teachers are brought to the university campus during the summer. To qualify as a Portal Leader candidate, a teacher must be nominated by district administrators and possess a master's degree, a high degree of charisma, an open mind, and the confidence of fellow teachers. Summer Leadership Training is conducted as an intensive, three-week "minitute," during which the candidates participate in science education seminars, curriculum exploration through hands-on activities, and leadership skill training. Upon successful completion of all tasks, the teachers become certified Portal Leaders.

The second phase of the Project is initiated during the final days of the minitute when the Portal Leaders develop a course outline to be implemented in the form of teacher workshops the following fall.

Since its beginning in March 1974, the Arizona Portal School Project has sponsored 10 leadership minitutes in science, science materials, metrics, outdoor education, and energy. A total of 273 Portal Leaders have been certified; 7,286 classroom teachers have participated in the Project. Analysis of data from a 1977-78 NSF-funded evaluation of the Portal School indicates significant statistical differences in teaching behaviors between those who have had Portal training and those who have not.

The major objectives of the Project are to:

- assist local school districts in identifying their needs in science education and to develop programs which would respond to these needs,
- cooperatively plan and conduct workshops in the districts which would assist in implementing the program,
- develop science education leadership within the local school districts,
- develop new science teaching competencies, and
- develop a self-supporting structure which would continue the pursuit of excellence without federal assistance.

In meeting these Project objectives, the Arizona Portal School Project is altering the "ivory tower" image of the university. The Project is designed to encourage a constant flow of communication from the elementary classroom to the university and back to the classroom. Portal Leaders act as liaisons for the university and the classroom where the philosophy and technique of the Project are applied. Feedback from these leaders provides for ongoing evaluation and refinement.

STRUCTURING FOR ENERGY EDUCATION

The concept of energy has been flagrantly misused by the media, the commercial sector, and by most politicians. Consequently, when most people think of energy, they think of fuel, and then they think of petroleum. Energy is not a resource; it is a result of how resources are utilized. Energy, therefore, also means strength, force, life, and the potential or capacity for action. To begin considering energy from this perspective is mind-expanding, and certainly breeds more optimism.

All questions about energy are really human questions of values. Accepting this, the next consideration is how do values define options. If options seem limited, what is limiting them? What can be done to create more options? In 1976, a year before President Carter outlined his energy proposals, the Arizona Portal School Project offered its first leadership training in energy. In 2 years, 614 teachers have been enrolled in Portal Energy Workshops. Potentially, they affect over 18,000 students. Through hands-on activities, teachers and children have since explored all kinds of systems for energy transfer and conservation. Evaluation of the energy workshops by participants indicates the following changes in attitudes and behavior:

- as a result of the workshops they pay more attention to media and community reports about energy,
- they can better interpret this information and decide what is reliable,
- they have instituted conservation measures in their homes, and
- they have incorporated energy-related activities into their respective science curricula.

This broader base of information and understanding allows for changes in values, and, subsequently, in priorities. Options not before apparent can be considered.

This process of education fosters a more scientifically literate citizenry—a citizenry that can exercise power in manipulating the forces responsible for its lifestyle. It seems reasonable that it is this kind of citizenry that is vital to a working democracy.

SYSTEMS DESIGN CONSIDERATIONS FOR FARM DIGESTERS*

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i e associates
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An anaerobic fermentation tank is basically a container which holds a mixture of organic materials and excludes air. These units vary in size and complexity from a one gallon jug with a cork and tube used for a gas outlet to the sophisticated tanks with floating covers used by sewage treatment facilities. Nature provides the microbial population which is active from ambient temperatures (as seen in the generation of marsh gas) to about 120°F in modern thermophillic reactors. Man, up to the present, has not been able to significantly improve upon the gas production which lies in the range of 1 to 5 cu ft of gas/pound of volatile solids added. He has, though, been able to decrease the amount of time needed to capture from 70% to 90% of available gas from about 30 days to as little as 3 days, under special conditions.

Thus, we know that fermentation systems do work from a biochemical perspective. If further research is really needed, it will probably be in the biological area and will yield an order of magnitude increase in gas production. But these will be second generation units. Today, small, farm-scale units are available, provided one uses good, common sense engineering and sound systems and site analysis before design and construction of a unit. The greatest barriers to adoption are poor engineering design and lack of foresight in planning the location of a system and the use of heat, electricity, and biogas. The complexity of the units and the variables make the economics very site specific.

Under contract with the U. S. Environmental Protection Agency, we have been monitoring two full-scale systems which were constructed as commercial ventures. Additionally, we have studied in some detail a self-designed system constructed from brewery tanks for use on a horse farm and a "3-cow" pilot plant. We have also been cataloging and analyzing information from other farm units throughout the United States. Our specific objective was to ascertain the lower size limit for economic viability in the United States given current farming practices. We had additional interests such as understanding the feasibility of using municipal solid waste in conjunction with animal wastes and ascertaining the legal, political, and social barriers to adoption of this technology. Our principal site, a 125-head dairy operation, was completely re-engineered once during the course of study and had three different motor/generator units operating at various times. As a biological fermenter, it performs well; but, as an electromechanical system for moving waste and producing gas, heat, and electricity, it is an unreliable and extremely expensive unit. Interestingly, though, the unit does not have significantly more problems than other units currently extant which are aimed at the current farm market.

In carrying out the analysis for the EPA and in a preliminary assessment for the U. S. Department of Energy, several crucial design factors became very apparent. First, there is a step function associated with capital costs of these units. Pumps, pipes, cement, tanks, engine/generator units, and similar components have a base cost regardless of size as does labor. The cost does not increase linearly with increasing herd size. Because the small farm produces less energy, the economics become very sensitive to design and operational criteria. The 125-cow unit in Rice Lake, Wisconsin, cost $40,000 originally and would have a duplication cost of $55,000. Components costs alone are in the neighborhood of $25,000 which includes about $12,000 for an engine/generator unit. Note that the power production portion of the system can account for about half the capital investment and, as will be shown, can be the primary economic "albatross" for fermenter systems.

Figures 1 and 2 show the lifetime costing of the study unit for various depreciation rates and for different energy options (gas or electricity). These economics are based on current accounting practices which utilize standard business discounting techniques, adjust for the farmer's income level, and reflect moderate inflation and energy price rises. Several crucial factors are apparent. First, economics or bookkeeping practices which predict returns on investment based on monies borrowed or saved can radically alter projected worth of a system, especially at the small farm level where the highest sensitivity exists. Secondly, for small farms, returns on investment are very site specific. What works on one 100 cow operation might fail, economically, on a second operation of familiar size. Finally, the use of biogas to produce electricity is not only the single most costly expense from a capital investment perspective, but offers the least efficient option for the use of the biogas and hence proves to have the highest lifetime cost.

A commercial engine/generator unit can expect a major overhaul once every two years at a cost of about

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*Work supported in part under Contract (R-804457-01) by the U. S. Environmental Protection Agency.

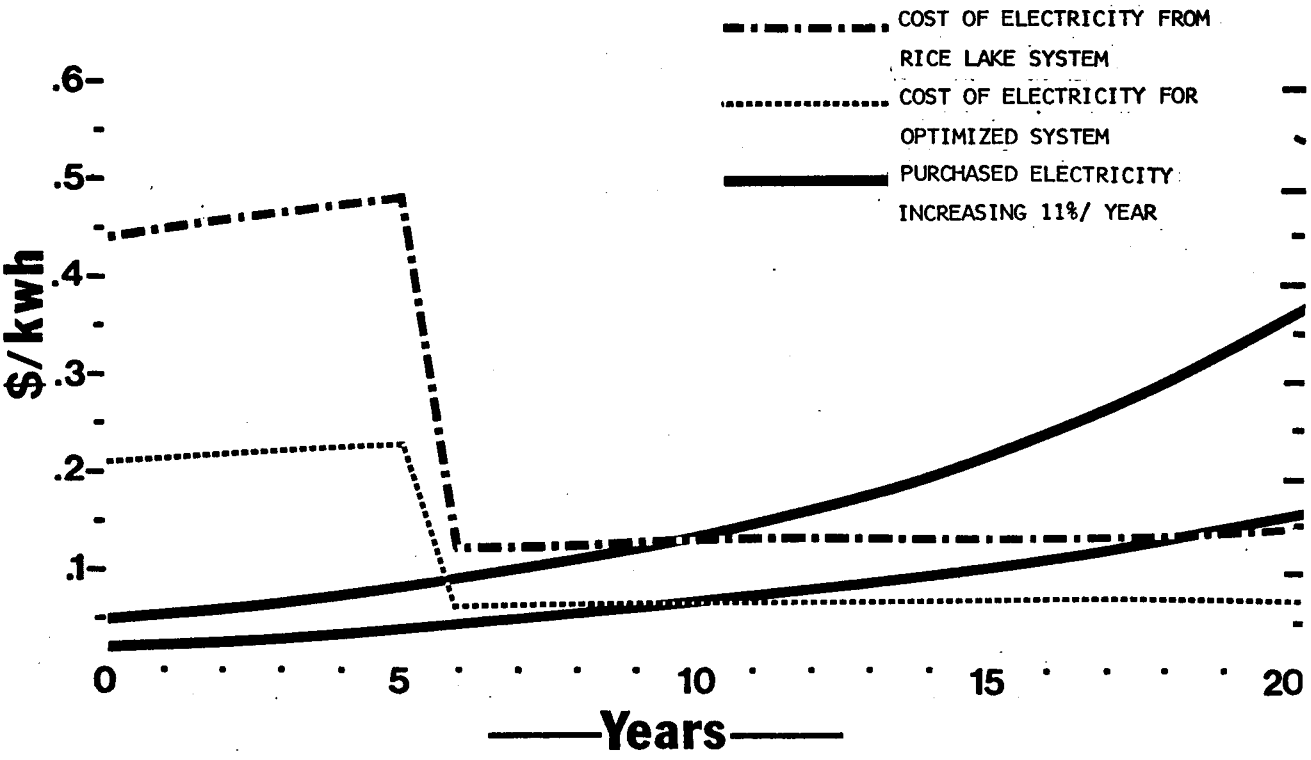

Fig. 1a. Range of costs for electricity from digester systems (100 cow dairy

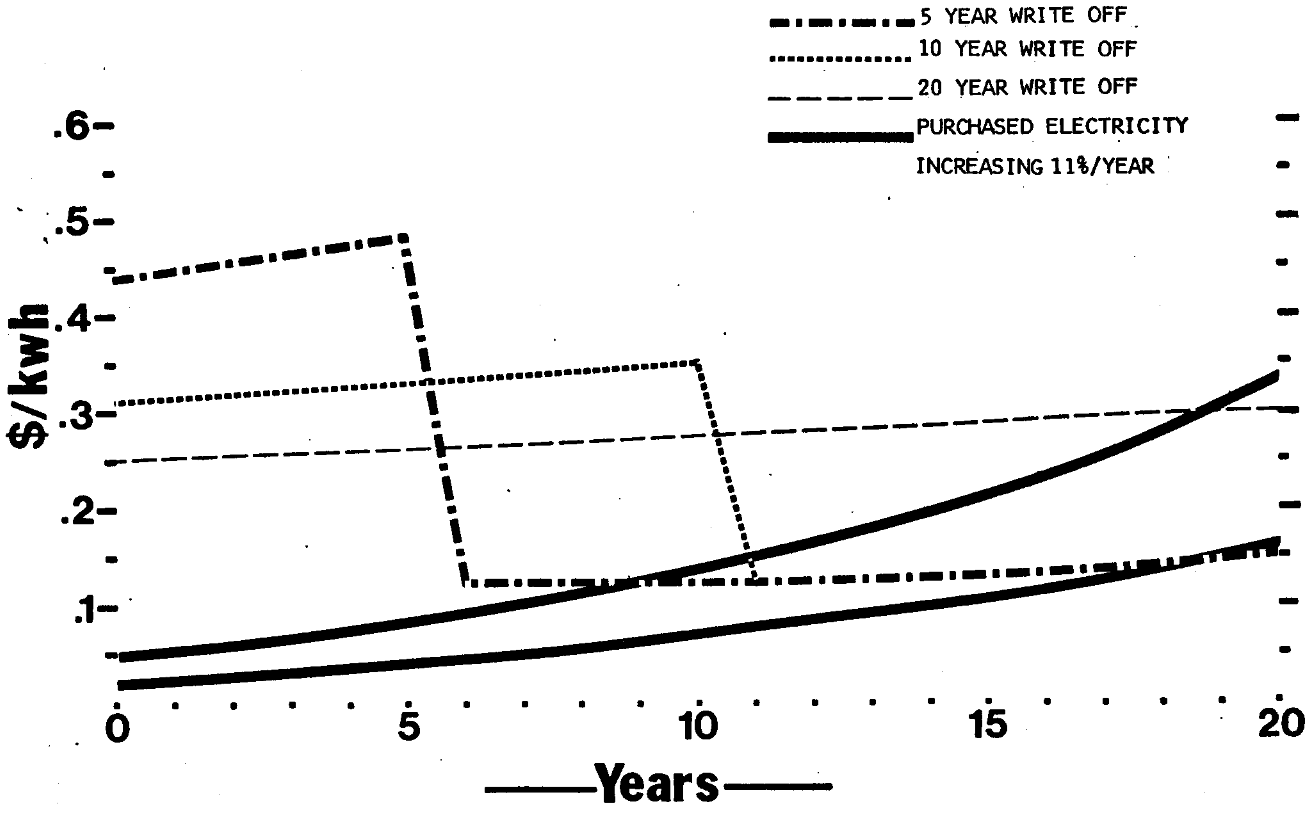

Fig. 1b. Cost of electricity from $40,000 digester vs. cost of electricity from utility company

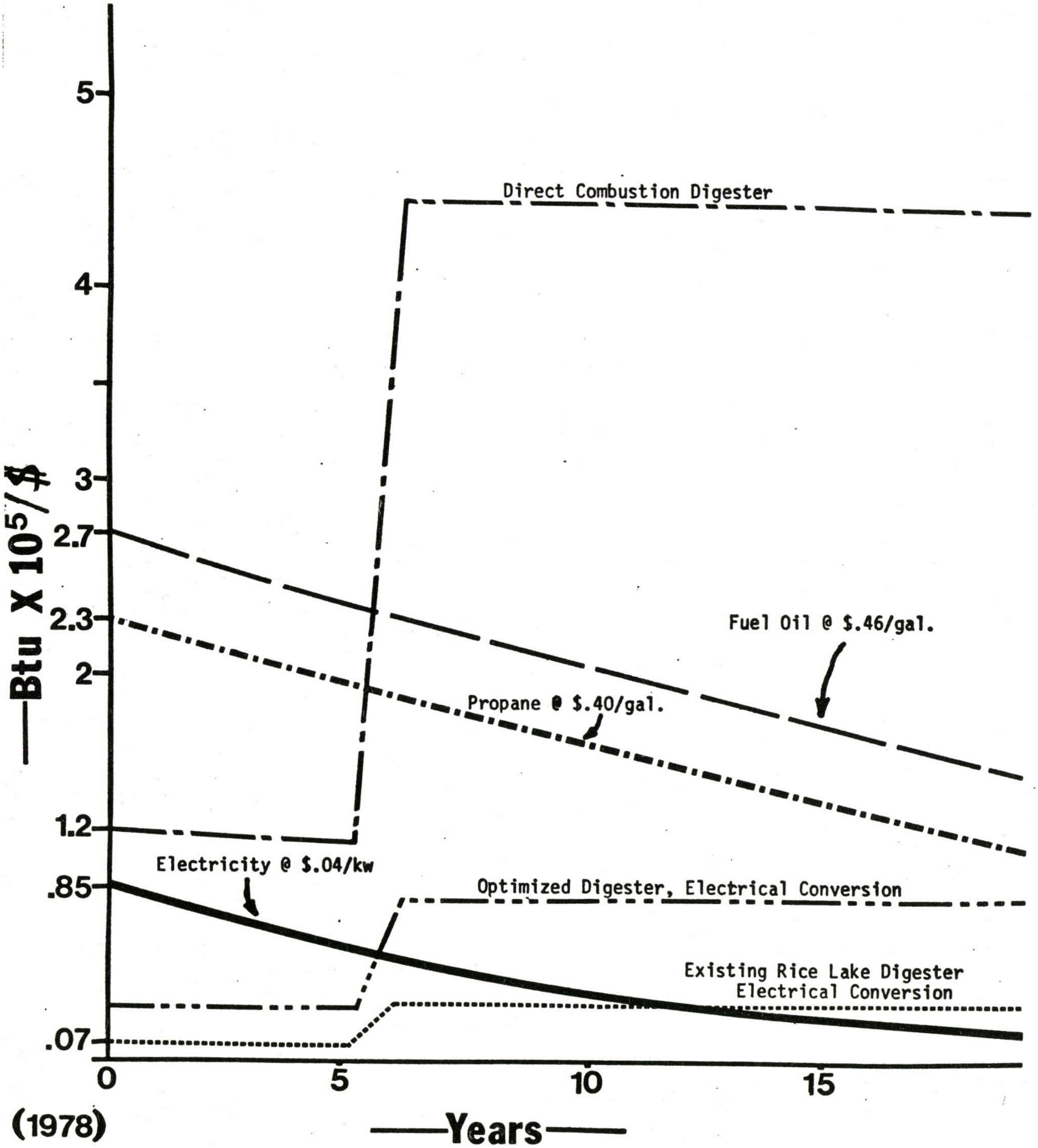

Fig. 2. Btu/$ of different energy and digester types

$1,200—or an average daily cost of from $1 to $3. If a small farm ran a 10 kW unit for 10 hours per day under full load, it would experience a base cost of from $0.01 to $0.03/kWh excluding amortization and operational expenses. The cost, of course, diminishes with larger units provided that they, too, operate under full load. This makes an application very site specific and requires careful load matching and sizing. It clearly indicates the problems which power companies experience with regard to peak loadings.

In reality, unless a farm has undergone a load leveling program or is buying peak power from the utility while using the generator as a base load unit, the generator is operating at less than full conditions and base costs rise. Additionally, using the utilities for peak loads, if these peaks are coincident with normal utility peaks, could lead to decreased economic benefits.

Another point to consider is the fact that engine efficiencies also decrease under conditions of less than full load. What is even more important is that converted gasoline engines operate under field conditions with only 10% to 15% fuel conversion efficiency and dual fuel (diesel/biogas) operate with only a 25% efficiency under full load. If biogas were valued at $2/MBtu, then, at 25% efficiency, the engine/generator would produce electricity at $0.03/kWh without considering capital costs, maintenance, and depreciation. The digester at Rice Lake produced electricity at $1.26/kWh under actual conditions.

One method of lowering the cost of electricity is to distribute a portion to that fraction of the waste heat which is used either for heating the fermenter or for on-farm use. Although the credit approach is appropriate, it does clearly point to the fact that in excess of 75% of the energy used in the engine/generator does appear as thermal output. While cogeneration is an appropriate technology, one does ask whether or not the electricity should be produced in the first place or in the quantity which normal farms are accustomed to.

Our studies show that full utilization of the biogas for thermal loads could prove to be a significant problem in the midwest and, we suspect, in other regions where the REA and the promise of cheap electricity have many farms supplying thermal loads by resistance heating. To effectively utilize the gas many items such as stoves, hot water heaters, and some space heaters will have to be shifted from electricity to gas, often at considerable expense.

Where there are high seasonal thermal demands such as fall grain drying and winter heating, a seasonally peaked biogas plant (Figure 3) might be a viable option. Here energy is stored in the form of manure during off peak and seasonally increased by increasing fermenter feed rates.

Even with seasonal peaking, care must be taken in evaluating the use of the biogas. For example, it might prove cheaper in the long run to capture waste heat from the bulk tank compressors for dairy hot water needs than to use biogas. Also, cheap energy has allowed for continuous, high-temperature grain drying. Economizing by using combination high/low temperatures (perhaps with solar) might prove more beneficial than using the fuel requirements to justify a biogas plant. The key is careful systems evaluation and planning which might imply site-specific solutions on similarly sized farms with different management patterns.

In carrying the economic justification for digesters one step further, some individuals have credited benefits for pollution control (odor and run-off), increased fertilizer value of effluent, and uses in aqua and algal culture. Good pollution control and fertilizer (nitrogen) preservation can be obtained from using a covered lagoon, which we recommend for fermentation systems, in any

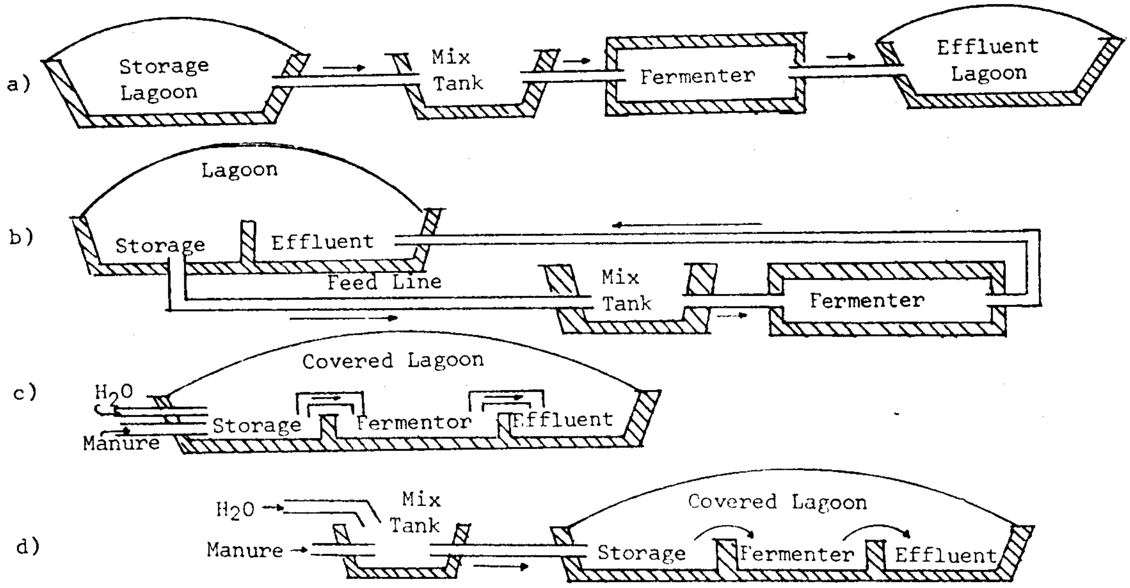

Fig. 3. Schematic for a variable feed system

case, as low pressure storage for gas. This implies that the tank and machinery for producing and using the gas must be justified on energy alone.

In passing, one might look at a covered lagoon as a non-heated fermentation tank that produces gas in the same way that nature does at the bottom of a lake. The lagoon cover would serve as a low-cost solar collector. Thus, if time and quantities of gas were not crucial, the amount of energy from this system might be a plus without going to the trouble of developing a fermenter system.

Increased fertilizer value is a very sensitive issue, and we believe that a long-term study needs to be carried out to verify any additional benefit which may accrue from fermentation. Animal wastes, when incorporated in the soil, are first broken down by microbial and physico/chemical action which is slow. The byproducts are then used by plants. In the case of synthetic chemicals, the process is similar to hydroponics with the soil serving as a matrix. Fermented materials probably fall between these two extremes, and there is no clear evidence, over time, what the difference in quality is—or if there is any net benefit from fermentation.

The same argument applies to aquaculture, algal culture, and the heavily emphasized area of animal refeed. A number of groups are carrying out refeed studies on fermenter effluent. Although there is some evidence of increased protein content in the digested slurry, it is not clear whether it is of nutritive value to the animals and/or which animals should be fed slurry from various fermenter materials. In fact, feeding of animals with undigested manures has had mixed results, and cross comparison studies have not been done.

In all these studies, there are so many variables that conclusive data may never be obtained in the near term. Exact numbers are not crucial, but "ballpark" figures are needed. It is our belief that the systems are technically feasible and are economically viable for site-specific applications. Constraints on both economic and technical feasibility can be eased when better answers are available on the use of fermenter effluent.

Even when site-specific economics "appear" to be viable, careful design is still needed to actualize the benefits. Part of that design involves the degree of labor involved, from daily maintenance to trouble shooting. A case in point is gas handling and utilization. Biogas contains water which can be trapped or "scrubbed" out. Although pipeline quality dryness is not imperative, it should be realized that methane forms hydrates which freeze at temperatures above that of water and thus can create problems even in pipes buried below the frostline. For small-scale systems, scrubbing of the biogas to remove carbon dioxide is not crucial for combustion or engine operation; hydrogen sulfide removal, though, is necessary for engine maintenance, but removes the ability to detect leaks via odor. Also, the higher the gas storage pressure, the more expensive the system.

Fermenter feeding is a crucial item. In cold climates, from 10% to 25% or more of the biogas can be used just to bring the manure in a barn up to the temperature of the fermenter, especially in winter. If this is not done prior to loading, there is the danger that thermal shock could hamper gas production. Additionally, 20% or more of the biogas can be used just to maintain temperature of the fermentation tank. This implies that over 50% of the realizable energy could be consumed just by the system itself. Interestingly enough, research with earth-integrated structures shows that burying a fermentation tank could be ineffective as an energy saving design technique if care is not taken. Small changes in moisture can increase earth conductivity almost linearly. Even well insulated tanks (3-4 in. of foam) can take about 3 years to get the ground to come to a thermal equilibrium which provides beneficial insulating properties.

Feeding the fermentation tank is the most crucial component in fermenter operation. An ideal situation would allow gravity flow of the waste from barn or feedlot to the fermentation system and on to the lagoon. Here only winter freeze and an occasional plug will be problems if no bedding is involved. In most cases, some form of pumping is employed and the problems are magnified. Of all the problems which we have analyzed, pumping has to be the paramount issue which causes the most operator time for maintenance and systems operation. This is compounded when there are several pumping tasks such as feeding the fermenter, removing materials from the tank, and refeeding the fermenter with effluent to prevent microbiological washout on short detention time operations. Even with the most efficient chopper pumps or macerators, bedding, animal hairs, rocks, wood, and similar debris present problems. Ram pumps work well for feeding the fermenter, but systems using these then need other pumps for handling effluent. More pumps imply more management and operational problems. Pump sizing is another real problem.

Electrical power presents a unique set of issues which have to be faced by a systems operator and/or designer. These include both technical and political issues. Full load operation is desired during the time the generator is operational. This means either undersizing the system and buying power or very careful load leveling and power matching. If the unit does not operate 24 hours per day and waste heat is used for fermenter temperature maintenance, then either supplemental heat must be supplied or the system swings with the environment. Another management issue is frequency maintenance and power distribution on the farm.

This latter area is of interest if the farm hopes to either parallel with the existing utility hookup or participate in a power buy-back program. The parallelling approach is the easiest method of handling power distribution on the farm if total independence is not to be achieved or a utility hookup is to be maintained for emergencies. Another approach would be the separation of the circuits into utility-supplied and onsite-supplied.

Besides the technical system problems and the integration with utilities, new issues such as zoning, safety (especially with hired help and OSHA), insurance, and financing will become issues with the proliferation of this technology. The possibility of combining farms with common systems and town/farm systems is also of interest. Each has its own set of unique problems which must be handled. The point is to handle them now rather than after systems are installed. A fermentation plant is a combination sewage plant/energy center with tremendous potential or headaches depending on the amount of systems planning done beforehand.

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WOOD HEATING

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PART I

THE EFFECT OF FUEL VARIABLES ON WOOD STOVE PERFORMANCE

When our wood stove testing program began three years ago, it was our intent to compare and understand the performance of various stove types and models. Some progress has been made toward this objective [1, 2], but our early work made it apparent that the performance of a wood stove is very much affected not only by its design but also by how it is operated. Thus our recent research efforts have been aimed at exploring and understanding variables such as fuel type (species), fuel moisture content, fuel piece size, fuel load size, fuel stacking arrangements in stove, use of stove and stovepipe dampers, and the power at which the stove is operated. A full understanding of these variables is required before a good performance test standard can be written.

A full exploration of all these variables would be a very large undertaking, as they are not necessarily independent from each other, and their effects will not generally be the same in different stoves. A flat-black Jøtul 602 (Fig. 1) was chosen as the stove for this series of tests because (1) its small size simplifies certain testing procedures, (2) we suspect that results obtained with this stove will not be atypical for many other stoves (it does not represent a design extreme such as a true down draft stove, or a stove with extraordinarily high heat transfer efficiency), (3) the stove is sufficiently air-tight that good control of the amount of combustion air is possible, and (4) we had the stove in our testing collection.

Since stove performance is affected by so many variables, it is useful to keep fixed all the variables except the one of interest in each test series. For instance, in probing the fuel variables, since a constant average rate of heat output is usually the objective of using a stove, we attempted to operate the stove at a uniform average power output (of about 5,000 watts [about 17,000 Btu/hr]). Thus the required air inlet setting varied with the fuel moisture content (moist fuel generally requiring more air to achieve the same useful heat output rate). The air inlet setting was usually left fixed during all but the initial portion of each test.

Typical tests involved burning 10 to 20 kg of fuel over a 10- to 15-hour period. Except when wood piece size was the particular variable under investigation, wood piece volume and length were held roughly constant (at about .002 m^3 and 0.4 m). Typically the stove was refueled when its power output fell to about 3,000 watts (10,000 Btu/hr). The glowing coals were raked forward (as is recommended by the manufacturer of this stove) and two pieces of wood were added, which constituted

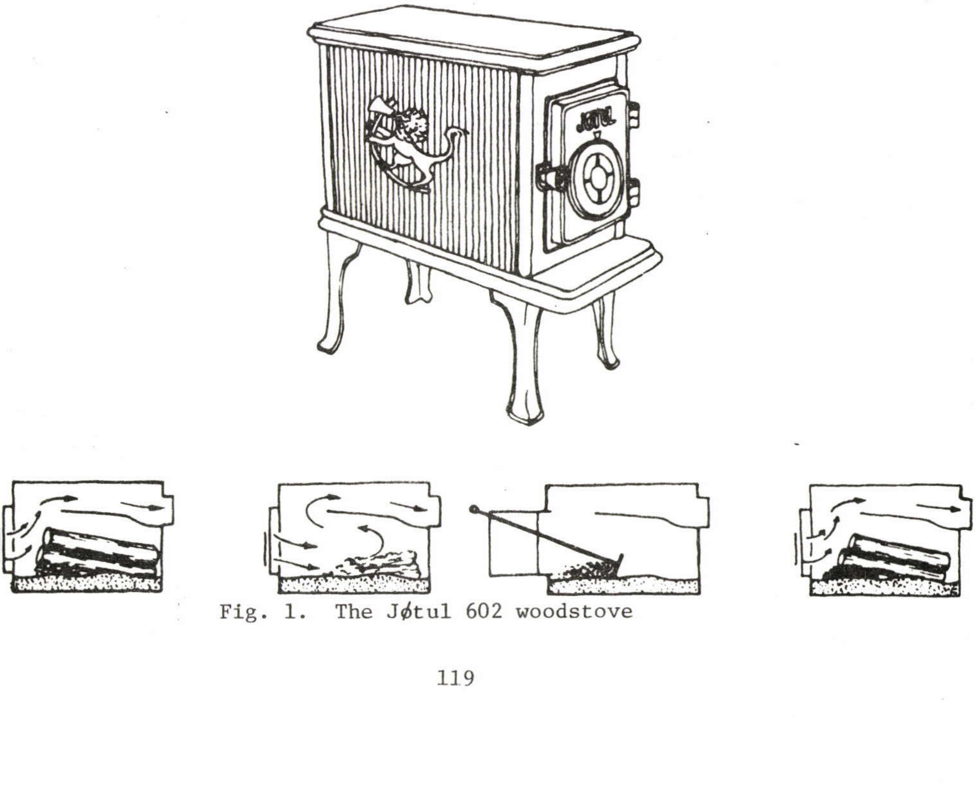

Fig. 1. The Jøtul 602 woodstove

roughly half the stove's fuel capacity. Red oak was the standard fuel, with white pine being used for our limited check on species dependence. Moisture contents of representative samples of the fuel were determined by oven drying to constant weight. A representative set of data relating to stack losses and heat output is shown in Fig. 2.

The effect of moisture content (Fig. 3) proved to be somewhat unexpected. Overall energy efficiency de-

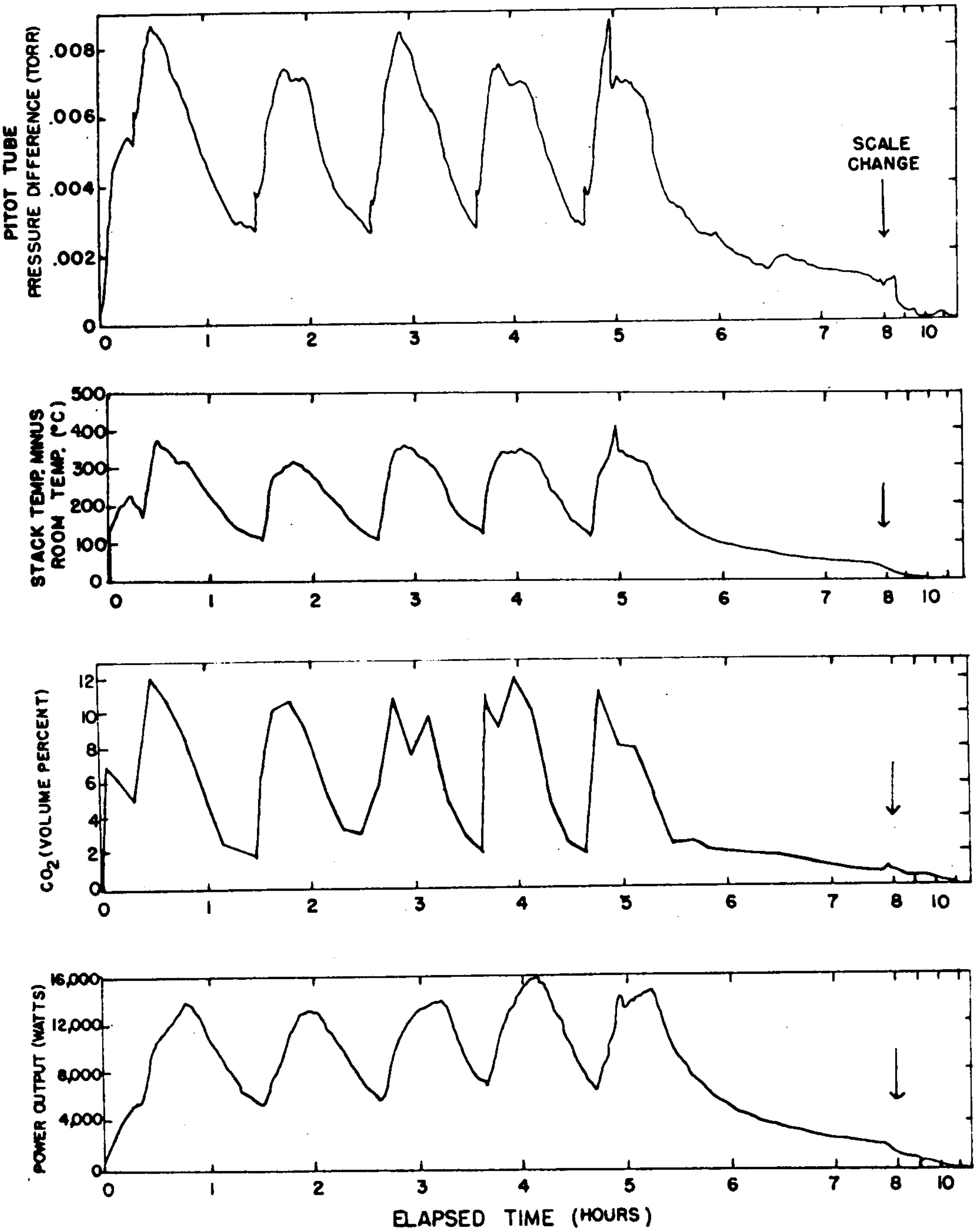

Fig. 2. An example of some of the parameters measured during our stove tests. The top graph is the output of a Pitot tube type sensor in the flue. The second and third graphs are stack temperature and CO_2 concentration in the flue gas. CO_2 was measured every 10 min. with a Dwyer wet-chemical absorber. The last graph is the stove's power output as measured by the calorimeter room. The particular test illustrated is from the power output series and represents close to the maximum power capabilities of the stove. The run consisted of five fuel loadings.

clined both for very moist and for very dry wood. Consideration of the two component efficiencies, combustion efficiency and heat transfer efficiency, reveals a partial explanation. The heat transfer efficiency decreased with increasing moisture content throughout the range investigated (0 to 34 percent moisture on a moist wood basis, or 0 to 52 percent on an oven-dry basis). This is to be expected. Moist wood requires more air to burn with the same heat output rate (Fig. 4); extra air lowers flue gas temperatures and increases flue gas velocities, both of which are detrimental to heat transfer efficiency (Fig. 5).

Combustion efficiency decreased only slightly for very moist wood but attained its minimum value for very dry wood. Both these aspects seem to contradict conventional wood burners' wisdom. A possible explanation for the high chemical-energy stack loss with very dry wood concerns the timing of the release of combustible gases and tar aerosol from the wood. If use of dry wood were to result in the emanation of a larger surge of airborne combustibles from the fuel, the chemical energy losses might well be larger, since the oxygen supply is approximately fixed and is already effectively the limiting factor in the overall combustion rate. Such an increased surge might be expected from dry wood, for without the need to evaporate so much water from the wood, it would achieve pyrolysis temperatures more quickly, and in particular, a larger fraction of the fuel's mass might be simultaneously undergoing pyrolysis.

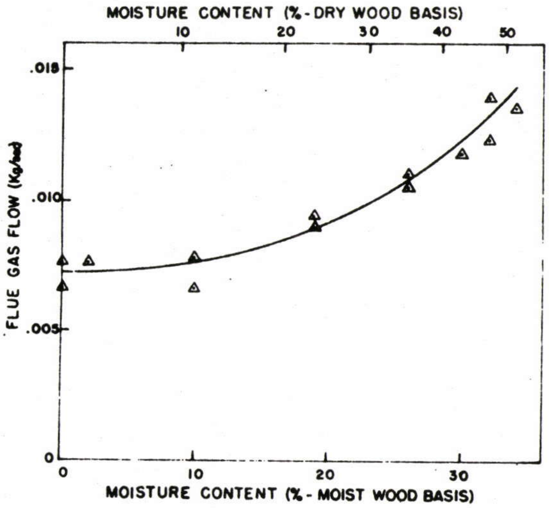

Fig. 4. Average flue gas flow for tests in the wood moisture content series. In order to maintain constant average power output in this series, the amount of combustion air (and hence the flue gas flow) varied.

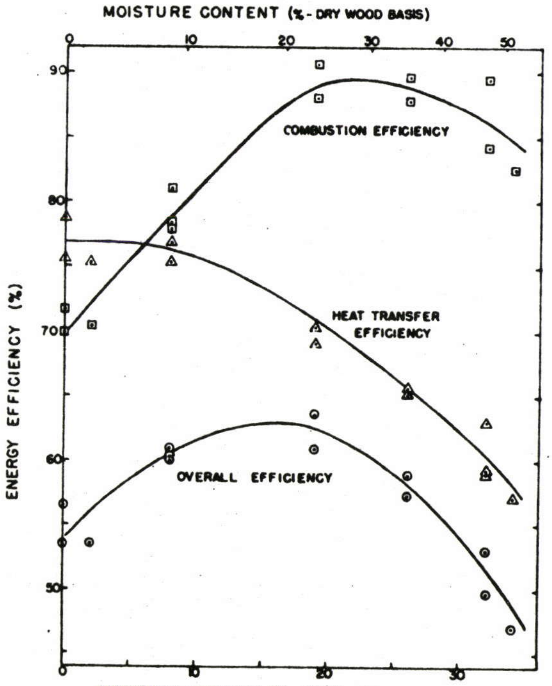

Fig. 3. The dependence of efficiencies on wood moisture content. Experimental uncertainty is about 2 percentage points on both the vertical and lower horizontal axes.

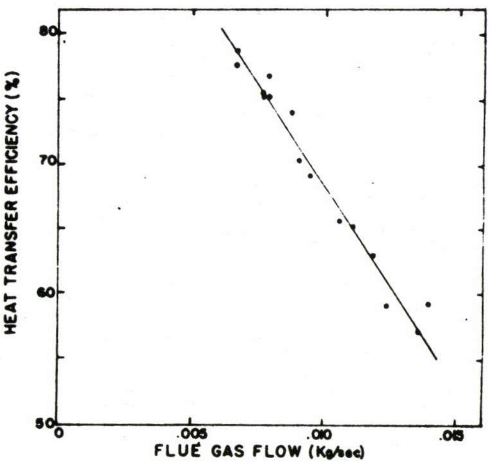

Fig. 5. Heat transfer vs flue gas flow for tests in moisture content series

With medium moisture wood, combustion processes may be steadier, pyrolysis and the combustion of gases and charcoal all occurring at the more nearly constant rate. This, plus the larger amount of air admitted when burning medium moisture wood, may be the cause of its more complete combustion. In a sense, there is less excess air when burning dry wood, but the concept of excess air is not as straightforward when the amount of air admitted affects the rate at which fuel is consumed, and the elemental release rates from the wood are unknown. (Combustion efficiency probably does not decrease substantially with decreasing moisture content when wood is burned in an open fireplace, for then ample combustion air is generally always available.)

There may be other contributing causes to the observed variation of combustion efficiency with fuel moisture content. The total yield of gases and fog aerosol depends on the rate of carbonization or pyrolysis; yields have been observed over a range from 50 percent to 88 percent (on a mass basis) as carbonization times vary from 24 hours to 1 minute [3]. Higher yields of combustibles would typically result in lower combustion efficiencies since in most wood stoves the air supply limits the rate of combustion. However, more work is required to determine whether it is moist or dry wood which undergoes quicker carbonization. Computer modeling and visual observations both suggest that the average temperature of a dry log rises more quickly through the temperature range in which pyrolysis occurs; but the same evidence suggests much higher temperature gradients in a moist log (due largely to the energy required to evaporate the moisture). Thus it may be that each mass element in a moist log undergoes pyrolysis more rapidly than mass elements in dry wood. Further modeling and experiments are underway.

Still another factor may be direct chemical effects on pyrolysis and oxidation reactions due to the moisture in wood. Limited amounts of moisture have to be beneficial in some combustion situations.

The overall efficiency is the product of the combustion and heat transfer efficiencies (Table 1). Overall efficiencies were around 60 percent over a wide range of moisture contents but declined for very dry wood due to poor combustion and declined at high moisture contents mostly due to poor heat transfer. It is the relative values of these efficiencies which are significant; the absolute values have not been corrected for the higher than normal temperatures (about 35°C) in the test room environment and for the higher than normal convection in the test room. We have measured these corrections to total on the order of -5 percentage points; whatever the value, it is about the same for all tests in this series. Our reported efficiencies include the heat output contribution of 70 inches of 6" blue steel stovepipe with one 90° elbow and no stovepipe damper. (Our test room has now been modified to largely eliminate the forced convection and high room temperatures.)

Tests on the effects of fuel load size were done with red oak at a moisture content of 26 percent (moist wood basis). Overall efficiency was not significantly different when the stove was filled to capacity at each reloading as compared to one-half capacity, two-piece loadings. However, combustion efficiency declined by about 11 percent (not percentage points) and heat transfer efficiency improved by about 12 percent. The larger loads require less air to achieve the same combustion rate; hence heat transfer efficiencies should be higher. Combustion efficiency probably declines because of inadequate air and/or air distribution to permit combustion of the larger surge of gases and tar aerosol generated from the larger fuel loads.

Thus far in our initial testing for wood species dependence, only white pine has been compared to our standard fuel, red oak. Operating the stove in the manner described previously, use of white pine with a moisture content of 8 percent resulted in higher overall energy efficiency of the stove by about 13 percent compared to red oak with the same moisture content. The pine was assumed to have an energy content 2 percent higher than that of red oak [4, 5]. The most important factor seems to have been the more complete combustion of the pine, which was about 11 percent higher than that of the oak. Higher combustion efficiency of white pine was also observed with both species at a moisture content of 18 percent for full stove loadings and for both

TABLE 1

$$\text{Combustion efficiency} = \frac{\text{heat energy (sensible plus latent) generated in combustion}}{\text{wood energy input}}$$

$$\text{Heat transfer efficiency} = \frac{\text{useful heat energy output}}{\text{heat energy generated in combustion}}$$

$$\text{Energy efficiency (overall)} = \frac{\text{useful heat energy output}}{\text{wood energy input}}$$

$$= \text{(combustion efficiency)} \times \text{(heat transfer efficiency)}$$

Definitions of efficiencies: Each efficiency may either represent an average value over a full burning cycle, in which case each factor represents the total energy over the cycle, or an instantaneous value, in which case each factor represents an energy flow or rate. As is the convention in the United States, we take as the wood's energy content its higher or gross heating value, which includes the latent heat of the water vapor from combustion.

very small and very large piece sizes. The probable explanation is that since the pine was less dense by nearly a factor of one half, our equal wood volume loadings resulted in less mass of pine fuel per loading; this would likely result in a smaller surge of combustible gases and tar fog, a larger fraction of which is likely to be burned; the situation may be analogous to the large versus small load tests with oak, with respect to combustion efficiency.

Piece size effects were investigated using relatively full loadings of red oak and white pine (separately), both with a moisture content of 18 percent. Two of the large pieces and about 18 of the small pieces filled the stove to capacity. Air inlet damper settings were chosen to yield a power output averaging about 5,000 watts, as in the moisture content series. Overall efficiencies were on the order of 15 to 20 percent (roughly 10 percentage points) higher with the large pieces as fuel, and this was the result of more complete combustion. Heat transfer efficiencies were not very sensitive to piece size.

Our tests of the power dependence of the various efficiencies were conducted with four-piece loadings which nearly filled the stove to capacity. The fuel was 22 percent moisture content (moist basis) red oak. This test series was conducted with a uniform average test room temperature of about 25°C in order to eliminate the effect of room temperature on radiant heat exchange. Output powers were varied from 1,500 watts (5,100 Btu/hour) to 9,600 watts (33,000 Btu/hour). Although we as yet have inadequate data to be quantitative, the trends are clear. Overall efficiencies showed no variation with power to within our roughly ±2 percentage point uncertainty. Heat transfer efficiencies declined with increasing power. Qualitatively, the dependence of heat transfer efficiency on flue gas flow for this power test series was the same as for the moisture-content series illustrated in Fig. 3. Combustion efficiencies increased with increasing power output. In the lowest power tests, combustion was a nearly flameless smoldering process. At higher powers, the higher temperatures and larger air supply resulted in more complete combustion. We have seen some indication that the overall efficiency curve may not be as flat for other stove designs but may peak at some intermediate power output and decline slightly at lower powers due to low combustion efficiency, and decline quite steeply at very high powers due to poor heat transfer efficiency.

It is interesting to speculate about the apparent contradiction between the conventional wisdom that drier wood is less prone to result in creosote accumulation in chimneys and our experimental result that drier wood results in larger chemical energy losses up the chimney. It is possible that more water may condense on flue surfaces when moist wood is burned because of the wood's higher moisture content (although the larger quantity of air usually required to burn moist wood could result in a higher dew point for the water vapor in the flue). Thus, although the total condensate seen dripping from a chimney or stovepipe may be large in volume, it may be mostly water, not combustible organic material, and thus not be inconsistent without measurements indicating relatively complete combustion with moist wood. Another possible resolution is that condensation of water and organic materials are dependent processes; the presence of more water vapor in the flue gases or a water film on the flue surface may in fact enhance the condensation or deposition of organic material (gases, particles, and droplets) on the flue surfaces. Thus a larger fraction of the relatively smaller total amount of organic material generated from burning moist wood could be deposited, resulting in a larger total deposit. Another possibility is that the presence of moisture in the wood affects the pyrolysis and combustion reactions sufficiently to result in a different array of organic flue products which are more likely to be deposited in the flue. Also, as mentioned previously, the rate of carbonization affects the yield of charcoal; hence the rate also affects the average carbon content of the gases and tars. Quicker heating yields less charcoal and hence a higher carbon content for the materials driven out of the wood, and hence, in all probability, higher average molecular weights. Another possibility is that our wettest wood was not moist enough to yield the "expected" poor combustion. Finally, two important possible resolutions of the apparent paradox are to question its existence. It may not generally be true that more creosote (either on a volume or solid residue basis) results from burning moist wood; or, our experimental results may not generally be true—we have only measured the effect in a particular stove operating under particular conditions. We are experimenting with direct creosote measurements to try to help resolve these issues and similar ones concerning pine's reputation for creosote potential and our measurements indicating pine's relatively complete combustion.

It is important not to generalize too much from this limited series of tests. Only one stove was used, and with other stoves, the results could be different. Tests on fuel load size were performed only with 26 percent moisture content red oak. White pine and red oak were compared only at 8 and 18 percent moisture content, and no other species were tested. Most tests were performed at only one average power output. The task of fully characterizing the effects of these and still other fuel and operator variables is clearly a multidimensional experimental problem, and results obtained along one line in the multidimensional matrix of possibilities do not necessarily translate to other parallel lines in the matrix.

Notwithstanding the above provisos, if these results prove to be general, the following are some practical conclusions for users of wood stoves. Wood can be too dry, resulting in more smoke and less overall energy efficiency, but this would normally happen only if wood were stored indoors in a dry heated space for a year or more; i.e., if the wood had a moisture content of less than about 15 percent. When moisture content is above about 30 percent (oven dry basis) overall energy efficiency decreases due principally to poor heat transfer efficiency. The wettest wood we could burn (about 50 percent [oven dry basis]) resulted about a 20 percent (10 percentage points) decrease in overall efficiency. Small fuel loads and large fuel pieces both improve overall energy efficiency through better combustion efficiency; they probably also decrease creosote formation in chimneys, although in our testing we have not yet verified a correlation between high chemical energy loss and high creosote accumulation. Of course, use of larger fuel loads is more convenient because less frequent reloading is needed. Although white pine seems to be a more energy efficient fuel than red oak, its much lower density results in the need for more frequent refueling of a stove and in its not being the better buy, unless fuel wood is available for a fixed price per unit dry weight (rather than a fixed price per unit volume [cord]).

PART II

CENTRAL WOOD HEATING VERSUS STOVES

There seems to be something of a debate going on among woodophiles as to whether or not central wood heating is going to take over the wood heating market. Central wood heating involves a wood-fired furnace or hot water boiler or steam boiler feeding hot air, hot water, or steam into the conventional heat distribution systems—ductwork, hot water baseboard radiators, or steam radiators.

Right now devices made to heat just one or a few rooms and installed in the room to be heated dominate the market. Examples are fireplaces, stoves, and fireplace stoves (stoves intended to be operated with doors closed or open, such as Franklin-type stoves). I like to call such devices room heaters because that is what they are, although many national safety organizations and building codes do not define room heaters to include fireplaces and fireplace stoves.

A central wood-fired heating system clearly can deliver 100 percent of a house's heating needs and maintain a uniform temperature throughout the house. Such systems perform like conventional oil or gas systems, except that wood is the fuel.

In many houses, one room heater cannot really heat the whole structure. I have done it in my home, but rooms far from the stove and on the same floor are likely to be considerably cooler than the room with the stove. Thus a single room heater is likely to be supplemental, not a 100-percent heat source. However, two or three stoves will heat most homes very comfortably. Therefore, in comparing 100 percent wood heat systems, a central system has the advantage that there is only one fire to tend instead of two or three. And since the central wood heater will likely be designed for larger diameter and longer length wood, there can be a significant savings in fuel preparation effort (or cost).

Central heaters are typically located in basements or utility rooms. Thus the little annoyances of ash, sawdust, bark, and beetles will not invade the neater living spaces of the house. And if living space is at a premium and basement space is available, a central system has an advantage.

However, room heaters have their own advantages. I recently moved into a new house and installed a wood-fired central hot water boiler whose heat is distributed through conventional pre-existing baseboard convectors. The worst thing about the system is also its best feature—the uniformity of the temperature throughout the house. There is no "hot spot" you can get close to when you are cold. With a stove, no matter what your temperature is and no matter what temperature the house is, there is a comfortable distance to be from the stove. I notice it most in the morning before the house has come up to comfortable temperatures—I can't get warm by cuddling up to a stove.

Room heaters generally respond more quickly than does a central system (particularly a central water or steam system). This is partly because you can get warm standing close to a hot stove even when the house is still cold and also because water and steam systems have large masses in the boiler. Once such a system cools down, it can take significant time to warm it back up. (Wood-fired forced-air furnaces can warm a cold house quite quickly.)

However, the high mass typical of hot water systems has advantages as well. One can use their heat storage characteristic and have two or three large, hot, clean burning, low creosoting, low air polluting fires a day, each one charging the water and steel or iron in the boiler up to, say, 200°F and then drawing on this stored heat until the water temperature drops too low to be useful. In typical wood stoves or furnaces this is not possible—the house would overheat. The water systems have a built-in buffer between the house and the fire so that the fire's heat output does not always have to match exactly the heating needs of the house. This permits manipulating the fire to minimize smoke and, hence, creosote and air pollution.

Stoves are less expensive than furnaces and boilers. Thus, if one stove can contribute the same amount of heat, its lower price is an advantage. Chimneys are expensive so that if one system would require a new chimney and the other would not, the economics can be swayed.

For people who do 100 percent of their heating with wood, I suspect less fuel is consumed by the stove users than by those with central systems. There is not enough evidence on the energy efficiency of wood furnaces and boilers to be able to compare them to stoves. But houses heated with stoves generally are kept at a lower average temperature, and, hence, less fuel may be required. People tend to concentrate their activities in the warm room(s) with the stove(s) and let the rest of the house be cool. It is much like a thermostat set-back for parts of the house.

Some people like the atmosphere of having a stove in the living space. Its presence and the activities surrounding its firing can be pleasant. For them a central wood heater lacks charm and is too remote.

Central systems generally require electric power to operate thermostats and pumps or blowers. In the event of a power failure, little if any heat can be delivered to the house. Stoves and fireplaces are, of course, not susceptible to power failures.

Potentially, central heating with wood may have the advantage of having automatic fueling. This will almost surely require use of wood chips or pelletized wood fuel. The convenience of automatic feeding is considerable. However, one would need a large fuel storage bin and would require regular fuel deliveries. Thus much of the independence of heating with wood would be lost.

Most safety problems with wood heating are due to unsafe installations, sloppy operation, and poor maintenance, not unsafe equipment. Hence, there is no inherent safety difference between central heaters and room heaters. However, in practice I suspect the central systems may have a statistical advantage. Central wood heating systems are more likely to be installed by a professional, and professionals are more likely to do it right. There tends to be less combustible material in basements so that sloppy observance or ignorance of safe clearances is less likely to lead to a dangerous situation. And finally, being in a remote location, unknowledgeable people are less likely to operate the unit, or place wood on it to dry, or move furniture too close, etc.

Both central and room wood heating systems usually have conventional back up—an ordinary electric, gas, or oil system. Central heaters may be "dual fuel" devices, burning either wood or a fossil fuel, or a central wood heater can be installed beside an existing conventional unit. In either case, the whole system is usually arranged so that the conventional system (e.g., oil burner) comes on automatically whenever heat is required and the wood fire has died out.

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Contact Dr. Jay Shelton, 36 Hawthorne Drive, Williamstown, MA 01267, for price and ordering information.

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SMALL WIND GENERATOR APPLICATIONS

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INTRODUCTION

The earliest record we have of wind power is a 5,000-year-old drawing of the use of a sail on a Nile river boat; wind turbines apparently made their first appearance in Persia for grinding grain about 200 B.C. Use of windmills was subsequently widespread in the Middle East and Mediterranean. They were introduced to Europe during the Middle Ages by the returning Crusaders. The Dutch made the most use of windmills, having close to 10,000 machines in use by the start of the Industrial Revolution. The steam engine caused a sharp decline in the use of windmills in Europe; but after the Civil War, the American-style water pumping windmill became widespread and essential to agriculture and railroads in the arid, developing West. The first practical wind generators were born of a marriage of the World War I refinement of the modern propellor and the automotive generator. Thousands of these homemade and manufactured 6-volt electric systems provided rural America with electric lights and radio contact with the rest of the country. The larger 32-volt system with capacities of 1 to 3 kW became popular in the 1930s with over two dozen domestic manufacturers providing tens of thousands of wind electric systems. The industry was quickly extinguished by the depression-fostered Rural Electrification Administration (REA), which brought power lines to even the most remote hamlet.

Interest in wind-generated electricity was revived abruptly in 1973 with the realization that the country could not depend forever on nonrenewable, polluting energy sources. Studies showed that the winds flowing in high potential areas of the country alone held the energy potential to provide hundreds of times the current electric power requirements. Utilization of wind energy continues to be hampered by the high cost of wind generating equipment, the variable nature of the wind itself necessitating either storage or immediate consumption, and the heretofore impracticality of wind generators in the multimegawatt sizes.

A shift in economics favoring small wind electric systems may be occurring as a result of recent cost reductions in small wind machines, rapidly escalating utility rates and fossil fuel costs, a growing objection to power lines and noise and fumes from internal combustion engines in certain locations, and an increasing desire on the part of certain individuals to be energy self-sufficient. A review of a 1930s farm wind electric system reminds us that individual wind electric use can be both practical and convenient. A current successful commercial application of wind power to operate the KFMU radio station transmitter in Oak Creek, Colorado, illustrates that there are dozens of applications today where the use of wind power is cost-effective and can prevent unnecessary despoilation of the countryside with power lines.

POWER IN THE WIND

The question is often asked, "Why not build a wind generator that is so easy to turn and with sufficient blade area that it can generate usable power in winds of less than 5 mph?" The answer lies in the amount of power available in wind of different speeds as given by Equation 1,

$$P(\text{watts}) = MV^2/2 = [(\rho AV)V^2]/2 = .0045A\,(\text{ft}^2)V^3(\text{mph}) \quad (1)$$

Equation 1 applies at 5,000 ft above sea level, and the power in the wind increases by 3% of every 1,000 ft decrease in elevation as the air becomes more dense. Values obtained from Eq. 1 for different wind speeds are shown in Row 1 of Table 1.

Since the power in the wind varies with the cube of the wind velocity, a machine designed to produce usable amounts of power in a 5 mph wind would be overloaded by winds of only slightly higher speed and would not be able to take advantage of the power in the higher wind speeds. Many years of design experience have shown that to minimize the loss of energy at wind speeds below the generator cut-in speed and above the generator rated speed, the generator rated speed should be about twice the average wind speed of the site at which it is installed.

Wind energy is the kinetic energy of a moving mass. Power is extracted by slowing down the air mass in a manner causing it to do work. Since the air mass cannot be stopped completely at the wind turbine, there exists an optimum amount by which the air stream should be slowed by the most efficient wind turbine. The most efficient turbine should slow the air stream to one-third the initial velocity and will extract 60% of the power of the moving air mass. We refer to 60% of the power in the wind as the maximum available wind power, and this is shown for various swept blade areas in Table 1. A typical wind machine will extract on the order of 50% of the available power when blade, mechanical, and electrical losses are taken into account.

The performance of a typical wind generator is shown in Figure 1 where the power available in the area swept by

Table 1. POWER IN THE WIND

Figures shown for 5,000 feet above sea level. Increase (decrease) by 3% for each decrease (increase) in altitude of 1,000 feet.

$$P = 1/2MV^2 = 1/2(\rho AV)V^2 = .0045A(ft^2)V^3(mph) \text{ in watts at 5,000 ft}$$

Power/mph	5	10	15	20	25	30	40
kW/ft^2	.00056	.0045	.0152	.036	.07	.122	.288
8' Blade*	.017	.136	.459	1.087	2.114	3.684	5.829
10' Blade*	.026	.212	.716	1.696	3.313	5.746	13.57
20' Blade*	.106	.848	2.862	6.784	13.25	22.896	54.27
100' Blade*	2.65	21.2	71.55	169.6	331.3	574.6	1356.5

*Available Power = $.0045A(ft^2)V^3(mph).6$ in watts at 5,000 ft

a 10-ft blade is compared with that actually measured at the electrical output terminals of a wind generator having a 10-ft blade. The energy in winds below the cut-in speed is small because the power is so low, and although there is tremendous power in winds above the rated speed, the energy is small because the amount of time the wind exceeds the rated speed is a small percentage of the time the wind blows.

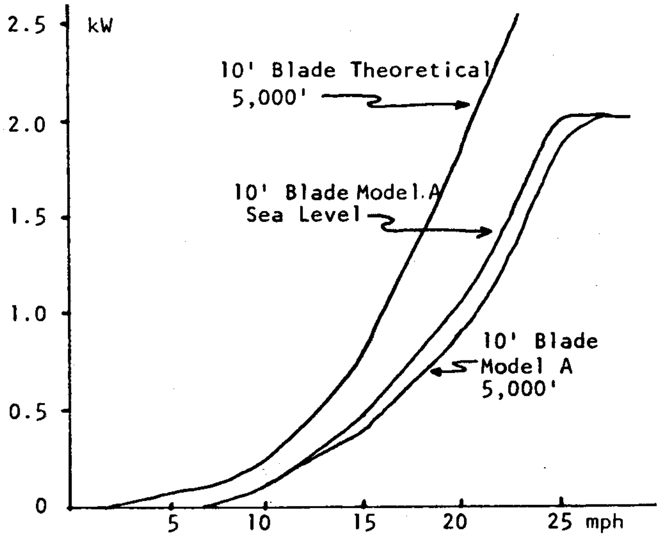

Fig. 1. Efficiency of a wind generator. Overall efficiency of Model A is 54% at 20 mph wind speed at 5,000 ft

ENERGY IN THE WIND

Equations 2 and 3 illustrate the difference between power and energy.

E = Power x Time = Size of Coal Pile (kWh) (2)

P = Energy/Time = Rate of Coal Consumption (kW) (3)

Energy is what you pay for, and power is the rate at which you consume the energy. The practicality of a wind generator is determined by how much energy it will produce in a month's or a year's time and the cost of that energy. The amount of energy obtainable from a wind generator depends as much on the wind conditions at its location as on the wind generator itself. The energy which can be extracted at a given site depends on both the average wind velocity and variability of the wind. In general the energy actually obtained will be from two to three times that which is calculated from the average wind speed alone as shown in Table 2. The ability to extract the extra energy of more variable winds depends on having low rotor inertia to follow the gusts and on the wind machine being able to yaw quickly enough to follow the changes in direction that accompany highly variable winds.

ENERGY BUDGET

Table 2 gives estimates of the monthly energy output to be expected from a typical 2,000-watt wind generator in various wind regimes. The value of the energy output is obtained by multiplying the local utility rate/kWh times the estimated output. To determine if the estimated monthly output is sufficient for your electrical needs, you may consult your previous electric bills to determine monthly kWh consumption, or you may draw up an energy budget such as that of Table 3 which represents a small, rural household.

Clearly it is impractical in any normal wind regime to use a small wind generator which produces 200 kWh per month for electric heating, cooking, or water heating. Table 4 illustrates an energy budget that comes within the capabilities of a 2,000-watt wind generator. Electric cooking has been eliminated altogether, and electric water heating is done only with the excess power after other requirements have been met. Clearly there will be more wind-provided hot water during some months than during others. The color TV of Table 3 has been replaced by a black and white solid-state model which is much more energy efficient, and the refrigerator has been replaced with a smaller, more efficient model. The use of lights has also been reduced primarily by making sure unused lights are turned off. It is seen from Table 4 that with proper management a small wind generator can supply the electrical necessities with some extra for water heating. Table 2 can be revised to give the output of any size wind generator by finding its output at the various average wind speeds, $\bar{V}$, and multiplying by the appropriate Energy Pattern Factor, K.

BATTERY STORAGE REQUIREMENTS

Although a modern wind generator may be used without storage to provide constant voltage AC or DC when the wind is blowing, its acceptability and usefulness are

Table 2. ENERGY IN THE WIND

E = Size of Coal Pile = Power x Time (Measured in kWh)

P = Rate of Coal Consumption = Energy/Time (Measured in kW)

Examples: 10' Blade, Overall Efficiency 50%, 5,000'

1. 10 mph for 2 hr, Ave = 10 mph, E = .21 kWh
2. 8 mph for 1 hr, 12 mph for 1 hr, Ave = 10 mph, E = .28 kWh
3. 5 mph for 1 hr, 15 mph for 1 hr, Ave = 10 mph, E = .38 kWh
4. 0 mph for 1 hr, 20 mph for 1 hr, Ave = 10 mph, E = .91 kWh

MODEL A MONTHLY OUTPUT VS. AVERAGE WIND SPEED AND VARIABILITY

	Constant		Steady		Variable		Gusty	
$\bar{V}$	K	kWh	K*	kWh	K*	kWh	k*	kWh
9	1	55	1.2	66	2	110	3.2	176
10	1	76	1.25	95	2	152	3	228
11	1	101	1.3	131	2	202	2.8	283
12	1	130	1.35	176	2	260	2.6	338
13	1	166	1.4	232	2	332	2.4	398

*K is the Energy Pattern Factor = $\frac{\text{Energy Obtainable}}{\text{Energy Calculated from } \bar{V}^3}$

Table 3. TYPICAL ENERGY BUDGET

Use	Power	Hr/Day	kWh/Month
Water Heater	2,000	3	180
Cooking	4,000	1	120
Lights	300	6	54
Freezer	300	6	54
Refrigerator	250	6	45
TV	300	5	45
Water Pump	200	2	12
Shop	300	1	9
Washing	200	0.5	3
Sewing	100	1	3
Toaster	800	5 min	2
Stereo	50	13	12
Total Monthly Energy Consumption			539 kWh
Electricity Bill at $0.05/kWh			$26.95

Table 4. WIND POWER ENERGY BUDGET

Use	Power	Hr/Day	kWh/Month
Lights	200	6	36
Refrigerator	100	6	18
TV	75	5	11
Water Pump	200	2	12
Shop	300	1	9
Washing	200	0.5	3
Sewing	100	1	3
Toaster	800	5 min	2
Stereo	50	8	12
Total Consumption			106 kWh
Available for Water Heating			94 kWh
Average Monthly Consumption			200 kWh
Value of Wind-Generated Electricity at $0.05/kWh			$10/Month

Payoff period for $2,000 wind system producing 200 kWh per month assuming $0.05/kWh electricity value with 10% inflation rate and financing charge: Approximately 16.5 years.

greatly enhanced by adding storage sufficient to provide minimum electrical needs for several days of calm. Table 5 illustrates the method of calculating the required battery size to power a minimum load for a period of one week.

Where utility power is available, no battery storage is required as the deficit in wind power can be made up by the power company at any time. Should the wind generator be producing more than your immediate needs, the excess power can be fed back into the power lines (which is not yet legal in some states), or it may be fed to a water or space heater. In general it does not make economic sense to return power to the utility company because it can only pay the fuel value of the electricity minus the transmission costs, and it is of more value to the wind generator owner to use the extra power for water or space heating.

In locations without utility power the battery size may be considerably reduced by relying on a backup generator which may be started either manually or automatically when the batteries get low. In Table 5, for example, if the amount of battery storage were reduced to two days for a cost of, say, $250, the savings would easily purchase a backup gasoline generator.

Table 5. BATTERY STORAGE REQUIREMENTS
(Minimum Load for One Week of No Wind)

Use	Power	Hr/Day	kWh/Week
Refrigerator	100	6	4.2
Lights	150	4	4.2
Water Pump	200	1.5	2.1
Shop	300	0.25	0.5
TV	75	2	1.0
Stereo	50	13	4.6
Sewing	100	0.25	0.2
Total Energy Consumption for One Week			16.8 kWh
Ampere Hour Battery Capacity for 120 v System			140 AH
Twenty 6-volt Truck Batteries at $40 Each			$800

THE WAY TO A SOLAR SOCIETY:
ONE STEP AT A TIME

Dr. Paul Rappaport, Executive Director
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The solar revolution is upon us and with it come many problems and challenges but, thus far, not many solutions. The President, Congress, and the American people are very supportive of solar development; but there is an urgent need to set goals with guidelines to achieve those goals and it is particularly important to assure that they are realistic. If they are not, the resulting disappointment could reduce that support and seriously retard solar development. The big question is how do we get from here to there; the answer is, we do it one step at a time. However, there are many individual human choices that must be made to achieve the real benefits of a solar society.

Choices will be required in the area of conservation because without conservation, solar energy does not make sense. People are not practicing conservation principles because they are not yet willing to make certain human choices. For example, to achieve conservation of gasoline, people should live closer to their places of work; they should travel on vacations via mass carrier (planes, trains, etc.); they should give up their large recreational vehicles; and the traveling salesman should be a thing of the past. Perhaps we must double or even triple the price of gasoline and learn how to make smaller automobiles to encourage these actions. To conserve other kinds of energy we must learn to live with fewer comforts.

Because their lifestyle already embraces many of the concepts associated with the use of solar energy, people living in rural areas will probably have less difficulty adopting solar energy than will urban dwellers. However, major changes will be required of utilities and some industries, and new business concepts for marketing energy will need to be developed. We will probably see this revolution take place in other countries, because of their lack of a utility grid and their greater decentralization, before it happens in the United States.

THE BEAUTY OF SOLAR ENERGY

Solar energy is democratic and, in many cases, simple. Since the sun shines on everyone, we won't have to be sitting on an oil well to feel prosperous in the future. The sun is as important to the individual as oil is to "Exxon."

Solar energy encompasses many diverse fields, from farming to sophisticated electronics. It is a field that requires scientists, engineers, lawyers, environmentalists, architects, and many other disciplines. It is a field that can generate jobs but may also use highly automated production lines. It can appeal to the poor, to appropriate technologists, and to small and large businesses.

SOME REALISM

There is a dichotomy between what can be done in terms of social benefit for society and what must be done to save energy. Currently, our nation uses about 80 quads* of energy annually. To save one of those quads by using photovoltaics on the roof of a house would require about 15 million homes each equipped with 200 sq ft of photovoltaic panels. To produce that quantity of panels would require an industry perhaps 100 times larger than that of the current semiconductor industry. This would obviously have a great impact on our technical society, and its production will require a large, high automated industry. The photovoltaic panel would cost about $20,000 per home today, but in 1990 the cost may be more like $1,000, still more expensive than more conventional electricity would be. As conventional energy costs rise and photovoltaics costs are reduced, and as incentives are applied to solar technologies, the crossover where solar electricity is cheaper than conventional electricity may occur sooner than most people expect.

We need to be more aware of the social benefits of using solar energy; and we will need to provide incentives and subsidies, and perhaps other economic measures, to make it economically worthwhile for a homeowner to choose solar over cheaper, more conventional energy sources.

Energy is the most pressing problem concerning the future of our society. It determines the quality of our lives, the stability of our society, our economic independence. What is the real price that we apply to these important factors in society?

Passive systems are economically justifiable today; but, in the short term, it is very difficult to justify active solar on purely economic grounds. Perhaps only hot

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*One quad = 10^{15} Btu

water heating, some areas of industrial process heat, and some areas of bio/chemical conversion make economic sense today. For the long term, there is no question that solar will be needed; and certainly by the year 2000, we should be producing between 10 and 20 quads of solar energy in the United States. By the year 2050, the two major renewable energy sources will be solar and fusion. To achieve these goals, we must start now. Some supporters of solar energy feel that there needs tobe a short-term payoff; and if we can't deliver, they may become disenchanted. It is necessary to understand the long-term absolute requirement for solar to justify the short-term difficulties.

SOME TECHNICAL CONCEPTS

Solar energy can produce four different forms of energy: electrical, mechanical, thermal, and chemical. An important consideration is to use energy in the form that is ultimately needed. For example, if you need mechanical energy, choose a device that gives mechanical energy directly. This is a tenet of so-called "soft technology," and solar fits into that concept very well. The hard technology approach is to build large electrical baseload stations to supply energy, no matter what form is needed, including heating and mechanical energy. The question of centralized versus decentralized energy systems is of interest here. The large centralized system is conducive to a hard technology; the decentralized system is more conducive to soft technology. We will probably see more centralized hard technology approaches in the United States; and in the less developed countries of the world, we will see more decentralized soft technology approaches. Perhaps this choice will result in the countries that are less developed now being far better places to live 100 years hence than some of the highly developed societies.

RESEARCH AND DEVELOPMENT

It is not the purpose here to discuss current solar research and development at length. Suffice it to say that many solar options are technically ready for commercialization if the economics are right. Such options include solar heating, wind power, and some forms of photovoltaics and biomass. There are other solar options that require more engineering development and some research, including photovoltaics, ocean thermal energy conversion, and some forms of solar thermal systems. Two solar options—photovoltaics and artificial photosynthesis—could benefit from considerably increased research. All these options require some research and development to improve reliability, lower cost, and increase efficiency. System study or understanding is needed even in some of the simple domestic hot water systems to develop maximum efficiency of the system. At SERI, we are working on aspects of solar research and development which address many of the problems just mentioned.

COMMERCIALIZATION

Many solar options consist of well understood technologies which are already being employed in the United States and around the world. For example, Israel has 300,000 domestic hot water systems; and Japan has nearly 2 million such systems. The question arises then, why aren't there more in the United States and other parts of the world? The answer lies in uncertainties regarding the business nature of solar energy and barriers that still impede its progress. There are questions regarding legal issues, financing, building codes, and solar rights that must be answered before customers will be able to buy solar systems easily. Trained installers and warranty and service organizations are needed so that a customer will know that his system will be kept operational. Questions regarding utilities and disincentives also need to be answered. When we know more about these uncertainties and barriers, we will find more entrepreneurs ready to enter this exciting field.

One of the most exciting aspects of solar energy is the possibility for the existence of small communities powered almost exclusively by solar energy. Somewhere between 100 and 1,000 homes could be provided with electricity, heating, cooling, and storage on a seasonal basis. This type of community would need little or no energy from the utility, and it could involve its own service and financial organizations. It might not be as reliable as our current utilities are most of the time, but neither will it suffer blackouts when some catastrophe occurs in a utility that is 500 miles away. Such communities certainly will cause social change and affect human choices, but they will bring people together for a revolution in living that offers a solution to the most urgent problem of our time.

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