Strategies for Development of Energy-Efficient Housing

by

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S.B. in Civil Engineering

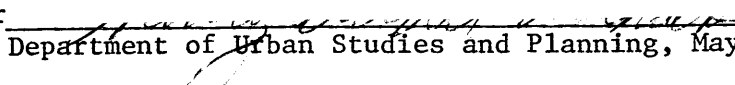Massachusetts Institute of Technology, 1974

SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREES OF

BACHELOR OF SCIENCE IN URBAN STUDIES, and

MASTER OF CITY PLANNING

of the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
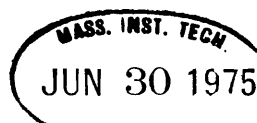
May, 1975

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                    Department of Urban Studies and Planning, May 12, 1974

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Submitted to the Department of Urban Studies and Planning on May 12,1975
in partial fulfillment of the requirements for the degrees of Bachelor
of Science in Urban Studies, and Master of City Planning.

The United States is facing a chronic and worsening shortage of
fossil fuels. Immediate implications of this shortage include rising
energy prices, and continued risk of political manipulation of energy
supplies. The energy shortage will affect housing development in America
since over 15% of American energy consumption is for residential energy
needs, mostly for space heating. The shortage should therefore affect
the decision-making of home buyers, housing developers, and government
housing policymakers.

This thesis presents strategies for reducing domestic energy consumption
for space heating at least 75% from present building standards. The
goals of these strategies are to reduce fuel expenses to the home owner,
and reduce national consumption of fossil fuels, while maintaining or
improving the feasibility and desirability of housing development.

These strategies are in the form of patterns of residential site
planning and macro-unit design that should reduce energy consumption.
Energy savings are quantified where possible. The patterns are designed
explicitly for the northeastern United States, but most should be applicable
elsewhere.

Also included is background information on energy-efficiency
principles, including information relating th the use of insulation and
microclimate for energy conservation, and information relating to the
use of solar energy as an alternative to fossil fuels. Benefits and costs
of solar collection will be examined.

This thesis concludes with a survey of government strategies designed
to accelerate energy conservation in the housing sector, including a
presentation of energy benefits and likely costs for each proposal.

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I. THE NEED FOR ENERGY-EFFICIENCY

The world today lives on fossil fuels. It is the major source
of transportation energy, industrial power,and and residential heat.
The fossil fuels of oil and natural gas are a major raw material in
producing electrical energy. Powerful, inexpensive, and convenient,
fossil fuels have been a major ingredient in the recent dramatic growth
rates of American industrialization, mobility, and prosperity. Some
facts on fuel consumption in America:

- In 1970, energy consumption in the U.S. included 5.5 billion
barrels of oil, 22 trillion cu. ft. of natural gas, 510 million short
tons of coal, 266 billion kilowatt-hours of electricity from hydropower,
and 37 billion kilowatt-hours from nuclear power, totalling 68,500 trillion
BTU's of energy consumed yearly.[1] This energy is equivalent to each
person having 80 human slaves.[2] 77% of the BTU's consumed are from oil
and natural gas.

- Half of the petroleum production to 1970 occurred during the
1960's. Projecting recent growth rates, more energy will be used between
1970 and 2000 in the U.S. than the total used previously by mankind.[3]

- The U.S., with 6% of the world's population, consumes 35% of
its energy.[4]

These growth rates, however, cannot continue. Evidence now exists
that the oil and natural gas supplies of this planet are very limited.

Examination of the facts indicates that, inevitably, fossil-fuel energy will permanently slip from a surplus commodity to a scarce one, both in the United States and in the world.

The theoretical basis for this limit is clear: the natural formation rate of fossil fuels is 1,000,000 times slower than the present consumption rate. In the time it takes to read this fact, fossil-fuel energy was consumed that took a year to create. [5]

In addition to a theoretical limit, there is empirical evidence that we are approaching that limit. Throughout the free world's oil and gas producing areas, estimates are made of proven oil and gas reserves, and probable reserves not yet discovered. Despite rigorous exploration, proven reserves have increased less than production (a net decrease) in eight of the last nine years. The trend indicates that oil is getting harder to find, and that perhaps most has already been found. [6]

In the U.S., it is estimated that over 50% of all probable oil reserves (known and presumed) have already been expended. The implication of this is that most American oil reserves will be exhausted in 15 years at present demand growth rates. Natural gas reserves should last about 20 years. [7]

Elsewhere in the free world, reserves are also limited. Western Europe and Japan could deplete all known Middle East reserves in seven years, if recent demand growth rates continued. While it is assumed that much oil outside the U.S. has yet to be discovered, it is probable that the world will exhaust all readily available oil and gas supplies within the next half century. If present growth rates continue, experts place the upper limit on the lifespan of free world oil at 40 years. [8]

A Dangerous International Situation

Even before oil and gas supplies are depleted worldwide, local shortages of this commodity, on which much of the world is severly dependent, will increase international tensions. One would hope that the world's nations will cooperate with each other in the management and distribution of remaining fossil fuels, but it seems likely from recent evidence that they will not. Nations with excess fuel supplies may succumb to the temptation of using their fuel as a weapon, threatening embargo or offering preferential treatment in return for economic or political gains. In addition, nations with shortages may be placed in such desperate national situations that they may risk war to increase their fuel resources.

A world solution is indeed difficult. From a national standpoint, security can only be guaranteed when a nation is capable of existing on its own energy supplies, for an extended period of time.

Future Life in America

Recognising the limit to presently popular energy supplies, it is clear that a "do-nothing" approach will have severe consequences for life in America in the near future. Provided that premature shortages are not induced politically, it seems probable that fuel prices will remain relatively low for a few years, inducing further dependence on fossil fuels, followed by a period of exponentially increasing prices and severe shortages as it becomes impossible for fuel production to increase with demand, and then even to hold its own. Our economy, based on fuel consumption, would be under heavy strain. Our major source of transportation energy and winter heat would be lost. Our agricultural production, highly

mechanized with fossil fuel equipment, would fall rapidly. Without preparation, the result could be confusion and decay, and possibly cold and hunger.

Of course, the nation would act rapidly to make changes when threatened with immediate crisis, but action may require too much time. It would take a long time to reorganize the agricultural and industrial producers on low energy systems. It would take time, and energy, to produce low energy equipment, and to develop alternative energy sources. To solve the problem we would need to replace our housing stock with low-energy consumption housing, locating it and orienting it on the assumptions of fuel scarcity. City development patterns would have to change; site planning patterns would also.

These things can't be done overnight. It is necessary that we begin now, because removal of our dependence on fossil fuels will take time, and is a problem that must be solved within no more than 50 years.

50 years is not a long time to rebuild our cities around different principles, replace our housing stock, reorganize our industrial production around different fuels and production principles, and revolutionize life-styles.

As we have seen from the crisis of the brief Middle East embargo of 6% of the American energy supply, a 50-year time span before national crisis is optimistic. We will be increasingly dependent on foreign energy sources, given present trends. Also, the 50-year estimate to severe worldwide shortage is based on maximum reserve estimates, and may therefore be overoptimistic. [10]

The Energy-Efficiency Solution

The necessary first steps to this problem should be undertaken immediately. It is clear that we must substitute plentiful or renewable

energy resources for fossil-fuels. If complete substitution is not possible, total energy-consumption should be reduced, to conserve remaining fuels, and lower national demand.

This thesis proposes methods for reducing the use of fossil fuels for residential space heating, which account for approximately 15% of national energy consumption. If similar solutions to these are applied to commercial space heating as well, these methods could affect over 20% of American energy needs. //

Obviously, parallel work is needed to lower transportation energy demands, industrial demands, and agricultural demands.

Residential space heating demands can be lowered in a variety of ways:

- CHANGE OF HABITS. Living through winter at lower building temperatures is necessary to reduce energy needs.

- IMPROVE HEAT RETENTION OF HOUSING UNITS. By improving insulation methods and using advantageous building forms and site designs, the energy required to heat housing units will be decreased.

- AFFECT MICROCLIMATE. It is possible to affect average winter temperatures in local areas with building location, vegetation placement, and surface grading. Small increases in average winter temperatures can lead to dramatic reductions in fuel requirements.

The Solar Energy Solution

An important alternative energy source is solar energy. It is by far the most abundant form of energy available to man, the longest lasting, and the most wasted. The energy striking ½ of 1% of American

land surface could supply all of American energy needs to the year 2000. [12]

Technologies are now available for collecting and storing solar energy, and are continuing to be developed. They appear particularly applicable to residential space heating because:

- Solar radiation is everywhere, and is therefore usable by decentralized energy collection systems, such as on the roofs of individual housing units.

- Solar energy collection is most efficient at lower temperatures (100° to 200°F) which are adaquate for operating space heating systems, but are generally inadaquate for industrial use or electric power generation.

- Solar energy heating systems have advantages over fossil fuel systems of no pollution (smoke), or waste (ashes), less fire or safety problems, and an inexhaustable free energy supply. [13]

Solar energy can be collected "actively", through dynamic collector and storage systems with ducts and fans, or "passively", by letting winter sun shine on buildings and through windows. The applications of both of these approaches to residential space heating will be discussed in this thesis.

The Goals of This Thesis

The intent here is to suggest strategies to the homeowner, the builder, and the nation, that will improve the energy-efficiency of housing units, consistent with their shared and individual objectives. The hypothesized objectives of these groups, used as a basis for strategy generation, are outlined in the next section.

These strategies will be in the form of patterns for residential site planning, and housing unit design. Background information will be supplied that is the basis for these patterns, and government programs will be suggested than can expidite their use.

It is believed that the patterns proposed here will reduce the heating demands of housing units at least 50% from present standards. It is further believed that the use of active solar energy systems, when and where applicable, can economically reduce the remaining heating demands over 50% again. The result would be at least a 75% reduction in fuel requirements over common existing housing.

When these patterns are reflected in a majority of the housing stock, national energy savings could be reduced 10% as a result of their use. If they are applied to commercial space heating as well, a reduction of 15% will be accomplished.

It is clear that this 10% to 15% savings will not solve all of our energy problems. At best, it will preserve our fossil-fuel energy supplies 15% longer, and reduce our dependence on foreign oil for a few years.

However, energy-efficiency in housing as part of a complete program of energy conservation can be very worthwhile. If we can cut the demands of fossil fuels for all other needs by 75% as well, this will make a significant alleviation in our demands on energy resources, and leave us better prepared to adjust to an age without fossil fuels.

Therefore, this thesis is not undertaken with inflated hopes. The strategies will help solve national problems, but only in an incremental way as part of a complete energy-reduction program.

Before deciding to implement these strategies, their benefits

must be evaluated against their costs to society. Some may be too expensive.

Others will be costless, for even at present, the home owner and developer

can save money with some energy-efficiency techniques, reducing heating

costs while maintaining winter comfort. For this reason, some reduction

in national energy consumption can probably be achieved without any

specific costs to society, and with very little or no intervention by

government.

It is hoped that this thesis will provide useful information to

readers previously unacquainted with energy-efficiency concepts. Principles

are defined intuitively, without great scientific or thermodynamic analysis.

The significance of energy-saving proposals is quantified in measures

useful for comparison, such as "gallons of fuel saved per season". It

is hoped that this thesis will result in interest and application of energy

efficiency principles to common practice and national policy, and not

just additional academic rhetoric on present research.

The recommendations of this thesis are specifically designed for new

housing development, with concentration on an example of housing for temperate

climates of suburban to near-urban densities. Although this is a sizable

segment of future housing development, it is clearly not all of it. It is

hoped, however, that these recommendations will suggest energy-saving

approaches to rural and high-rise urban housing, and to development in the

more extreme climatic regions of the U.S.

Because the recommendations specifically apply to new housing development,

the benefits of these strategies are limited by the housing growth and

replacement rate, historically about 3% per year. Again, it is hoped that

the principles presented here will suggest approaches to improving energy-

efficiency in existing housing, and that future research will concentrate

II.   PERSPECTIVES FOR EVALUATION OF ENERGY-EFFICIENCY

When evaluating strategies for developing energy-efficient housing, it is necessary to consider the interests of the homeowner and developer, as well as national interests. Only when provision is made for all of their concerns can a successful program leading to energy-efficiency be accomplished.

National Energy Objectives

As previously explained in the introduction, it is essential that the U.S. embark on a program that reduces our dependence on fossil fuels. This is necessary for national security in the short-run, so that we can reduce our reliance on foreign energy sources beyond our control. It is also necessary so that, in the long-run when world oil and gas supplies diminish, the U.S. is better prepared for smooth transition to a society based on different quantities of energy, and different energy forms.

Government's objective, therefore, is to solve this fossil fuel problem. It can do this in both of the following ways:

- Substitution of plentiful energy resources for scarce ones. Plentiful energy resources, such as solar energy, wind power, and geothermal energy, should be developed. These energy sources are long-lasting and unlimited. As they are developed, they sould be substituted for non-renewable, exhaustable, or potentially unavailable resources, such as fossil fuels.

- <u>Reduction of national energy demand</u>. Energy conservation measures, such as promoting energy-efficiency and preventing energy waste, should help in several ways. By lowering our yearly energy demands, we would be prolonging our reserves, reducing our dependence on foreign energy resources, and preparing ourselves for more limited energy availability in the future.

A method commonly proposed for reducing energy consumption is to destroy the ability of the economy to purchase fuel by making it expensive through taxes and other means. This measure closely corresponds to the situation that will be caused by energy shortage in the future. It creates hardship and stress among industries and individuals reliant on fuel and works to promote inflation and recession in the economy. A weak economy, in turn, lowers the national tax base, and reduces the funds available to the government to apply to national problems. It should therefore be a government objective to try to reduce consumption without resorting to programs causing economic distress.

In developing alternative energy sources and promoting energy-efficiency, processes will be proposed that will yield significant externalities of air pollution and other environmental degradation. Coal burning, for example, produces sulphur and other pollutants. More efficient automobile engines may require greater exhaust emissions. If the basis for government's objectives is concern over the future quality of life in the U.S., it is necessary to maintain an objective of non-wasteful, non-polluting use of <u>all</u> natural resources. Otherwise, while improving future living conditions in one way, we may be making these conditions unbearable in others.

Resident Energy Objectives

The home buyer, home owner, and home renter may have strong concerns for national problems, but from their vantage points, they realize that their own housing decisions will have very small effects on national energy problems. The individual will make his own decisions on the basis of his own values, spending his money to his own best advantage. National programs, therefore, must assume that individuals will act independently, and not necessarily for the "common" good. If energy programs are to succeed, they must fulfill the resident's personal objectives, while fulfilling national ones, as well.

Among the resident's concerns are the following:

- A resident desires to buy (or rent) the unit of greatest value to himself for the lowest possible cost. If an energy-efficient unit costs more than another less efficient housing unit, and the additional cost is not justified with energy savings, he will choose the less-efficient housing unit, in all likelihood.

- The resident, however, will desire to be secure that there will be heat for his unit through each winter. If an energy-efficient unit will be more likely to provide this security, he may be willing to pay extra for energy-efficiency.

- If an energy-efficient housing development looks or works differently from conventional housing developments, potential residents may be hesitant to move into them for reasons of conservatism. Especially the home buyer, who is purchasing both a home and an investment, will be reluctant to consider unusual housing.

- In the long run, however, housing tastes should evolve. Even

if change is slow, tastes should eventually change in favor of housing

forms that are functional, useful, comfortable, and enjoyable to live in.

The resident's objectives, therefore, will change with time. This

must be considered in planning national strategies.

Developer Objectives

The developer wants, above all else, to make a profit on his

developments. To do this, he tries to achieve the following objectives

in his investments:

- Build housing that is in demand, ie., that home buyers want to

buy. If he builds what is not wanted, he will be unable to sell his units

quickly, and may not make a profit. To build housing that is in demand,

the developer basically caters to resident objectives.

- Choose housing features that will maximize profits . In choosing

accessories or additional features in housing developments, such as

energy-saving features, the developer will add only those items that add

more value to the unit than their costs. Therefore, the developer

will only add energy-saving features if the public willing to pay

enough extra for them to pay his costs, plus profit.

- Take the smallest possible risks. When a developer is making

an investment, he wishes to build those housing types that will provide

the most secure return, not necessarily the highest. If the developer is

unconvinced of the profitability of energy-efficient techniques, he may

be reluctant to try them.

- Make investments that can be financed. A developer wants to

build with other people's money, in general. Therefore, he will give

greatest consideration to developments that will be financed by banks

or other sources. The banks, in turn, are conservative investors, and

will only provide financing on investments that are low in risk. /

The Problem

This thesis will now attempt the simultaneous solution of these

varied objectives. For some of them, simultaneous solution is easy.

For example, if energy-efficiency provides home owners with secure winter

heating supplies, it should also improve demand for energy-efficient housing

by home owners (a developer concern), and result in greater use of energy

efficiency techniques, lowering national fuel consumption (a society

goal).

Unavoidably, however, there are conflicts. Energy-efficiency

may produce unusual housing, which is less desired initially by home

buyers. This lower demand affects builder's concerns, and makes financing

more difficult.

There are also conflicts between reducing energy consumption and

avoiding economic problems (as described), between conventional housing

design and energy-efficient design, fuel substitution and ecological

considerations, and many more. This thesis will attempt to resolve these

conflicts.

III.   ENERGY EFFICIENCY CONCEPTS

Methods of improving energy efficiency in dwelling units are of

three basic strategies:

1) reducing the winter heat loss of dwelling units to the

outside(insulation),

2) increasing the heat gain from solar radiation in winter

(insolation), and

3) raising the exterior air temperature to reduce the heating

requirements of the unit (control of microclimate).

Properties of insulation, insolation, and microclimate that

are useful to the design of energy-efficient housing are outlined in

this chapter. The purpose of this chapter is to acquaint the lay reader

with the concepts that are the basis of the later recommendations for

energy-efficiency. It is not the purpose of the chapter to be a text on

these subjects, since complete information could, and does, fill several

volumes. Sources of more detailed information are listed in the appendix.

INSULATION

Buildings lose heat energy to a colder outside environment in three ways:

1) Heat passes through the walls, floors, and ceilings of housing units to the colder exterior surfaces, where heat is radiated away, or carried away by the wind.

2) Warm air infiltrates out through doors, window frame gaps ("cracks"), and through air-porous building materials to the outside, carrying heat energy along with it. Likewise, cold air infiltrates into the unit.

3) Heat energy radiates to cold windows and wall areas, where it is passed to the outside environment by the processes in #1.

Important Insulation Terms

A. U- VALUES

A U- value is a measure of the heat-loss of a wall. A wall with twice the U-value of another will lose twice as many BTU's (British Thermal Units- a measure of heat) under identical environmental conditions, in the same period of time. U- values are in units of heat loss per unit area, per unit time, for a wall of given temperature difference between interior and exterior. Common units are BTU/ $^\circ$F/ sq.ft./ hour.

Walls composed of highly insulative materials have low U- values. Good insulating materials include polyurethane foam (one of the best, though expensive), fiberglas, blown vermiculite, and (to a lesser extent) polystyrene. Air spaces between wall layers add significantly to lower-

ing U- values, and therefore many layers of material will produce low
U- value walls.

A good exterior stud wall with plywood and shingles on the exter-
ior, sheetrock interior, and 3 1/2" of fiberglas insulation, will have
a U- value of about .07. [1]

Other U- values:

- the same wall with no insulation, .25

- 12" of brick, .32

- 8" of concrete block, .48

- A single glass window, 1.13

- A double-glass window, .55

- A triple-glass window, .36 [2]

B. DEGREE DAYS

The heat loss through any building wall is proportional to the
temperature difference between the exterior and the interior. The hy-
pothesized average temperature difference between the exterior and in-
terior for a given day is recorded by weather stations and is measured
as degree days. Sums of degree days over the course of a heating season
are also compiled and recorded.

This sum of degree days per season is directly proportional to the
heat loss per season through any wall surface, regardless of its construc-
tion. In an environment with twice the degree days per season of another,
any exterior surface, whether it is 3 1/2" of fiberglas, 20' of stone,
or a piece of tin foil, will lose twice as many BTU's per season as it
would in the warmer environment.

Heating Costs

A given environment will have a heating demand expressible in degree days. The heating demand for Boston, for example, is approximately 5700 degree days per season. The implication of this demand is that each sq. ft. of building surface will lose 136,000 BTU's per season, per unit of U- value of a wall. Therefore a sq. ft. of wall with a U- value of .5 will lose 68,400 BTU's per season.[3]

The cost of a BTU depends on the type of heating equipment and the fuel used in a dwelling unit. 100,000 BTU's (called one "therm" of energy) will be supplied by one gallon of fuel oil, with common oil-burner efficiencies, or by 30 kilowatt-hours of electricity, or by 130 cu. ft. of natural gas.[4] At present common domestic prices of $ .40 per gallon for fuel oil, $ .03 per kilowatt-hour of electricity, and $ .30 per 100 cu. ft. of natural gas, one therm costs approximately $ .40 in an oil-heated home, $ .39 with natural gas, and $ .90 with electricity.

Now we can estimate the impact of affecting a wall's U- value on heating costs. With an oil-heating system, multiplying the U- value of a wall by $ .54 (1.36 therms per U, times $ .40 per therm for oil) will give the cost of the heat loss of a sq. ft. of wall, per season, in Boston.

A sq. ft. of wall with 3 1/2" of insulation will lose .1 therm/ season in Boston, costing 4 cents with oil heat. Each sq. ft. of stud wall without insulation will cost 13.6 cents. An 8" concrete block wall will cost 26 cents/ sq. ft. in heating costs, and single glass window will cost 61 cents/ sq. ft. Likewise, costs can be computed with other wall materials, other fuels, and in other localities (with

different degree days per season).

Insulation Problems

Problems with insulation of dwelling units include the following:

- Adding additional insulation to lower U- values is expensive, and in general, better insulating materials are more expensive than cheaper ones.

- Building skin materials with high U- values may be necessary; for example, window areas are necessary for light and air in dwelling units, are required in most building codes, and are used for aesthetic reasons, but have high U- values and large heat losses.

- Temperatures often vary inside dwelling units at various points around the unit. For example, hot air rises and tends to collect at the ceiling. Therefore heat differences between interior and exterior will be greater at the roof than on the walls, and the heat losses will increase proportunately. Therefore, lowering the U- value is of more benefit on the roof than the walls. More generally, warmer locations in dwelling units have greater need for low U- value walls. [5]

Other Heat Losses

A. WIND

A layer of still air exists on wall exteriors that is of high insulating value. Winds blowing past the exterior of a dwelling unit will strip this layer of still air from the exterior surface. Removal of this layer by winds will cause severe drops in wall U values. There-fore, blocking winds from exterior surfaces is desireable. [6]

B. AIR INFILTRATION

Air infiltration is a major form of heat loss. In a typical dwelling, there will be a complete air change about once an hour. This is more than is needed for proper ventilation of a dwelling unit. Although air carries only .018 BTU/cu. ft./ $^{\circ}$F, such tremendous quantities of air infiltration occur over the course of a heating season that a reduction in air infiltration can create major savings.

Weatherstripping windows and doorjams will reduce air infiltration significantly. A well-built double-hung wood frame window, subjected to 15 MPH winds and 5700 degree days per season will have a heat loss of 14.4 therms/season. If the same window is weatherstripped, heat loss will be reduced to 8.8 therms/season, a savings of 5.6 therms or $2.24 in oil at present prices.

Each foot of weatherstripping along doors and windows saves about .4 therm/season. If weatherstripping is done each 5 years, $.74 to $1.66 will be saved for each foot of crack weatherstripped, making it a generally worthwhile investment. [7]

INSOLATION

Sunlight is a powerful energy source that is generally wasted for space heating. On a sunny day, 250 to 350 BTU's of energy strike each square foot of sunlit surface, each hour, perpendicular to the sun's rays. [?]

Most of this energy is reflected off light ground surfaces and back into space, or absorbed by darker ground surfaces and re-emitted as heat. While this re-emission is useful in that it warms the atmosphere and keeps our planet livable (average air temperature is $504^{o}F$ above absolute zero), there would be no major environmental effects to diverting as much solar energy as we would like for domestic use.

In the next chapter, we will discuss possible solar collection systems for major solar energy use. Here we will explain how energy is trapped by a common building component, the glass window.

A glass window has the fortuitous property of being transparent to solar energy, allowing most of the 250-350 BTU's/sq. ft./hr. to enter a housing unit. Also, since glass is not transparent to heat radiation, it has some insulating value (albeit poor) to retaining interior heat.

Effect of Orientation

The figure of 250-350 BTU's/ sq. ft./ hr. applies to a surface perpendicular to the sun's rays. In order to admit this much radiation through a sq. ft. of glass for any period of time, the glass would have to follow the sun's movement across the sky, remaining perpendicular to the sun's rays at all times. If it did not, the energy admitted through the glass would be reduced for two reasons:

1) The projection of the sq. ft. of solar radiation on a non-perpendicular surface would cover more than a sq. ft., meaning that the radiation is more diffused.
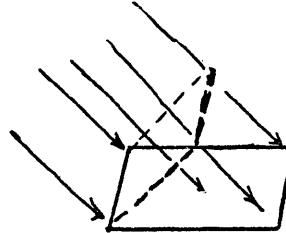
2) A property of glass is that it becomes more reflective and less transparent at sharp angles to light, causing a reduction in the amount of energy penetrating the glass.

In addition to the daily solar travel, sun angle changes with the seasons. From its peak altitude at midday (due south) of 90°, minus the latitude of the particular location, during spring and fall equinox; the peak altitudes will vary from $23 \, 1/2^\circ$ above this altitude on the first day of summer, to $23 \, 1/2^\circ$ below this altitude on the first day of winter. As an example, the mid-day sun altitude in Boston (42°N latitude) would be 48° during spring and fall equinoxes, $71 \, 1/2^\circ$ at summer solstice, and $24 \, 1/2^\circ$ at winter solstice.
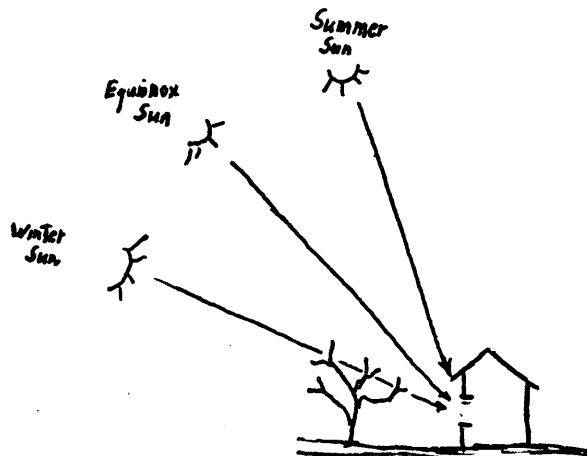
This large variation between summer and winter means that mid-day solar radiation will be strongest in summer on relatively horizontal surfaces, while in winter, more vertical surfaces will have strongest radiation.

Of course, even in summer, the sun altitude is lower to the ground in the early morning and late afternoon, so vertical surfaces will receive strong summer radiation on summer mornings and afternoons, as well.

The implications of these facts for windows on fixed vertical building walls are clear. South-facing windows (facing mid-day sun) will receive strong solar radiation in winter, and much less in summer. East and west facing windows (facing morning and afternoon sun, respectively) will have strongest radiation in the long mornings and afternoons of summer, and less on the shorter winter days. [9]

Calculating heat gain through windows

Heat gain through windows is calculated by computing the radiation striking the window, per sq. ft., and multiplying it by the window size, and the transparency of the glass. The radiation striking the window is a function of its orientation, as described above, but also climatic and seasonal weather conditions. Hazy and cloudy weather conditions, of course, reduce solar radiation. The weather bureau keeps records of "% possible sunshine", by month, which can be used as a factor to correct for cloudy weather.

In the appendix, a chart is listed giving typical heat gains, per day and per month, of vertical windows of each compass orientation, for the Boston area. The chart considers all factors mentioned here. Information sources for developing charts for other areas are listed in the appendix. [10]

MICROCLIMATE

Besides reducing heat loss with insulation and increasing heat gain with insolation, a third way to reduce a unit's heat load is to create a warmer climate in the area immediately surrounding the unit. This reduces the heat losses of units proportionately. Affecting the temperature of the air near the ground in a local area is known as a microclimate control.

Ground temperature

It has been shown that air near the ground (within 10 ft., more or less) has a temperature that is related to the ground temperature, as well as to the upper air temperature. Therefore, by controlling the temperature of the ground, air immediately above the ground is affected. "

The temperature of exposed ground areas often vary between day and night to greater extremes than higher air temperatures.

Exposed ground temperatures experience the following day and night phenomena:

- During a sunny day, solar radiation strikes the ground. Although much is re-emitted or reflected, some is absorbed, making the ground warmer. Depending on the particular ground characteristics, soil temperatures can rise above prevailing air temperatures during the day.

- At night, the ground loses energy to the cold upper air (the "sky") by radiation. The ground may continue to radiate energy until it is cooler than the prevailing air temperature since upper air

temperature ("sky" temperature) is lower than prevailing temperature.

DAY   **NIGHT**

Air - Warm

Ground - Warmer than Air

Upper Air - Coolest

Air - Cool
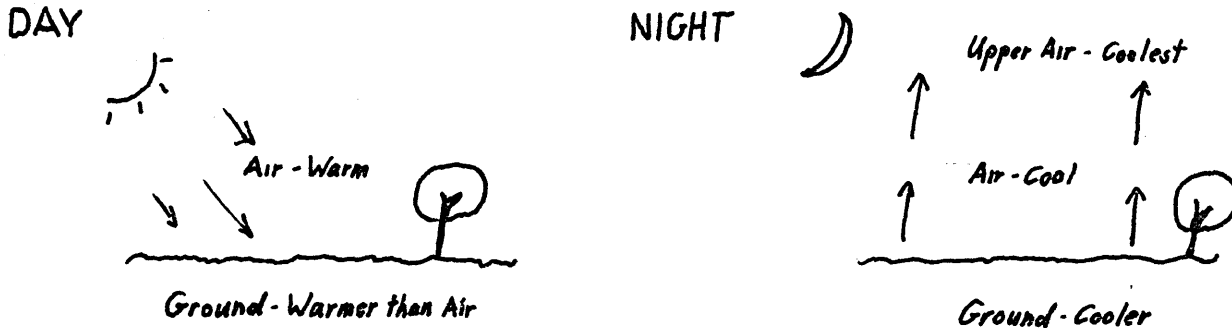
Ground - Cooler

Surface air temperature

When the earth is cooler than the prevailing air temperature, it cools the air near the ground. A thin layer (6 ft. to 20 ft.) of surface air becomes cooler than the prevailing air temperature. Night temperatures of $2^{\circ}F$ to $15^{\circ}F$ have been recorded between surface air and higher air. Differences are the smallest in mid-winter ($2^{\circ}$to 10°), and approach 15° throughout the summer. Temperature variations are poorly documented, but a likely range for temperature differences between surface air and upper air are 7° to 10° through much of the heating season.[12]

Likewise, warm ground can warm surface air. The temperature differences between surface air and upper air are smaller, however, since warm air tends to rise.

As can be detected from the generality of this discussion, micro-climate is an emerging field, suffering from a lack of adequate data to establish solid quantitative relationships. The existence of these effects is well documented, however, although the order of magnitude is not precisely known.

Conditions that affect microclimate

Among the physical characteristics of a site that affect micro-
climate are the following:

A. TREE COVER

A canopy of vegetation over the ground can have two effects on
microclimate. It can block night "sky" radiation, and block solar
radiation during the day.

Night sky radiation will be stopped by a tree canpoy directly
over a piece of ground. Effectively, if you stop the ground from
"seeing" the sky, radiation to the sky will stop, and the ground and
covering air will not cool.

Daytime solar radiation will be blocked from different ground,
however. Since the sun is never directly overhead, the vegetation
shadow will be angled, occluding some area other than the ground di-
rectly underneath the vegetation.

Because a tree canopy blocks both day and night radiation, daily
temperature fluctuations will be less severe in tree-covered areas
than in clearings. [13]

B. EFFECT OF SOIL CONDUCTIVITY

Conductive ground surfaces can absorb and hold solar radiation.
The effect is that sun energy is stored during the day, and the ground
is warmer into the evening. Darker soils and stones are among the best
conductive ground surfaces, peat and white sand are among the poorer
ones. [14]

C. EFFECT OF WIND

Wind causes eddy diffusion, mixing the air near the ground with the upper air. Wind, therefore, reduces microclimatic effects on surface air. [15]

D. EFFECT OF SOIL MOISTURE

The process of evaporation of water absorbs large amounts of energy. Moist soil, therefore, will have significant evaporation, with a subsequent cooling effect on the ground and surface air layer.

Methods of using microclimate to advantage will be described in the "Design Patterns" chapter.

IV. <u>USE OF SOLAR ENERGY COLLECTORS</u>

In this chapter we will discuss the prevailing concepts of solar energy collection for domestic space heating and for hot water. This chapter will outline the principles of a collector system, its typical dimensions and effectiveness, its limitations, and likely improvements in the future.

For those interested in actual detailed design and construction of a collector system, sources are listed in the appendix that have most recent information.

<u>The Solar Collector System</u>
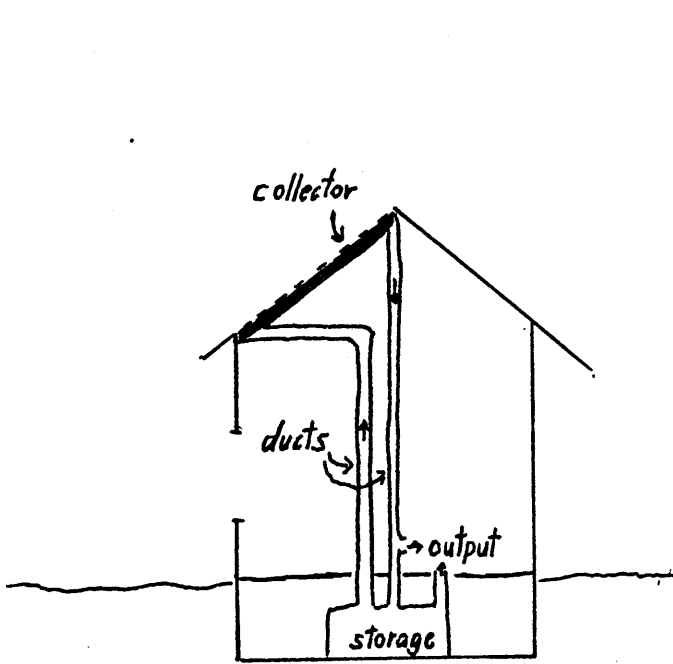
The Collector System
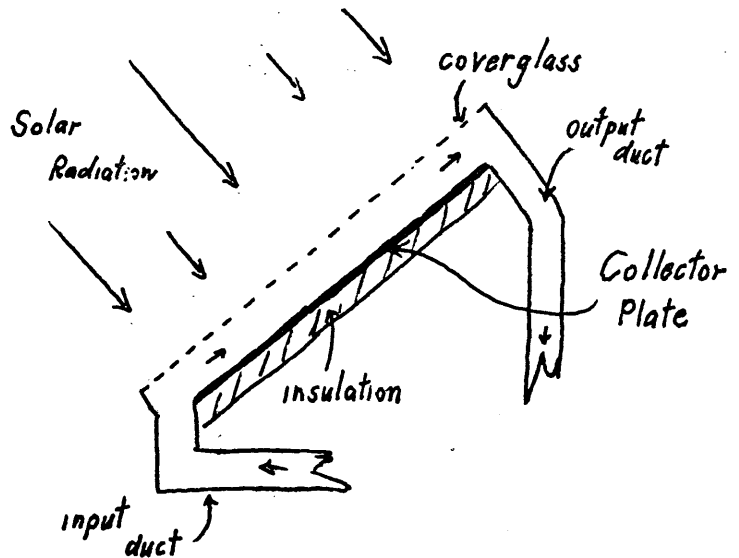
Detail of Air Collector Unit

Principal components of a collector system include the following:

1) The Collector: a box that traps the sun's rays, becoming hot in direct sunlight. The collector is usually located on the exterior wall or roof, although it need not be connected to the dwelling unit.

2) The Collection Medium: a fluid that is warmed in the collector box, and then pumped where heat is desired in the dwelling, or into storage. Air can also be a collection medium.

3) Pipes or Ducts: these carry the collection medium to and from the collector box. Pipes are used in a liquid medium system, ducts in an air system.

4) Storage: a container that can retain excess collecter energy until needed by the dwelling unit. The collector and storage are discussed in more detail below.

The Collector

The collector box is usually placed on the wall or roof of a dwelling. It should be oriented to receive as much solar radiation as possible, and is therefore usually placed on the south side of a building on a slanted roof or other surface. The collector absorbs the solar energy, and then transmits the energy to a collection medium (usually air or water) that is circulated through the collector unit. The warm collection medium then leaves the collector unit to be directly used in the dwelling as heat or hot water, or the medium is diverted into a storage container, where it can be used later.

The most common collector for domestic use is the "flat-plate" collector, which is basically a black metal plate covered by one or more

panes of glass. The plate is warmed by radiation from the sun. The collection medium (usually air or water) passes over, behind, or through the collector plate. The medium is warmed by conduction from the hot plate, and is then pumped away to provide energy for the dwelling unit.

Concentrating collectors of curved mirror surfaces can produce very high concentrations of heat, allowing heat storage to be concentrated in less material, and allowing solar energy to be used where high temperatures are required, as in the production of steam. They are not practical for domestic use, however, because they must be moved with the sun to remain in focus, which requires elaborate, expensive equipment. Curved reflecting surfaces are generally expensive, as well. Also, for domestic uses of space heating and hot water, the high temperatures of concentrating collectors are not necessary; in fact, they lead to greater system inefficiencies.

The "Greenhouse Effect"

Flat-plate collectors can rise to high temperatures because of a principle known as the greenhouse effect. The greenhouse effect describes how a greenhouse, or a solar collector, can let the sun's energy enter a space, but then not let it out, resulting in a heat buildup in that space.

This principle relies on the property of glass to be transparent to light energy (short-wave radiation), while being opaque to heat energy (longer-wave infrared radiation). Glass will therefore let light into a collector space, but will be more resistant to the movement of heat in either direction. The greenhouse effect also relies on the property of a black-surfaced collector plate (a "black-body", is the thermodynamic term) to absorb light energy, and then convert it to heat before re-emitting

the energy.

Therefore, the collector box lets light energy pass through the glass, where the black collector plate absorbs the light and then re-emits heat, which the glass traps within the collector space. The collector is therefore an energy "trap", resulting in high concentration of heat to be carried away by the collection medium for advantageous use.

The coverglass is not truly opaque to heat, however, and loses heat energy by conduction to the outside. Two coverglass panes are commonly used in northern climates to reduce this heat-loss from the collection space.

Energy Storage

Because the sun does not always shine, it is desireable to collect more energy than is needed during the sunlight hours, and store it for evening use and for use on cloudy days. The storage container can be located in the basement, roof, in a closet, or in a crawlspace between floors, with various advantages or disadvantages to each, depending on the storage material and the design of the dwelling unit. Typical storage materials are crushed rock or other solids, water, and experimental phase-changing salts.

Crushed rock is an inexpensive, relatively maintenence-free, though bulky, storage material. An air collector system can heat the crushed rock directly by pumping warm air through the rocks, and a water collector system can pump hot water down to a tank surrounded by rocks. When heat is needed in the dwelling, air is pumped through the warm rocks and then directed into the living areas of the dwelling unit. Usually a cubic foot of rock storage is provided for each square foot of collector. [2]

Water has higher specific heat than most common rock materials, and therefore requires less storage space. While water is very cheap, a high-quality, non-corrosive container is necessary, which is usually expensive. About one-half cubic foot of water is provided per sq. ft. of collector. [3]

Experimental phase-changing salts change from solid to liquid at about 90°F, and absorb large amounts of energy in the phase change. Then, at night when the liquid returns to the solid state, the energy is released. These salts can store seven times more energy than an equivalent volume of water. Although container materials are expensive, the major problem is promoting the reverse phase-change from liquid to solid, which often requires agitation. When this problem is solved, phase-changing salts as a storage medium will be highly advantageous, requiring only one cubic ft. per 15 sq. ft. of collector. [4]

Typical System Dimensions

Common solar collector heating systems are designed to provide 50% to 70% of the seasonal heating requirements of a dwelling unit. The systems are inadaquate to provide heating over a period of several cloudy days, and therefore back-up conventional heating systems are retained in solar heated houses, for the following reason:

Over a short period of time, heat gain from a collector system is proportional to the size of the collector area. However, when considering the percentage of home heating supplied by a collector system over the course of a season, collector area rises exponentially as this percentage

is increased.

Collector
Size

Collector Output

Collector
Size

% of Heat Load   100%
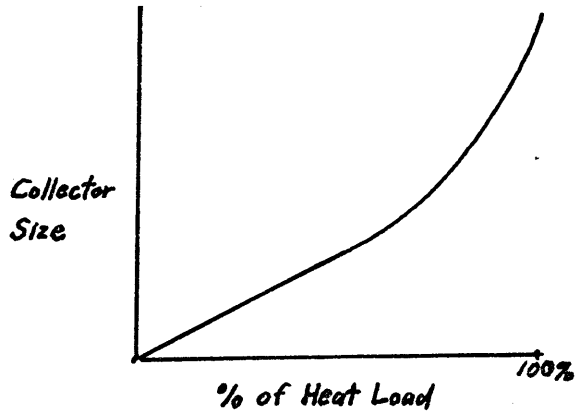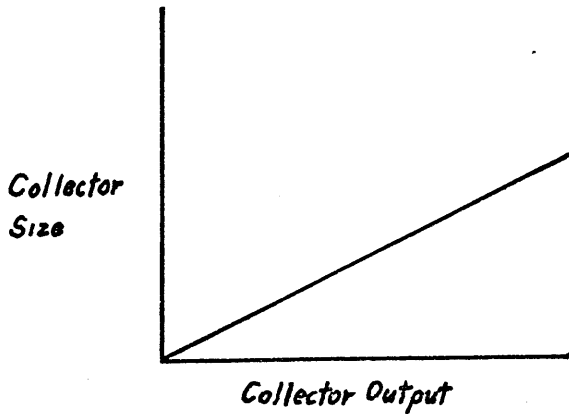
The reason for the exponential increase in collector area is the randomness of weather conditions. In order for a system to provide all (100%) of the heat load, the system must collect enough energy, and be able to store it, to last through the longest string of cloudy days on record. Such a system would totally overwhelm all surface areas of a dwelling with collector, and even more would be required; besides, it would be very expensive.

Therefore, although a conventional heating system is provided, causing additional capital expense, this expense is less than the additional collector required to make a solar system approach 100% of the heat load. [5]

Including all typical solar system inefficiencies, a sq. ft. of collector in a 50% solar system will deliver about one therm of useful heat to a dwelling unit each heating season. This "typical" collector system assumes that the collector operates efficiently, that it is oriented well to receive winter radiation, and that there is adaquate storage to save excess collected energy until it is useful. This also assumes that the collector system attempts to supply only 50% to 70% of the unit's

heat load. Above this percentage, the energy supplied per sq. ft. drops markedly. [6]

In a properly insulated, single-family dwelling unit subjected to 5500 degree days per year, approximately one therm of energy is required per square foot of floor area, per season, for space heating. A 1000 sq. ft. dwelling would therefore require 1000 therms of energy. For a 1000 sq. ft. unit to have 50% solar space heating, approximately 500 sq. ft. of collector would be necessary. This much collector would require a 25' by 20' solar panel to be placed on the roof or walls, for example, which would be difficult to place (though not impossible) on a house of this size. Additional collector would be necessary for hot-water heating. [7]

Using energy-efficiency techniques proposed in this paper, the typical unit described above could reduce its heat losses in half, cutting energy consumption to 500 therms per year. If this was done, only 250 sq. ft. of collector would be necessary for 50% solar heating, or one sq. ft. of collector per four sq. ft. of floor area. This is well within the range of architectural feasibility on most housing units.

One-day storage will be adaquate to use most energy collected by a 50% solar system, which, for this 1000 sq. ft. dwelling, could be approximately 250 cu. ft. of rocks, 125 cu. ft. (975 gallons) of water, or about 20 cu. ft. of phase-changing salts, when perfected. [8]

Benefits and Costs

For one therm of energy to be provided by a typical fuel-oil heating system, approximately one gallon of fuel-oil is required. Therefore our collector system is saving the equivalent of one gallon of fuel oil, per

sq. ft. of collector, per heating season. [9]

Since a conventional backup heating system is also provided, the solar system is merely additional capital expense in the construction of a dwelling, with little or no savings in size reduction or capital costs of the conventional heating equipment. However, if the collector is designed into the roof or walls of a unit, "building skin" materials are saved. These savings are presently $2 to $3 per sq. ft. [10]

Estimates of the costs of a collector system are highly variable at present, varying from $5 to $20 per sq. ft. of collector, including storage and ducts. Some collectors are being commercially manufactured at present; mainly copper and aluminum collectors with water or other fluid as the collection medium, with prices from $6 to $15 per sq. ft. for the collector alone. Air-type collector systems appear to be less expensive, but are not presently being commercially produced. It is therefore hard to be accurate about the present costs of solar collector systems. In our calculations, we will use a "best guess" figure of $10 per sq. ft. of collector, including storage and all accessories, for the present price. [11]

For each sq. ft. of collector, therefore, the costs and benefits are as follows:

COSTS: $10 per sq. ft. installed

                  - $ 3 per sq. ft. savings of "building skin" materials

            Net $ 7 per sq. ft. of collector

BENEFITS: 1 gallon per sq. ft. per season saved

            times $.40 gallon (common present cost)

            Net $.40 saved per sq. ft. of collector, per year.

With these benefits and costs, it would take approximately 17½ years for a collector to pay itself off in energy savings!

Since the $7 per sq. ft. price is hypothetical, it seems better to ask " at what price does it make economic sense to use a solar collector?" Using a 10% capitalization rate to determine the present value of $.40 yearly savings, one would estimate the "break-even" cost of a collector at approximately $4 per sq. ft. Implicit in a 10% capitalization rate would be about an 8% return on the initial investment in solar equipment, and a lifespan for the equipment of about 20 years. Because collectors designed today are expected to need replacement in 10 to 15 years, collectors would have to pay themselves off in less time, and a capitalization rate of 14% is commonly used. At this rate, the collector must pay itself off in energy savings in seven years to be considered economically feasible, and the "break-even" price for a solar collector system would be about $2.80 per sq. ft.

No one can presently deliver a collector system for $4 per sq. ft., and certainly not for $2.80 per sq. ft. It therefore appears disadvantageous at present to use solar collectors for space heating, at least in terms of economic considerations.

Benefits and Costs for Domestic Hot Water Heating

Hot water heating has analogous system components and costs. However, since the hot-water heater is beneficial on a year-round basis, typical system output is increased to 2 therms of useful energy per sq. ft. of collector, per year. /2

    2 gallons per sq. ft. per season saved

times $.40 per gallon

Net $.80 saved per sq. ft. of collector, per year.

For a hot-water heating system, therefore, each sq. ft. of collector
is twice as valuable. With a 14% capitalization rate, the "break-even" cost
of a hot-water collector system is $5.60 per sq. ft. Therefore, the use of
collectors for hot water heating is closer to the region of economic
feasibility, and should be the first use of solar energy on a large scale.

Additional Problems with Solar Collector Systems

Besides unclear economic feasibility, solar collection has the
following problems:

A. MATERIALS: The black collector plate should be highly conductive
to transfer heat to the collector medium, non-corrosive and long-lasting, and
inexpensive. At present, there is no such material. Copper is highly conductive,
and non-corrosive with water as the collector medium, but is becoming
scarce and increasingly expensive. Aluminum and steel are cheaper but are prone
to corrosion. Plastic is proposed for the collector plate in systems
where high conduction isn't necessary because the collection medium covers
the entire plate (as it would in a hot air system). Plastic isn't corroded
by water, and is inexpensive. However, plastic is damaged by ultraviolet
radiation, and is therefore not suitable as a collector plate at present.

Most present systems use copper, which is expensive, or aluminum or
steel with expected maintenence problems. [13]

B. HIDDEN COSTS IN SPACE: In addition to the direct costs of a
collector system, the storage and ducting consume interior space. This
is rarely figured into the analysis, but since building costs are generally
proportional to floor area, the expense of planning to use space for a
collector system is a real one. If a solar energy rock storage unit is

on useable floor area, at least 40 sq. ft. would be used (6' by 6' by 8'
container, plus controls and ducts) for a 250 sq. ft. solar collector.
At $25 per sq. ft. building costs, this space is worth $1000, or $4
per sq. ft. of collector in space costs. Space costs would be lower for
water or salt storage, and floor area costs would be figured at a lower
rate for less useable space, such as in an unfinished basement.

C. HIDDEN FUEL CONSUMPTION: A solar collector system may require
significant conventional energy inputs to operate pumps, fans, and
control equipment. From a national energy perspective, therefore, the
true fuel savings of solar energy may be less than expected.

In an air collector system, electrical energy input to drive fans
is 10% of heat output. In areas where fuel-oil is used to produce electricity,
3/10 of a gallon of fuel-oil will be consumed per sq. ft. of collector
per season, equivalent to 30% of the heat energy output, due to the
inefficiencies of producing electricity from fuel oil. For water collector
systems, electrical input power is four times less, because water is
a more efficient heat collection medium.[14]

Of even larger significance in the total energy perspective is the
fuel required in the production of copper, aluminum, or steel collector
plates and ducts; the fossil fuels required in the production of plastics,
and energy used in construction and welding of the system.   Estimates
should be made of the total energy inputs in collector systems. It is
possible that, from a national perspective, much of the energy savings of
solar collection will be false savings, due to the energy used in production.
For example, one gallon of fossil fuel goes into the smelting of a pound
of aluminum, about enough for a 1/16" thick, one sq. ft. plate. This

gallon of fuel input equals a year's collector output for a sq. ft. of

collector, and doesn't include power in rolling the aluminum into a plate,

transportation, ducting, and other collector materials. [15]

D. OTHER COSTS: Inflexibilities in design and site orientation imposed

by collector systems can cause significant costs. In order to follow the

site planning patterns proposed in the next chapter, portions of a site may

become unbuildable, resulting in a lower yield of housing units on a

given site. The lower number of units means higher property costs per

unit.

In addition, architectural and site planning restrictions imposed

by the use of solar energy may result in units considered less desireable

or attractive than non-solar energy units of the same cost. If this is

the case, then implementation of solar energy may have costs to the developer

of reduced demand and lower unit value.

Future Expectations

While solar collector systems are difficult to justify economically

at present, and have serious additional problems, it appears likely that

solar energy collection will become more practical in the near future.

A. COLLECTOR IMPROVEMENTS: Much research is being done into finding

non-corrosive, durable, and inexpensive collector plate materials. Non-

corrosive aluminum alloys are being developed, as are plastics that will

not degrade under ultra-violet light.

Research is being done into "selective surfaces" for collector

plates which would increase collector efficiencies. Selective surfaces

would absorb sunlight and retain the energy in the plate to transfer it

efficiently to the collector medium. Regular black-painted metal re-emits

the sunlight striking the plate immediately as heat energy, rather than retaining it in the plate, where it could be more efficiently transfered.

Continued research on phase-changing salts should result in a practical salt storage unit within a few years.

Mass production of collector units on a major scale, once the technology is perfected, should further reduce costs.

When these improvements occur, and the tremendous amounts of research in these areas suggest that they are likely within a few years, collector costs should drop at least 40%, and efficiency should improve at least 20%. [16]

B. FUTURE OF OTHER ENERGY SOURCES: Meanwhile, costs for fuel oil and other conventional energy forms should rise as supplies dwindle. Even if oil is politically available and there is twice as much oil as estimated in known reserves, the supply should be deleted in less than 40 years. 10 years from now, if we realize the limitations of the earth's energy supplies, heating oil may cost many times more than it does now, perhaps $1 to $3 per gallon in 1975-value dollars.

C. POSSIBLE BENEFITS AND COSTS IN 10 YEARS: If, in 10 years, collectors are 40% less expensive and 20% more efficient, and fuel oil is $1 per gallon, each sq. ft. of collector would have benefits and costs as follows:

BENEFITS: 1.2 gallons per sq. ft. per season saved.

            times $1 per gallon

            Net $1.20 per sq. ft. per season saved.

At a capitalization rate of 14%, the collector is worthwhile if its net cost is less than $8.40 per sq. ft. Greater collector durability may

justify a lower discount rate.

COSTS: $6 per sq. ft. installed (60% of present price)

                   - $3 per sq. ft. savings of "building skin" materials.

            Net $3 per sq. ft. of collector.

The unit pays itself off in energy savings in 2½ years!

In addition, use of phase-changing salt energy storage will mean

less space usage for the system, and more efficient collection will mean

that less electrical pumping may be necessary. Hopefully improvements will

be made in the energy-efficiency of collector material production, as well.

It may be possible that fuel oil may cost more than $1 per gallon in

10 years, that costs of building skin materials may go up, or that collectors

will be even less expensive and more efficient. Should any of these events

occur, solar collectors will be even more advantageous, economically.

Conclusion on Solar Collectors

At present, collector costs for space heating are above the economic

"break-even" cost, without considering additional hidden costs of space

and conventional energy input. For domestic hot water, it is not clear

whether the benefits exceed the costs at present. Much is unknown about

the practicality of solar energy, the costs of collectors in mass-production,

their life span, and the maintenence costs of collector equipment. But

taking the "best guesses" presently available, the case is not strong

for the use of solar collectors at present.

However, the trend of technological improvements and world economic

factors suggest that the "break-even" point may not be far away. It

should be clearly economically feasible to use solar energy with a few

years, possibly within weeks or days.

Preparations should therefore be made for the use of solar collectors. Housing developed today should be oriented and designed to accept collector systems in the future. Space should be left for ducts and storage; and people should be kept informed of the most recent "facts" on solar energy, so that the time lag between practicality and common usage of solar collection systems will be small.

V.   DESIGN PATTERNS

A major purpose of this thesis is to convey information to the
designer that is useful in producing energy-efficient housing develop-
ment. To this point in the thesis, we have approached this purpose by
presenting background information that would be the basis for the design.

Now we will explore another approach to conveying design knowledge.
This approach is to outline the rules or generalizations that a designer
might use when undertaking a design. The good designer has developed,
formally or informally, a mental catalog of solutions to design problems
which he uses in his work. This mental catalog of solutions is generally
referred to as experience, and many will claim that there is no substitute
for experience. We will, however, attempt to convey this type of infor-
mation to the reader. This information will be conveyed in simple, sin-
gular solutions to design problems, which we will heretofore call design
patterns.

Each pattern will contain a simple statement that will be useful
to a designer considering design problems. Each will include an explan-
ation of its merit, and a diagram if necessary. Support arguments will
usually be brief, and will refer to where more detailed information can
be found. The purpose and intent of this section is that it be a tool
for the designer, a handy catalog of solutions to problems of thermal
efficiency and designing with solar energy.

The patterns listed here are basically limited to housing site plan and macro-unit design considerations. Additional information referring to building materials, insulation techniques, and design details are beyond the context of this thesis. Some of these aspects have been discussed previously, and sources of detailed building information have been listed in the bibliography.

We will first outline simple design patterns defining singular solutions to singular problems, with the only exception being that many patterns will attempt to both prevent summer overheating in addition to promoting winter thermal efficiency.

Following these, more complex design patterns will be outlined. These are necessary because singular patterns tend to conflict when one attempts to incorporate all of them simultaneously, especially when the designer implicitly considers more traditional patterns such as those involving aesthetics, automobile circulation, maximum site yield, zoning restrictions, etc. These other patterns are not stated here, but assumed to exist, and our new singular patterns are likely to conflict with classical patterns.

The patterns are specifically designed to apply to the climate in the northeastern United States, for a designer planning a site of raw land for suburban to near-urban residential densities; contemplating low-rise development. Many, however, are universally applicable or are easily convertible to climatic considerations elsewhere or other site programs. Each pattern's explanation will outline the basis for the pattern, and its applicability to other situations should be determinable from this.

Calculation of benefits and costs.

The benefits and costs of implementation of a design pattern vary considerably based on the context. Pattern implementation costs involving building placement and orientation are particularly variable. For example, a pattern affecting building orientation may be convenient (and costless) to implement. Alternatively, the pattern may cause various degrees of difficulties in site planning, transportation circulation, increases in utility costs, or decreases in site yield. Therefore, depending on the particular site, implementation of many design patterns may vary from costless to very expensive.

In addition, fuel cost savings vary with the type of fuel, the location, and will indeterminately vary with time. For example, fuel prices ten years from now may be similar, but will likely be several times higher than they are now. Therefore a direct benefit-cost analysis is not possible, and is not included here.

The benefits, however, will be enumerated here when they can be estimated. A meaningful and determinable unit of benefit is savings in energy, per season, expressed in therms. Examples are given where these savings are converted to gallons of fuel oil, but they can easily be converted into other energy-source units.

Other patterns have savings more easily expressed in terms of the unit's heat load (energy requirements over the course of a heating season for a unit). These savings are expressed as a "per-cent of heat load." Typical heat loads of units can be estimated to convert "per-cent of heat load" savings to energy savings, and examples are given.

The user will thereby have the only "hard facts" possible. He must

then make his own estimates of pattern implementation costs on his site, and compare these with the likely energy savings.

To convert energy savings into dollars, the designer will have to guess the future costs of fuel. It seems reasonable, however, to assume that fossil fuel prices will continue to rise as world supplies diminish, and present-day prices should provide a reasonable "lower bound" to savings.

For many patterns, the savings are so large that implementation is generally worthwhile, even if energy costs stabilize in the future. For reasons such as security of energy supply, national interest, and others suggested in the goals, implementation of energy-saving patterns may be desirable even if they aren't clearly cost-effective.

The determination of the value of some patterns, especially the ones related to microclimate, are very location-dependent and the benefits are not estimated. Design, however, should consider these patterns and implement them where they are convenient (i.e., where the tradeoffs are low), for they "can't hurt." When implementation is not convenient, microclimate studies of the site are suggested to better determine the heat load-site location tradeoff. Estimates are made, however, of the magnitude of savings that is possible with microclimatic patterns.

The design patterns are now presented in four categories: heat retention design patterns, microclimate patterns, solar heat gain patterns, and patterns for the use of solar collectors. The categories refer to four separate approaches to the improvement of energy-efficiency, and the patterns in each category outline methods of achieving energy-efficiency through the category's approach.

At the beginning of each category, there is an introduction out-
lining any assumptions that are made. At the category's conclusion,
there is an evaluation of the methods outlined therein, and of the use-
fulness of the approach as a whole.

Design Patterns that Improve Building Heat Retention

The first patterns describe methods of improving the insulation quality of a housing unit by means of building design, placement, and orientation.

Not included are building material considerations and details of design which may be of benefit in improving the unit's heat retention, which have been discussed previously.

All examples assume that the unit consists of tight, high-quality construction, with walls and ceilings containing high-quality insulation, weatherstripping along windows and doors, etc.

The savings achieved by these patterns were generally quantifiable, and are expressed in therms-of-energy-saved-per-heating-season; or in percentage reduction of heating load per season. A summary and evaluation of these heat-retention patterns follows at their conclusion. Supporting computations and footnotes are listed in the appendix.

1.   PATTERN:
         "Minimize unessential window areas on the north side
         of units."

   SOLUTION TO PROBLEM OF: wall insulation

S ← → N
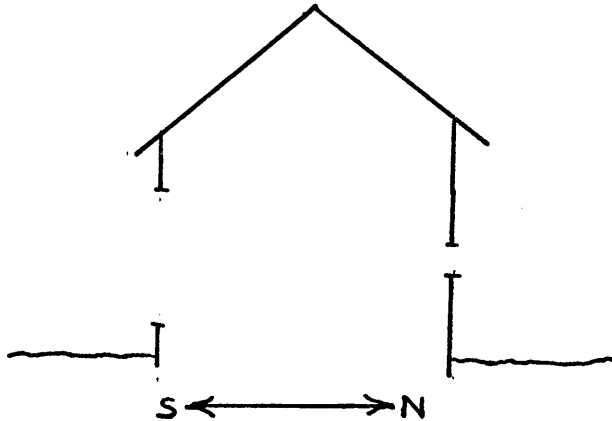
   Glass is a poor insulating material. Compared with a good exterior

stud wall with 3 1/2" fiberglass insulation, a single glass pane will have

14 times as much heat loss per sq. ft. Additional panes help, but a double-

glass window loses seven times as much as an insulated wall, and a triple-

glass window loses 4 1/2 times as much. Obviously some glass is necessary

for aesthetic and light considerations. But unnecessary glass is expensive.

. Excluding radiation gains or losses, each 3' x 5' single-pane window can

lose 22 therms of energy per heating season more than an insulated wall.

In an oil-heated home, this heat loss represents 22 gallons per year of

oil consumption per window.

   Radiation gains, however, can be significant, and are considered in

solar energy pattern #23. These gains offset heat losses on the unit's

southern walls.

2.   PATTERN:

"Use double-glass windows where windows are necessary."

SOLUTION TO PROBLEM OF: wall insulation-necessity of windows.
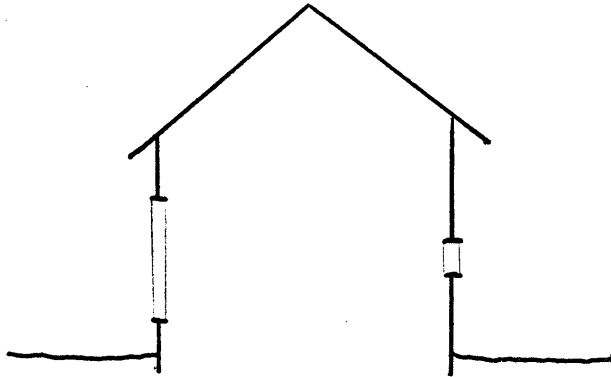
As described in the previous pattern, the heat loss of a double-glass window is half that of a single pane, and a triple-glass window reduces heat loss an additional 35%. Under typical northeast conditions, adding a second pane of glass saves .82 therms of energy/sq. ft./heating season. A third pane saves an additional .27 therm/sq. ft. For an oil heating system, a therm of energy saved approximately equals a gallon of fuel oil. Similarly, these savings can be translated into other energy form savings, and dollar savings for additional window panes can be computed.

At .40 per gallon for fuel oil, and with a 10% discount rate, double-glassing pays if it costs less than $3.30 per square ft. This assumes present oil prices continue, and is therefore a lower-bound to savings.[2]

3.   PATTERN:

"Apply functional interior shutters or heavy drapes
over window areas when not in use."

SOLUTION TO PROBLEM OF: wall insulation-necessity of windows.

DAY   NIGHT
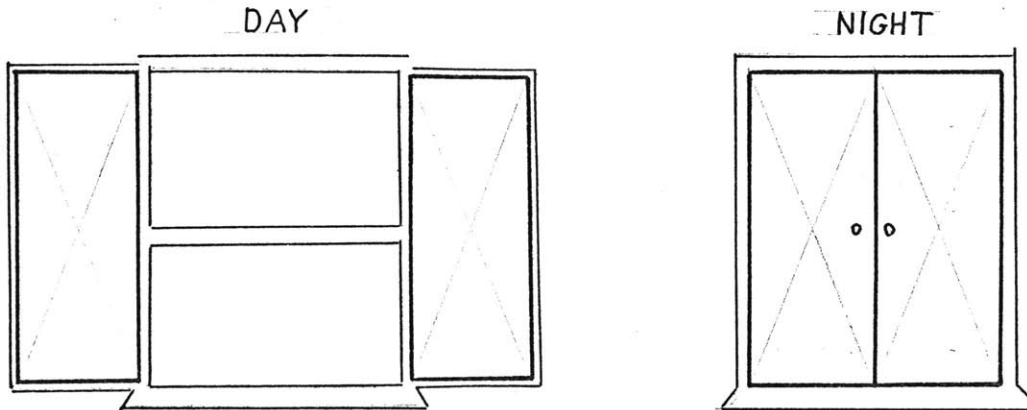
Even with double-glazing, windows have 7 times the heat loss of
an insulated wall, excluding radiation loss.

A functional interior shutter which includes insulating material
and which firmly fits in the window frame can allow the use of the win-
dow when it is most desireable and beneficial, and yet retain full-wall
insulation at night by simply closing the shutter manually. Estimated
savings are .27 therms/sq.ft./season, used over a double-glazed window.
A 3' x 5' window would therefore save 4 therms/season.

Using interior drapes provides insulation of greater or lesser
magnitude depending on the extent that the drapes "seal off" the windows
by preventing air flow from above or below. All drapes will lessen
radiation losses at night. [3]

4. PATTERN:

    "Insulate basement walls."

    SOLUTION TO PROBLEM OF: building design-wall insulation


SECTION
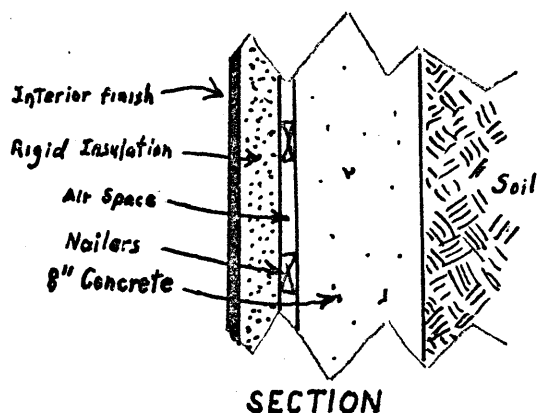
A typical subterrainean basement wall of 8" concrete has twice the heat loss of a typical insulated wall, despite the fact that ground temperature is warmer in winter than the average air temperature.

Adding equivalent insulation to a basement wall, as shown, will both result in a "finished" room, and result in a wall that has only half the heat-loss of normal, above ground insulated walls. The savings is approximately 1/7 therm/sq. ft./season.

For an 8' high x 25' long basement wall, the savings is approximately 29 therms, the equivalent of 29 gallons of fuel oil per season.[4]

5.   PATTERN:
                "Protect the entranceway of the unit form wind."

      SOLUTION TO PROBLEM OF: building design-air insulation.
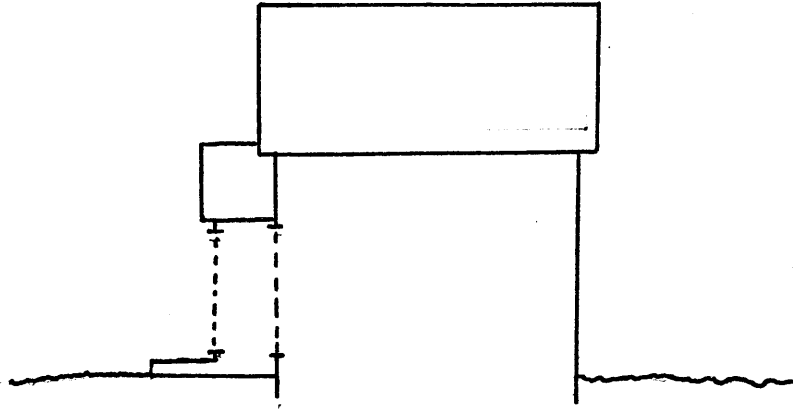
Significant heat loss occurs when a door is opened and an exterior

wind forces air infiltration. Placing the door in a place protected from

wind diminishes this heat loss.

A vestibule entranceway is a goodway to create a dead air space

directly outside the interior door. This prevents a breeze from entering

when the door is opened. Savings are difficult to estimate, but, assum-

ing that the vestibule stops an average 5-MPH wind form entering when the

door is opened, savings can be 16 therms per heating season. [5]

6.   PATTERN:

               "Place the Northside of the structure below grade as much as possible."

        SOLUTION TO PROBLEM OF: Building design-groundwork.

S ← → N
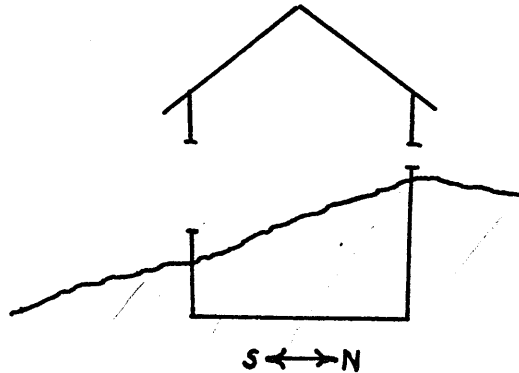
As described in pattern #4, an insulated below-grade wall will have only half the heat loss of an above grade wall. In addition, there will be less heat gain in the summer, and probably summer heat loss depending on the particular soil thermal characteristics.

South facing walls receive solar radiation in winter and therefore have less advantage to being placed below-grade.

Approximate savings is 1/20 therm/sq. ft./season in heating costs, for additional wall area below-grade. In addition, the unit will be cooler in summer.

7. PATTERN:
      "Build connected housing units."

SOLUTION TO PROBLEM OF: Building design-housing type
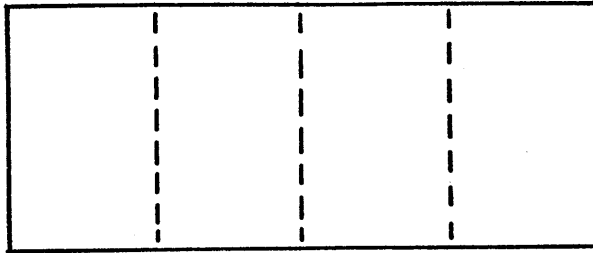
Shared walls in connected housing have no effective heat loss. Therefore, by connecting units, approximately .1 therm/sq. ft./season is saved for each sq. ft. on each side of a connected wall. As an example, the savings for a 1600 sq. ft. two-story town-house unit, of dimensions 20 x 40, would be 128 therms/season if both 40' walls were shared, as compared with a free-standing unit of the same dimension with well-insulated walls, and no windows in the 40' walls.

Also, insulation of shared walls is not necessary, which could mean additional material savings as well. [7]

8.   PATTERN:
              "Use fencing or vegetation to block winter winds."

      SOLUTION TO PROBLEM OF: wind heat losses
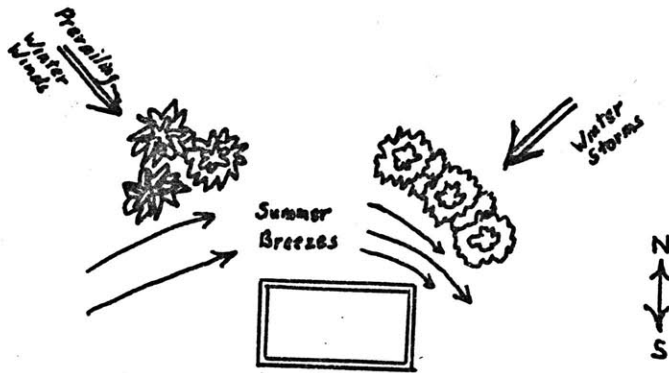
Wind has a significant effect on the heat loss of structures. A typical house exposed to 12 MPH winds at 32° F will have twice the heating load over a season as one exposed to 3 MPH winds. Heat losses due to wind occur by increased air infiltration and by direct reduction of the wall insulating value.

Prevailing winter winds are from the northwest in much of the country, while winter storms are from the northeast and summer winds are from the west and southwest. Therefore wind blocks on the northeast and northwest sides will diminish winter winds, while admitting cooling summer winds. The shape of the windblocks can also channel summer winds around the house, resulting in greater summer cooling.

A shelter belt of trees, shrubs, and/or fencing can be a significant wind block, and wind blocks in general become more effective at higher wind velocities.

Fencing should allow some air infiltration to reduce eddying behind the fence. [8]

Evaluation of Heat Retention Patterns

To evaluate these patterns, let's consider the following example.

We will consider four units, each with 1400 sq. ft. of floor area (typi-

cal three-bedroom unit) consisting of two stories of dimensions 20 ft. x

35 ft. x 8 ft. high. The unit has six major windows of 15 sq. ft. each.

The unit has a full basement, with ducts to provide heating, if desired.

The unit is well insulated and the windows are weatherstripped. The unit

is subjected to 5000 degree-days per heating season (slightly warmer than

Boston), and the basic unit requires 1100 therms (or gallons of fuel oil)

per heating season to maintain the temperature between 65° and 68°.

This figure for fuel consumption does not include basement heating.

Over the course of a heating season, fulfillment of the proposed

patterns would have the following effects:

1) Double-glazing all window areas:
Each window would save 11 therms/season.
11 therms x 6 windows   Savings = 66 therms

2) Adding insulated shutters, in addition to 1):
4 therms x 6 windows   Savings = 24 therms

3) Replacing a shuttered, double-glazed window with a continuous, insulated wall:
Savings = 6 therms

4) Insulating basement walls, if basement is heated:
Savings = 145 therms

5) Building vestibule to protect the entranceway from a 10 MPH wind:
Savings = 20 therms (max.)

6) Connecting the four units along the 35' wall:
Average savings = 80 therms/unit

6a) Connecting units, if basement is insulated and heated:
Average savings = 111 therms/unit

7) Submerging 4 ft. of north wall below surface:
(including part of side walls) Savings = 11 therms/unit

7a) Submerging 4 ft. of north wall of a connected unit:
(no side walls)   Savings = 6 therms/unit

8) Placing windblocks to slow winter storm winds and prevailing
winter winds:
Very Conservative Savings = 110 therms/unit

As an example, if the four units were connected, windows double-glassed and shuttered, a vestibule entranceway provided, 4 ft. of north wall submerged, and a semi-effective wind block added, fuel consumption would be reduced approximately 30%.

In terms of significance, the patterns can be evaluated as follows:

Connecting units, insulating a heated basement, and placing windblocks are likely to add very major thermal efficiency savings, each amounting to 10% or more of the total heating load in our example.

Double-glazing savings are also high, resulting in approximately a 1% reduction in the total heating load per window, a total of 6% in our six-window unit. Shutters on all windows will save an additional 2% in our example. Placing 4 ft. of the north wall below grade will save only about 1%, and the benefit to connected units is less.

Protecting the entranceway from wind will achieve less than a 2% reduction, making it not clearly worthwhile where achievement of this pattern would be difficult or expensive. Reducing the number of windows in a unit is of marginal benefit as well, saving less than 1% per window when compared with a double-glazed, shuttered window. This cost for windows is small compared to their positive values, although excessive window areas may be unnecessarily wasteful. [9]

Design Patterns That Use Microclimate Advantageously

The next patterns suggest methods of affecting the microclimate surrounding the unit in such a way as to improve unit thermal characteristics. The patterns include descriptions of geographical settings that should be chosen or avoided when considering microclimate, as well as methods to improve the microclimate in a given setting.

In general, the microclimatic design patterns are more theoretical, more location dependent, and of less certain significance than the preceding insulation patterns. Experimentation may therefore be necessary to determine their significance on a particular site.

9.   PATTERN:
                "Maintain a wooded canopy around units with deciduous
                 trees on the south side, and evergreens on other sides."

        SOLUTION TO PROBLEM OF: microclimate-radiation control
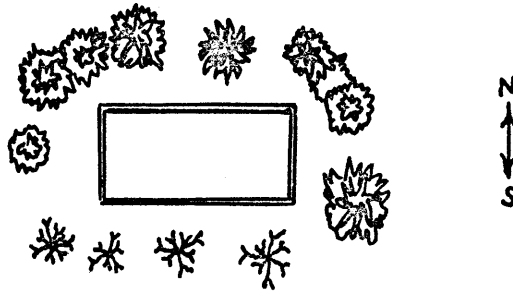
Trees around units, in addition to providing wind-blocks and

attractiveness to housing development, help control day and night radi-

ation advantageously.

A canopy around the unit diminshes night-sky radiation from the

soil surrounding the unit (see p.27). The air near the ground stays

warmer, and the heat load near the unit is decreased. Data suggests

that eliminating night radiation would make the night-time low air

temperatures 2°-10° warmer over the course of the heating season, resul-

ting in a decreased heating load of 5%-10%.

A high canopy of trees also makes a unit cooler in summer by

providing shade during the day.

Using deciduous trees on the south side allows sunlight to pen-

etrate in winter when leaves are shed, making solar heating possible in

winter, with shade in summer. [10]

10.   PATTERN:
              "Control cold air flows by letting them flow away from
              housing units in winter, while pocketing them in summer."

SOLUTION TO PROBLEM OF: microclimate-airflows
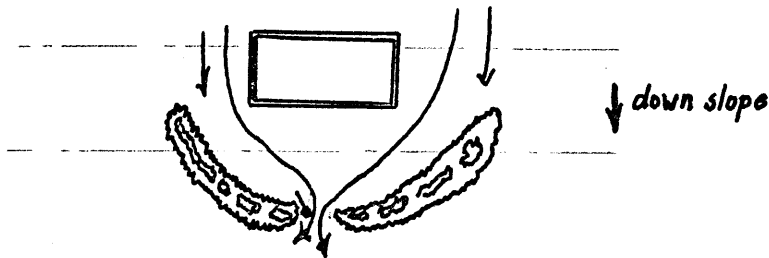
Cold air from night-sky radiation (see p.27) flows downward, like

water, and settles at the lowest point. It is therefore important not

to place housing units in low points likely to be cold-air pockets. Slopes

of as little as 1% can be adequate to channel cold air flows away from

units.

It is,however, desireable to create cold air pockets in summer to

provide comfortable outdoor spaces on warm summer nights, and to cool air

temperatures near housing units.

Control of cold air flows can be achieved with hedges and fences.

A summer cold-air pocket can be formed by using hedges and/or fences to

prevent a cold-air flow from continuing down a slope. A gate located at

the lowest point in the cold air "dam" can be opened in winter, allowing

the coldest air to escape. In additon, deciduous trees and shrubs will

impede cold air flow to a greater extent in summer than in winter, which

is desired. "

11. PATTERN:
"Build in warm bands on valley slopes."

SOLUTION TO PROBLEM OF: microclimate-air infiltration

Warm bands occur along valley slopes while cold air rests on the valley floor. (See p. 27) Therefore, structures on the slopes in areas likely to be warm bands will be subjected to smaller heating loads than those units located above or below them.

Vegetation changes can be indicators of the location of warm-air bands. [12]

12. PATTERN:

"Admit solar radiation to ground around the unit in winter; prevent it in summer."

SOLUTION TO PROBLEM OF: microclimate-radiation control
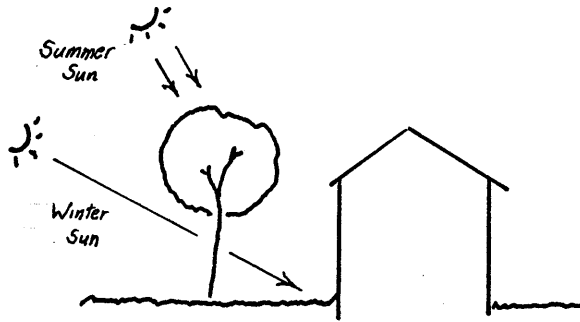
The earth surrounding the unit can absorb radiation from the sun during the day, and warm the air near the ground at night. It is therefore desireable to admit radiation in the winter and block it in the summer.

A good way to do this is, again, a high wooded canopy. Low sun angles in winter are able to enter beneath a high tree crown to warm the earth in winter, while the crown blocks the high summer sun. Likewise, any vine trellis, overhang, covered porch, or canopy of any kind will achieve the same effect.

Where high growth is not possible, as in new development with a limited landscaping budget, lower deciduous plantings will have the same effect by being transparent to radiation in winter, (when leaves are off) while blocking radiation in the summer. *13*

13.   PATTERN:
                "Surround units with conductive soils."

        SOLUTION TO PROBLEM OF: microclimate-site control
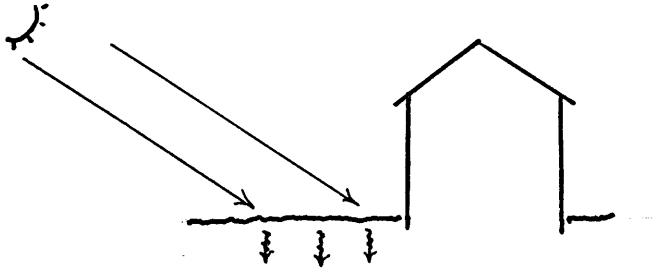
Conductive soils absorb day radiation and emit it at night. This results in cooler air temperatures near the ground during the day, and warmer air temperatures at night.

Conductive soils include dark stones and humus. Peat and sand are poorer conductors. Conductive soils are desireable in both summer and winter, since conduction will help prevent daytime overheating in summer, and will also help reduce night heat loss in winter. *14*

14.   PATTERN:

"Keep the ground surrounding the unit dry in the winter, wet in the summer."

SOLUTION TO PROBLEM OF: microclimate-soil control

Water absorbs energy when it evaporates, resulting in a cooling effect on the ground and therefore on the air near the ground. Water is therefore desireable on ground surfaces in summer, but not in winter.

For winter dryness the soil should be well drained, allowing sur-faces to dry quickly after precipitation.

In summer, vegetation or a lawn surrounding a unit will result in moisture that evaporates, lowering air temperatures near the unit. Lawn and garden watering in the summer will further cool the air. Artificial ponds and pools will be of benefit as well, but they should be able to be drained or removed in winter. *15*

15.   PATTERN:

"Large clearings should be avoided where possible."

SOLUTION TO PROBLEM OF: microclimate-night radiation
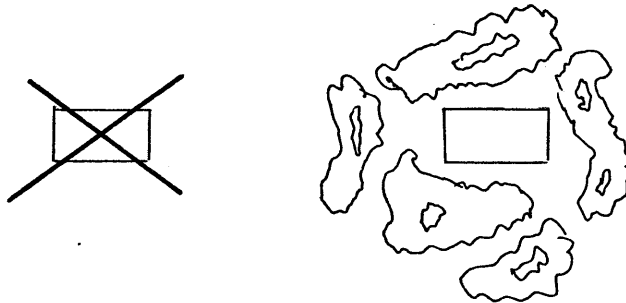
Night-air temperatures near the ground are lower in clearings

than in planted areas, due to night-sky radiation. Although a breeze

can assist in warming clearings, clearings tend to become cooler at

night as they get larger.

In order to minimize a unit's heating load, large clearings should

not be formed near a unit. Large clearings already present should be

broken up into smaller clearings with tree plantings.

Another solution is to build units on the North side of clearings.

This results in cool clearing air being blown away from the unit in winter. [16]

16.   PATTERN:
            "In clearings near the unit, admit winter wind."

      SOLUTION TO PROBLEM OF: microclimate-eddy diffusion control.
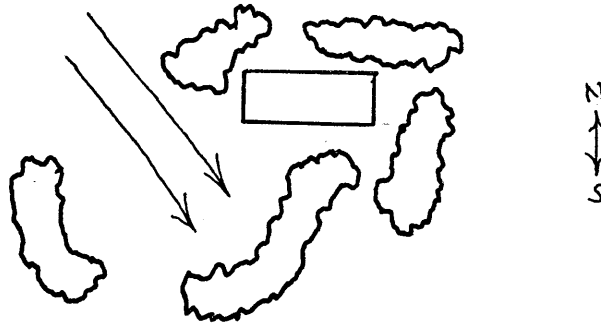
      Wind can actually warm surface air in open clearings at night.

This occurs because the wind causes the cool surface air layer to

diffuse with warmer upper air, resulting in warmer surface air (see

p. 30).

      It is therefore desireable to admit winter wind to clearings near

the unit, while it is necessary to keep wind away from the unit (pattern

#7). With careful plantings, as in the diagram above, this can be

achieved.

      Although wind can warm a clearing, it will be colder than a tree-

covered area where radiation is prevented. This pattern, therefore, is

not suggesting that clearings should be created, only that existing ones

can be made warmer with wind. /7

Evaluation of Microclimate Patterns

As previously mentioned, the value of microclimate patterns is not clear, and not generalizable over a variety of locations.

This is not to say, however, that they are not significant. Air near the ground that is cooled as a result of night sky radiation can be 10° cooler than upper air. Blocking this radiation with a tree canopy, or diffusing the upper and lower air with wind, can mean that the average daily temperature surrounding the unit may increase, resulting in less heat load.

Admitting daytime sunlight to the ground, and surrounding the unit with conductive soils results in warmer night soil temperature, with a corresponding increase in night air temperature near the ground.

Avoiding cold pockets, choosing "warm band" locations, and managing cold air flows, are building orientation considerations that will likely result in warmer air temperatures.

If the average air temperature is only 1^oF higher as a result of these considerations, the heating load will be reduced 3 to 4%. A total savings of 10% or more is probable between best and worst microclimatic locations on a site of varied topography and cover. [18]

It is therefore advantageous for the designer to consider these microclimatic patterns when placing units on a site, and when doing the landscape design. If it is convenient to place buildings in microclimaticly inferior locations for other reasons, then experimentation on the particular site should be undertaken to estimate the tradeoffs in energy vs. convenience.

Design Patterns That Maximize Winter Solar Heat Gain

The following patterns suggest methods of using solar radiation for thermal benefit in winter, without necessarily using solar collectors. These patterns will explain how to maximize heat gain from winter sun through windows and walls.

In that a building-mounted solar collector should be oriented to receive maximum solar radiation in winter, these patterns are useful in solar collection system planning as well.

Where possible, the benefits of fulfilling the patterns are expressed in therms per heating season.

Even in the Northeast, patterns that maximize winter solar heat gain can result in serious summer overheating. The patterns therefore suggest how summer overheating can be prevented while winter solar heat gain is being maximized.

17.   PATTERN:
                "Buildings should be sited with broadest areas facing
                south."

      SOLUTION TO PROBLEM OF: building design-orientation

Winter
Sun
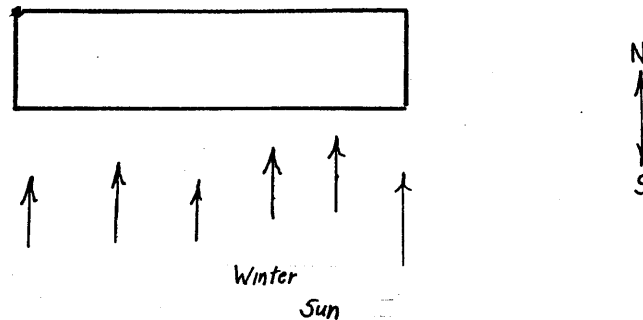
Greatest solar radiation strikes a building on the south side in

December through April.   In February and March, the insolation on East

and West walls is much less than on vertical south walls.[19]

Therefore, placing the broadest building dimension facing South

results in the largest proportion of building surface area being exposed

to sun during the heating season.

Solar radiation transmits a heat gain to south-facing walls, off-

setting winter heat loss.

In addition, placing the broadest building dimension facing south

allows the greatest surface to be available on the south side for windows

and solar collectors, which benefit from being placed in the direction

of maximum heat gain.

When considering the development of connected housing units, it

follows from this pattern that they should be connected along their east-

west walls.   This will result in buildings with the broadest dimension

facing south, and will also allow each unit to have an advantageous southern

exposure.

18.   PATTERN:

"Place most windows on the south side of buildings."

SOLUTION TO PROBLEM OF: building design-radiation control
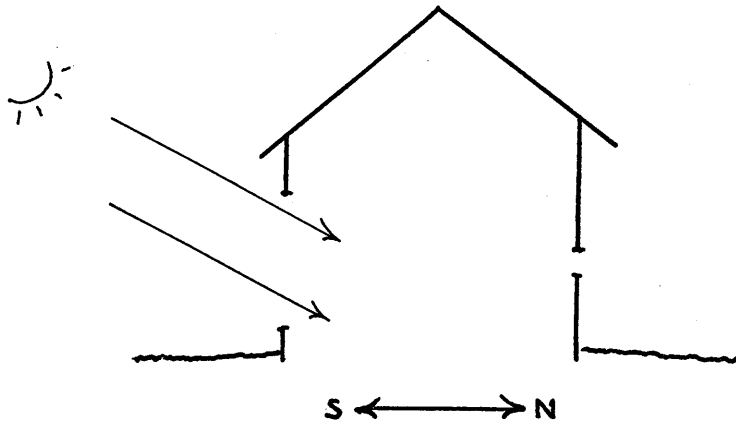
Although windows are poor insulators and have large heat losses, these losses are more than offset by solar radiation gains through a properly oriented window.

In the month of January, solar heat gains through a south-facing, vertical, double-pane window will exceed heat losses through the window by approximately .06 therm per sq. ft. This is a gain of 1 therm per 3' x 5' window for the month of January alone! Therefore south-facing window areas can be an attribute to energy economy, rather than an expense.

In addition, solar radiation on south-facing windows is less in summer than in winter, which is desireable, and can be controlled in summer as explained in pattern #20.

During the four coldest months of the heating season (Dec.-March) when most or all of the radiation through windows will offset needed home heating and not result in overheating, a south facing, double glass window will have a net heat gain of .33 therms/sq.ft., and as much as .80 therms if the window is equipped with shutters described in pattern #3.

SE and SW windows will have about equivalent heat gains and losses in Janaury. Over the four coldest months, they will have a net gain of .14 therms/sq.ft. and approximately .40 therms/sq.ft. with shutters. Summer radiation is greater, however, and more difficult to control.

By comparison, E and W windows will lose approximately .075 therms/sq. ft. in January, and will have the largest, most difficult to control, heat gains in summer. North windows will lose approximately .12 therms/sq.ft. in January. [20]

19.   PATTERN :

"Design buildings with high thermal mass."

SOLUTION TO PROBLEM OF: building design-temperature control
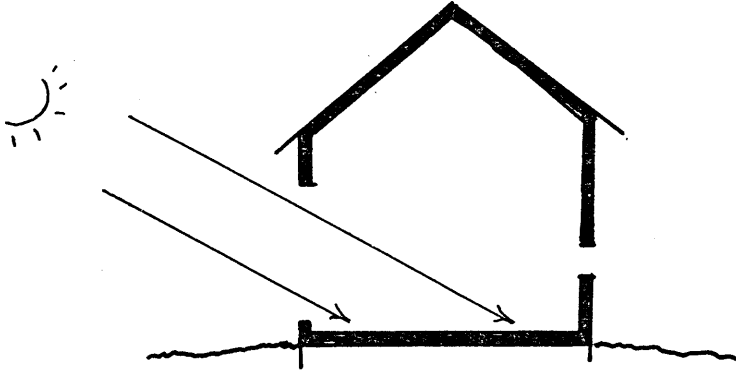
High thermal mass will extend the winter period when sunlight through windows can be used without overheating the unit.

This occurs because materials that can absorb large amounts of heat will store energy during sunlight hours and then emit energy when the unit cools at night.

In a 1500 sq. ft. unit, with 70 sq. ft. of window on the south side and 30 sq. ft. on the north side, 100% of the sun striking the unit in November through April can be used to heat the unit without overheating if the floor is constructed of 2" of concrete or 2" of wood. Less thickness is required for a stone floor. Also, if the unit has interior concrete or brick walls, these provide thermal mass as well. [21]

In such a unit, south-facing windows will have a net heat gain of .6 therms/sq.ft./season, or 42 therms for the 70 sq. ft. of south-facing window. [22]

20.   PATTERN:
                    "Design windows to regulate summer sun."

        SOLUTION TO PROBLEM OF: building design-radiation control.
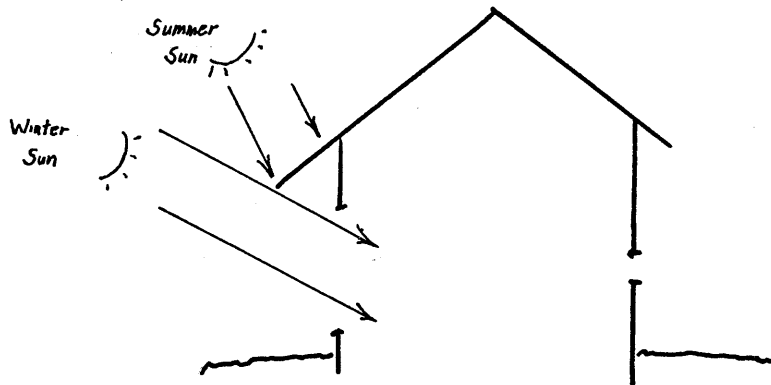
        While glass on the south side of dwellings is beneficial in winter,

precautions should be taken to prevent overheating in summer months.

        One approach is to design an overhang or trellis above the window.

If properly placed, it can obscure summer sun while admitting winter sun,

as demonstrated in the diagram above.

        Deciduous exterior vegetation can also control radiation by pro-

viding shade in summer, while admitting radiation in winter once leaves

are shed. [23]

21. PATTERN:

"Maintain clearance for winter sunlight on the south side of buildings."

SOLUTION TO PROBLEM OF: radiation control-site design
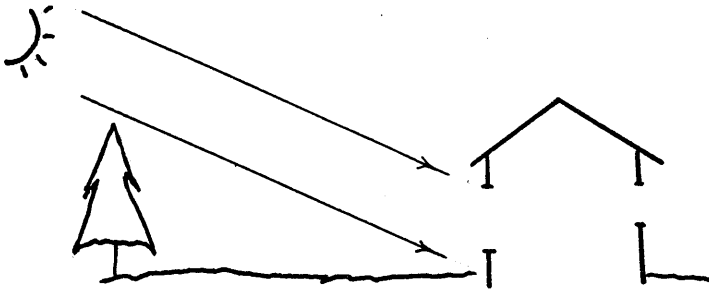
To reap the benefits of south-facing windows and any solar collector system, clearance must be maintained for winter sun. At 42°N latitude, the maximum altitude of the sun of winter solstice is 24 $1/2^{\circ}$ at due south. A 25' high obstruction of trees or buildings would need to be 55' away from the south side of a building to admit radiation to the base, and considerably farther away in the SE and SW to admit morning and afternoon radiation. There are several ways to provide this clearance, listed below, without simply obliterating all vegetation to the south of the unit.
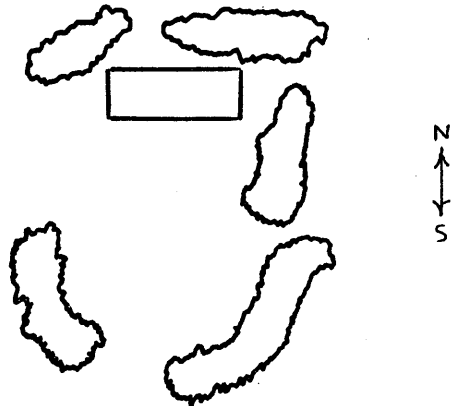
Build on the north side of clearings. Take advantage of natural clearings to allow winter sunlight without further vegetation removal. Building on the north side gives greatest clearing to the south of the unit.
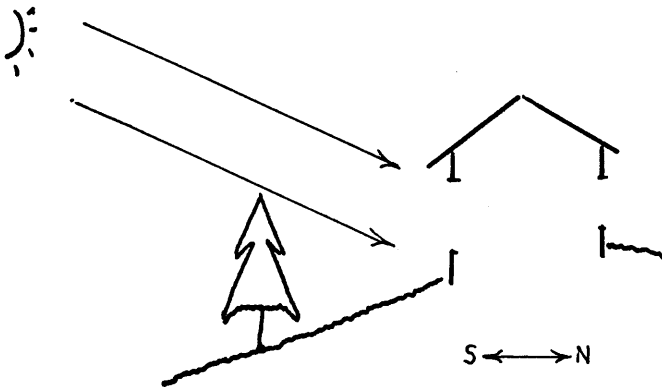
Build on south-facing slopes. On a southern slope, required clearance from obstructions is shorter. Likewise, it is important to avoid northern slopes, where the slope compounds the clearance problems.

Leave (or plant) scattered deciduous trees on the south side. Scattered deciduous trees, once they shed their leaves, are relatively insignificant sunlight barriers.
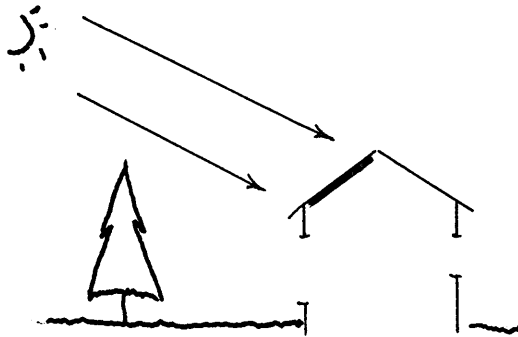
Place solar collectors high on the structure. The higher the collector, the less clearance required.

W ←————→ E
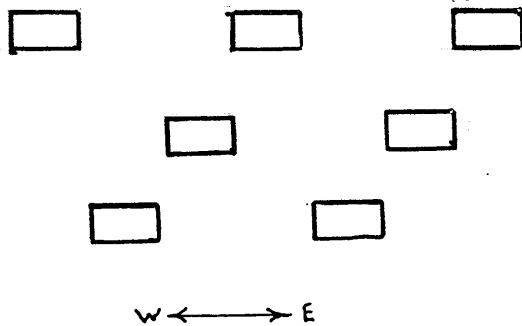
Stagger buildings along the E-W dimension of the site. If units are to be relatively evenly distributed on a site, greater clearance is possible if units aren't in a N-S line, since southern clearance is most important.

Don't let buildings shade each other. Low buildings, spaced adequate distances apart, are required. On a crowded site, build tallest buildings on the north side. Tall buildings to the north have no effect on buildings south of them.

Evaluation of Winter Solar Heat Gain Patterns

Solar heat gain through windows is of moderate significance. By placing large window areas on the south side of units, providing adequate thermal mass, and by insuring that winter sunlight can strike window areas, heat load of a typical unit described earlier can be reduced by 1% for each 15 sq. ft. of window on the south wall. [24]

More significant than the size of the heat load reduction is that windows on south-facing walls are not a detriment to thermal-efficiency. Unlike the design restrictions on window areas described in PATTERN #1, window areas on south, southeast, and southwest walls can be increased without limit at the whim of the designer without increasing the heating load.

This is, of course, only true if the designer has been careful to prevent overheating in sunny periods other than mid-winter. Increased window areas will require increased building thermal masses to prevent daytime overheating. Window designs should also screen summer sun. When these things are done, however, in addition to orienting windows correctly, it can be said that the problems of windows (excessive heat losses and heat gains) have successfully been conquered.

Design Patterns for the Use of Solar Collectors

Once the designer has considered the thermal-efficiency improvements that can be afforded through the previous patterns of insulation, microclimate, and direct radiation, the stage is set for the consideration of a solar collection system.

It is necessary to emphasize the sense of hierarchy between the use of solar collectors and the three previous approaches to thermal efficiency: solar collection is last, and can only be considered after the other approaches' benefits have been exhausted.

The reasons for this are two-fold:

1) Saving fuel by solar collectors is relatively expensive, in in terms of therms of fuel saved per year, when compared with the savings possible by intelligent building design placement, and orientation, as a rule.

2) A collector system can cover a significant percentage of the heat load only on a thermally-efficient house. The collector size for a solar-energy space heating system that can cover 50% of a unit's heating load can be as small as 30% of the unit's floor area, or as large as 80%. In a thermally inefficient unit, the collector size approaches the large end of this range and is highly restrictive and unwieldy to the design of the unit. Only on the small end of the range (thermally-efficient units) do collector sizes reduce to the point that they can be incorporated in more traditional building design.

Units that fulfill the preceding patterns will be well-suited for collectors, as well as achieving their specified goals. Specifically, patterns affecting the heat gain of windows will affect the performance

of collectors, as well.

The most significant patterns affecting the performance of collectors, therefore, have been mentioned in the contexts of other goals, and only three remain to be mentioned (or restated with different justifications) in this section.

22.   PATTERN:
                "Build connected housing units."

        SOLUTION TO PROBLEM OF: building design-storage efficiency

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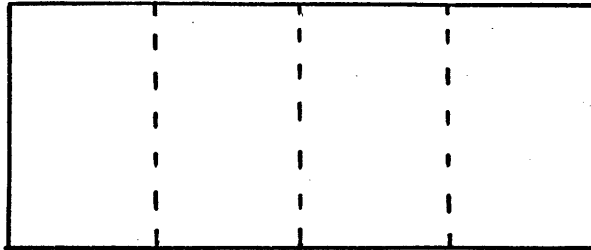
In addition to the insulation advantages of connecting units

(pattern #7), there are economies-of-scale in solar-energy storage that

make multi-unit systems desireable.

Large storage tanks are more efficient. The larger the tank (of

similar shape), the less surface area per cu. ft. of storage. This re-

sults in slower heat loss per cu. ft. of storage, as well as less stor-

age container cost per cu. ft. of storage.

By connecting four solar heated homes, 40% less storage container

material is necessary, a total savings of 400 sq. ft. of container mater-

ial for a typical hot-air system. This larger container will be equally

efficient in heat retention with 40% poorer insulating material. Alter-

natively, the larger storage will be equally effective to the four smaller

systems with similar container material and reduced volume, resulting in

storage material and space savings. [25]

23. PATTERN:
                "Place solar collectors on South-facing walls."

      SOLUTION TO PROBLEM OF: Building design-orientation of collectors.

S ←→ N
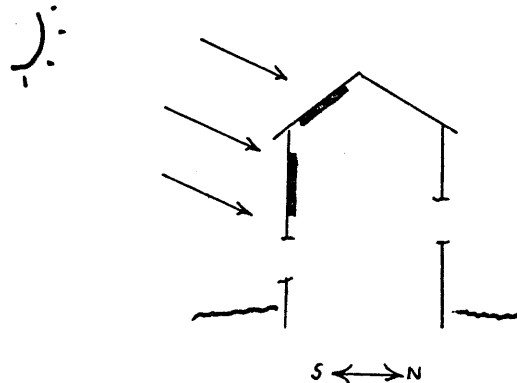
As described in pattern #17, south walls receive optimal solar radiation in winter, and therefore south is a desireable direction for solar collectors for space-heating systems.

In areas with much morning dampness, a SW orientation for collecttors may be optimal since morning evaporation will cool morning air, and the collector will operate most efficiently in warmer afternoons.

For solar heating systems with little or no storage, a SE orientation may be optimal, since the heat supply required to raise internal temperatures in the morning is greater than the heat supply required to maintain temperatures in warmer afternoons.

Local weather conditions can dictate optimality, if patterns of morning cloudiness or afternoon cloudiness are significant.

For solar heating systems with significant size and storage (capable of providing 50% of heating demand) the orientation is not critical. If a collector of given size works optimally facing south, almost no loss is indicated within 22 1/2° of south.

The losses of a collector facing 45° from South could be compensated with only 10% additional collector, in a well-insulated house. Therefore there is significant design flexibility between SW and SE.

Beyond 45°, however, collector efficiency drops off sharply, as glass surfaces over collectors tend to become reflective at sharp angles.[26]

24.   PATTERN:
                "Angle the roof properly for collectors."

        SOLUTION TO PROBLEM OF: Building design—orientation of collectors.
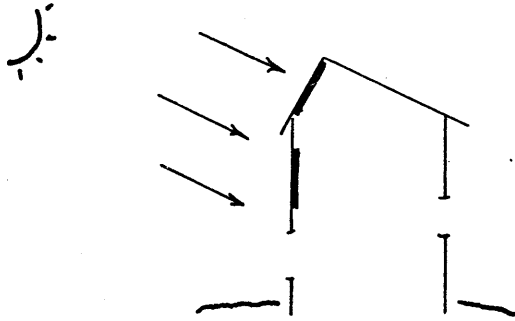
        Although accuracy is not critical, a solar collector for space

heating will work well at ~60° tilt from horizontal (angle of incidence

in winter), while a collector for year-round hot-water heating will work

well at ~45° (average angle of incidence).

        Significant variations from these angles will have small effects

in collector efficiency. Collectors for space heating may work equally

well on vertical walls (90° tilt). In areas with significant snow cover,

a vertical collector may be optimal due to reflection of sunlight off

snow in winter. A tilt as low as 40° would require only 5% more collec-

tor for the same heating load, on a well-insulated house. Similar vari-

ations are possible for hot-water system collectors.[27]

        As the building orientation varies from South, however, tilt flex-

ibility decreases. This is because the deviations of the building orien-

tation from the predominant sun direction will add (trigonometrically)

to each other, resulting in greater total deviation than either one inde-

pendently. Therefore a deviation in one lowers the flexibility of the other.

Evaluation of Solar Collector Design Patterns

The pattern of building connected housing units, rather than free-standing ones, is restated here since it is proposed for an entirely different reason than it had been previously. There is a definite economy-of-scale in the design of collector storage, and as greater numbers of units share a common system, the savings increase.

The patterns involving building orientation are presented here mainly to point out their flexibility. Collector orientation is highly "forgiving" to deviations from the optimal orientations, and building design should not be severely affected by collector design orientation.

As mentioned previously, the truly important considerations in the design, placement, and orientation of units with collectors are those mentioned previously under the heading of solar radiation, and all other patterns as well, since thermal efficiency is very important in any solar energy heating system.

VI.   <u>DESIGN CONFLICTS AND SOLUTIONS</u>

A designer, after considering all of the aforementioned patterns, could conceivably combine all of them into one optimal design. One possible way that the patterns could be combined would be as diagrammed below, for a 4-unit design:

A "PROTOTYPE" PATTERN:

elevation

S ← → N

top view

Evergreen

20

down slope
15

scattered
Deciduous

hedge

10

N ↑ ↓ S
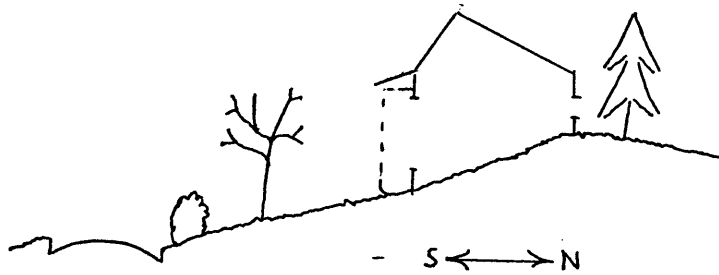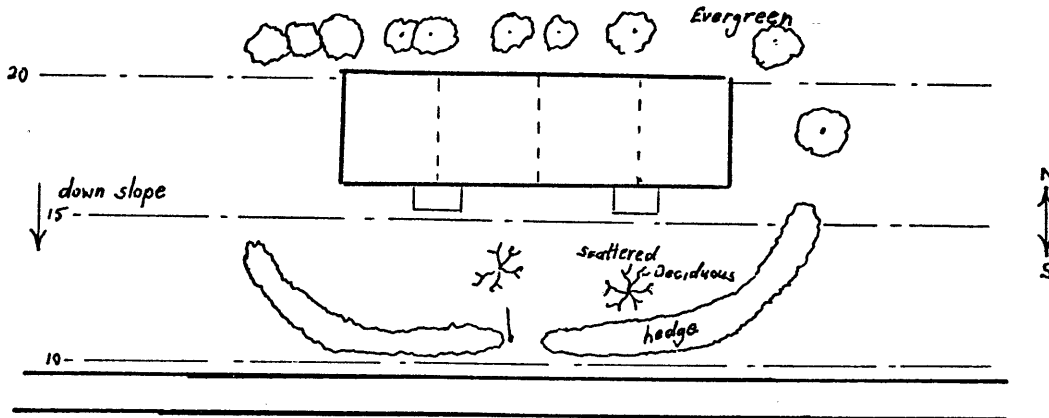
expanded pattern of a block

N ↑ ↓ S
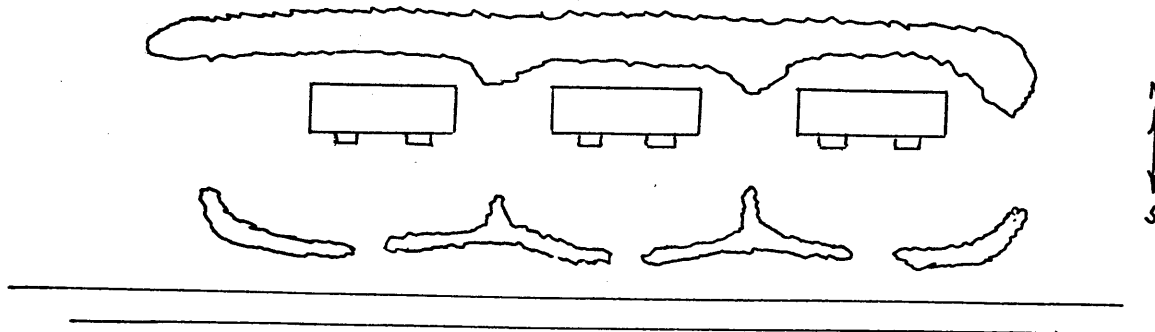
This design fulfills most of the energy-efficiency design patterns in that it:

1) Minimizes windows, except for large glass areas on the south side,

2) Places much of the north wall below grade,

3) Protects entranceways with vestibules,

4) Consists of connected units,

5) Uses vegetation to block winter winds from the northeast and northwest, and allows summer winds to sweep around the structure,

6) Pockets cold air running down the slope in summer, but allows it to pass by in winter by leaving the gates open,

7) Has a wooded canopy around much of the unit, with deciduous trees on the south and evergreens on the other sides,

8) Avoids large clearings,

9) Allows sunlight to strike the building and surrounding soil in winter,

10) Has broadest building dimension facing south,

11) Has collectors and large window areas facing due south,

12) Has overhangs and vegetation placed to keep summer sun off the building, and out of windows, and

13) Is built on a southern slope to minimize required clearance.

In addition, other patterns such as the use of conductive soils, control of drainage, locating buildings in warm bands, etc., are not precluded by this scheme, although they are not necessarily indicated by the design suggested here.

Using all of these recommendations together in a single pattern should result in savings of at least 50% of the heat load when compared with typical detached dwellings of the same size and dimensions. This does not include any fossil fuel savings from the use of a solar heating system. If a solar collector system is included that supplies 50% of the units' energy needs, these units will use 25% as much fossil fuel as average units built today. /

Even when these units are compared to similar connected dwellings that are less carefully placed on a site, the heat load of these units could be as much as 50% less, depending on the microclimatic characteristics of a particular site.

Limitations

This prototypical design may not always be convenient or desireable to the designer, however. It assumes that the following conditions hold:

1) that the designer accepts this particular use of the site (connected, linear row housing),

2) that the building sites are of a fixed relationship to the road (sites on the north side of a road),

3) that the sites and the road are of a fixed orientation and geometry (an east-west road through a site elongated east-west), and,

4) that the topography is cooperative with the prototype design (site slopes to the south).

Because these four assumptions rarely hold simultaneously, there are conflicts that are likely to arise. In this section we will suggest some additional patterns for variations in these four assumptions. These

patterns will then offer a set of solutions for a much wider variation

in tastes and site characteristics, and by mixing and choosing among them,

a range of design solutions should be suggested for a particular site.

Patterns will therefore be proposed to answer the following four

problems:

1) "What alternative approaches are there to arranging units

other than in a line paralleling the road?"

Instead of the linear pattern in the prototype, the designer may

feel that a better use of the site would be for the units to form court-

yard configurations or have irregular front orientations. We will pro-

pose methods of introducing flexibility while achieving the initial

patterns.

2) "How would development occur on the south side of the road?"

The prototype refers specifically to development on the north side

of a road. On the south side, a south-facing slope falls away from the

road rather than climbing from it, major solar radiation strikes the rear

of the units rather than their front sides, and winter winds strike the

front of the unit rather than the rear. The differences have implications

for development on the south side of the roads.

In addition, building on the south side of roads may result in

shading of winter sun from north-side units. We will suggest what types

of things might be done.

3) "How would development occur on non-east-west strips of

land?"

The prototype pattern would not easily be implemented on a site
that is elongated to the north and south, or NE-SW or NW-SE. Unit ori-
entations would be less satisfactory from a solar radiation standpoint,
and there would be greater tendencies for buildings to shade each other
on the same side of the road. Since most large sites are dissected
with roads, many of which may not run east-west, these non-east-west
land strips will necessarily be formed. We will suggest methods of
developing these strips.

    4) "How would development occur on a non-south-sloping topo-
graphy?"

Even with massive grading, it may be difficult to place all units
on south-sloping topography. Especially when massive grading is not
desireable, as is the case when one wishes to retain a tree canopy sur-
rounding the units, an inability to achieve a south-sloping topography
is likely.

As previously described, north-sloping topographies compound
problems of clearance to winter sunlight. We will suggest some solu-
tions to this problem.

The following four sets of patterns will respond to these issues:

PATTERNS FOR ALTERNATIVE UNIT ARRANGEMENTS

The original prototype was of a linear development pattern, with units in line and facing due south:
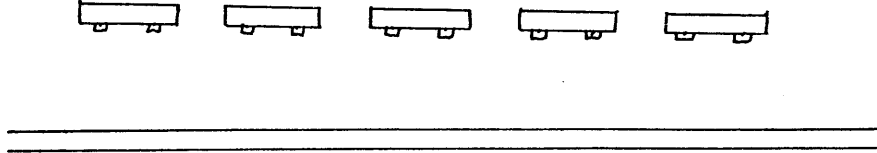
The designer may wish the units to enclose a space. This is a common pattern for defining a community space, for aesthetic purposes, for psychological purposes in promoting community interaction, and for practical purposes in allowing easier common use of recreational facilities, laundry facilities, walkways, utility connections, etc.

typical cluster
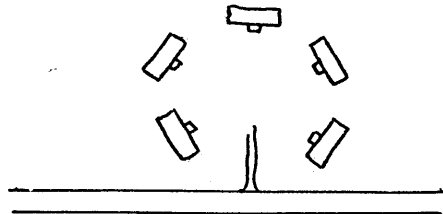
The problem with enclosing space with energy efficient units is that the units cannot be rotated without radiation energy loss. This is not an insurmountable problem, however. Approaches to enclosing space can employ the following techniques.

PATTERN:

"Vary the setbacks of units from the road to enclose space."
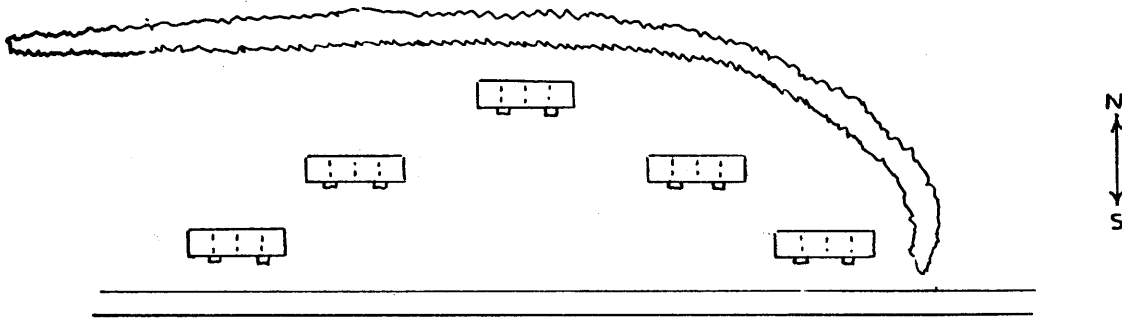
By varying the setbacks of buildings form the road, spaces can be enclosed from three sides (north,east, and west) with all units facing south and without causing significant problems of buildings sahding each other.

Blocking winter winds while admitting summer winds becomes more difficult, however, but can be achieved by extending the northern high hedge considerably to the west of the westernmost unit.

Enclosing the south side of the space without shading is difficult, and therefore this side is left open. Most advantages of clustering are retained, however.

PATTERN:
   "Stagger units along common walls."

N
↑
|
↓
S
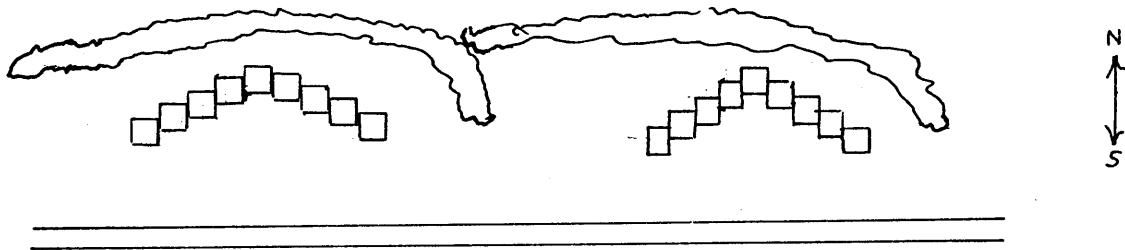
By slipping the units N-S of each other along their common walls,
a connected series of units can define an enclosed space. It is difficult
to enclose large spaces with this pattern, and some shading of each unit
is inevitable. Also, the thermal advantage of connecting units is lost
to the extent that their common walls are slipped apart. Also, channel-
ing summer winds to the eastern units of the cluster will require careful
hedge detail to deflect winds properly.

The pattern does allow most radiation to reach these units, and
allows achievement of most original design patterns while offering much
architectural and site planning flexibility to the designer.

PATTERN:
"Angle units east and west of south".
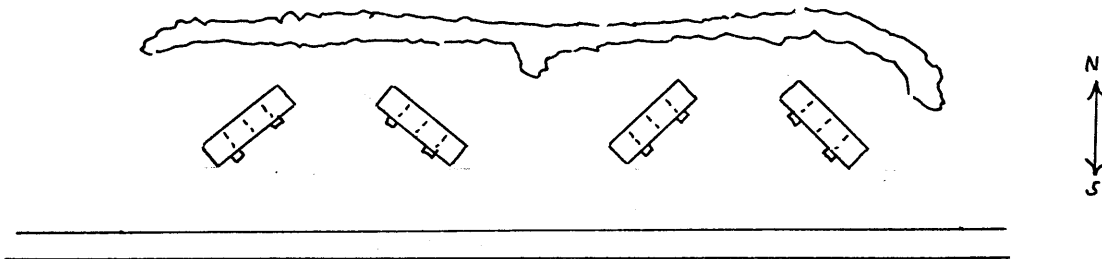
As described in the patterns on building orientation, the designer has relative flexibility to angle buildings from south to southeast or southwest without large sacrifice to the effectiveness of collectors or window areas. Angling will also reduce the necessary road frontage per unit, allowing denser use of the site. Again, easterly units will need careful hedge detail for diverting summer winds toward them, and some shading is also likely; but overall, angling units between southeast and southwest can be achieved without significant cost.

PATTERN:
"Combine space enclosure patterns."
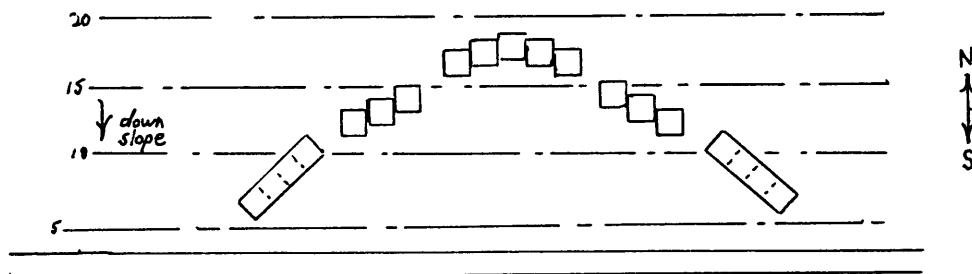
By varying setbacks, staggering, and angling units, the designer

can achieve significant design flexibility in enclosing space of any

dimension without large sacrifice of thermal efficiency.

PATTERN:
  "Build on a 'bowl-shape' groundform".
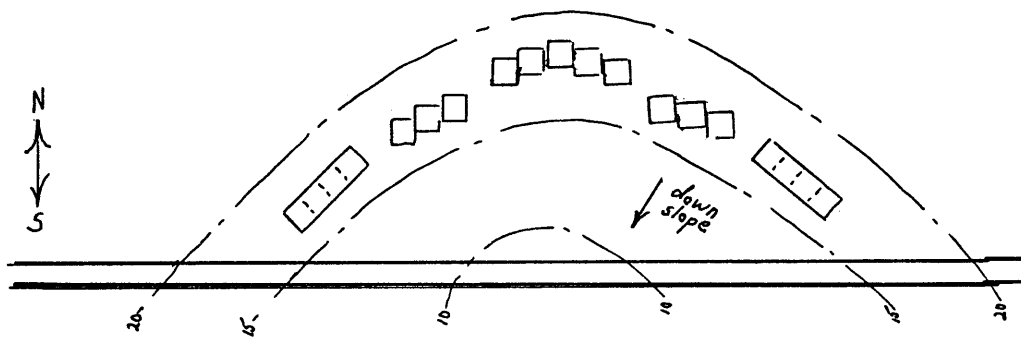
An alternative to building on a topography of a south-facing slope

that evenly descends downward from the unit to the road is a bowl-shape

·groundform, where the ground slopes downward towards the focus of the

units in a hemispherical enclosed space. This form may further define

the enclosed space, and may be considered aesthetically attractive by the

designer, or may be more convenient to use on a particular site.

The groundform does not prevent shading of northern units to the

extent that the "straight" groundform did, and may cause water pockets

at the low point.

These problems, however, can be overcome with careful siting

and drainage design, and otherwise the pattern is a viable alternative.

PATTERNS FOR THE SOUTH SIDE OF ROADS

On the south side of roads, units will be oriented with their
north sides facing the road. Therefore large glass areas will be in
the rear of the units, as will any solar collectors, while north-side
units have their windows and collectors in the front. The result would
be clear dichotomy in the architecture of unit fronts to either side of
the street.

One way to handle this problem is to ignore it.

PATTERN:

"Build units on the south side of the street analo-
gously to those on the north side, except that large
window areas should face away from the street."

S ←—→ N
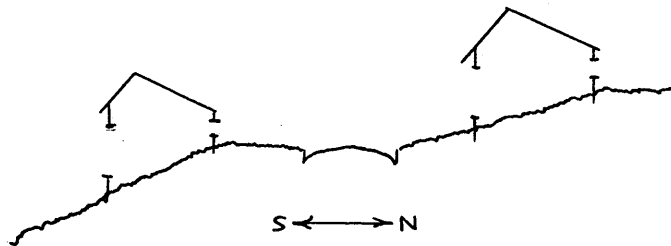
There is nothing that dictates that the "south side of the street"
pattern in wrong, or less desireable than the north-side pattern. The
units can get radiation, and the sites can be designed to be microcli-
matically advantageous. With careful architecture, attractive unit
fronts can be designed for units on either side of the street, although
each side will be typified by a different type of front.

One probable deviation from north-side patterns is that the
units should be above the road in altitude, so that drainage will
flow from the unit to the road, rather than the other way around.
While it is advantageous for the topography to be mainly south-sloping
for sun clearance, a north-sloping frontyard will have drainage ad-
vantages. On a south-sloping topography, cutting under the road, or
raising the unit, will result in a correctly draining north-sloping
front yard, while retaining a south-sloping rear yard, and retaining
sun clearance for windows and collectors in the rear.

Windbreaks can be accomplished with hedges between the street
and the unit. If visibility of the units from the street is desired, the
windbreak can be thinned directly in front of the units, since predom-
inant winter winds come from the northeast and northwest, and less often
from directly north.

PATTERN:
    "Units on the south sides of roads have similar design
    flexibilities to units on the north side."
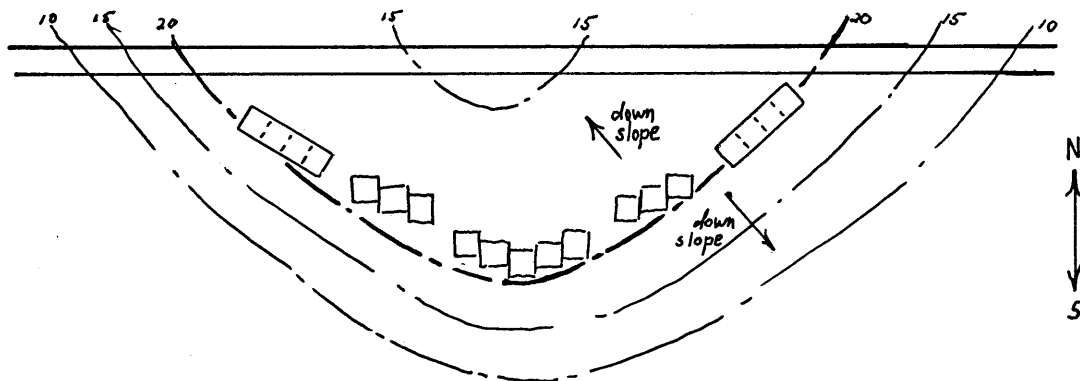
Unit arrangements for enclosing space can be analogous to previous north-side patterns, with the exception that groundforms are less flexible, again for drainage reasons. In a hemispherical unit arrangement such as the one diagrammed above, a good groundform would have a hemispherical shape, with the ground sloping downward to the south behind the units, and with the ground slightly sloping downward to the north in front of the units. This allows sun clearance without drainage difficulties.

Units arranged as diagrammed above have little difficulty with windbreaks, since the units closer to the road aid as windbreaks to the units farther away.

Another problem with south-side development is the possible shading of north-side units.

PATTERN:
> "Stagger units between the north side and south side of the street to prevent shading."
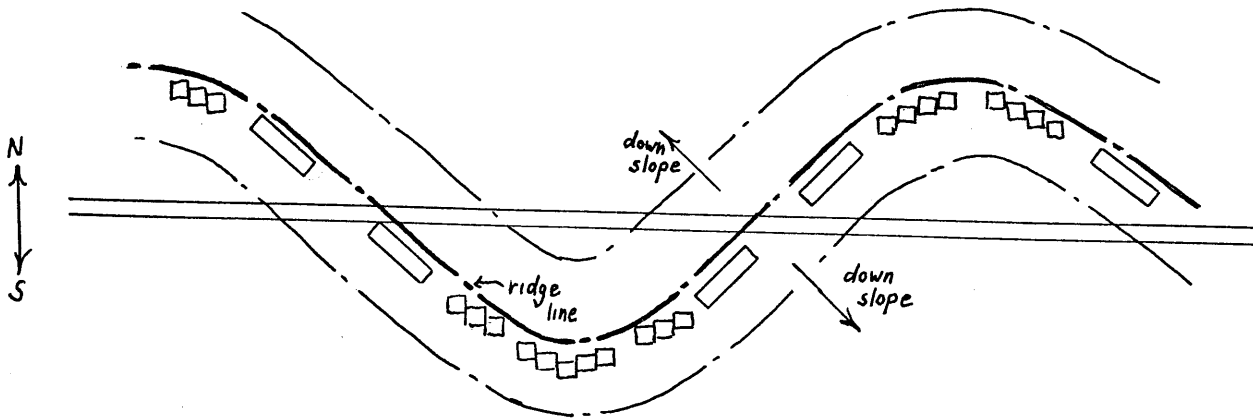
This arrangement allows clustered construction on both sides of the road without south-side development shading the north side. The gorundform places all units near a line of highest altitude, with south-side development on this crest, and north-side development in front of it (as viewed from the road).

A problem with this pattern is that development is single-loaded, i.e., there are only units on one side of the road at a time. This makes more road necessary than with double-loaded roads, and leaves tracts of land that are unbuildable (these tracts can be used for parking and recreation, however).

Where double-loaded roads are desired, the following pattern may be helpful:

PATTERN:

"Place units along ridges to either side of the street."
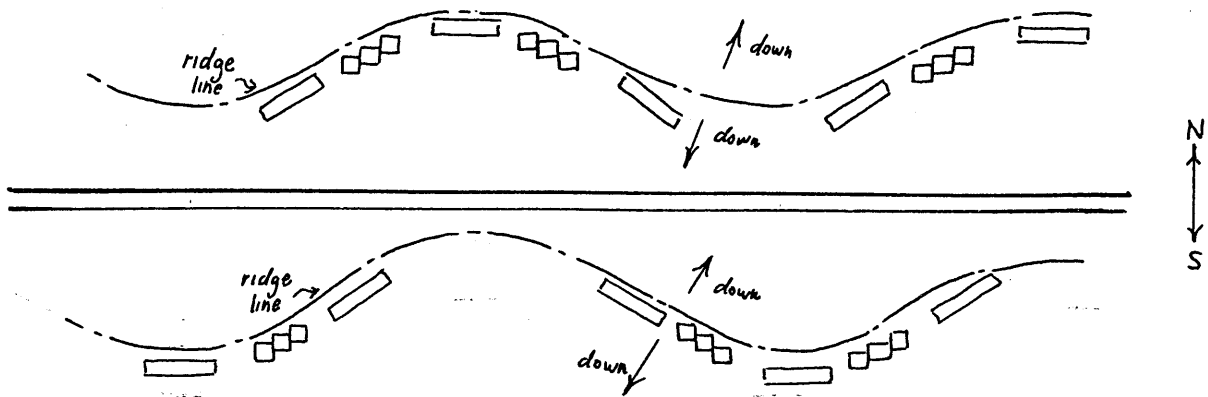
Shading is prevented if the distance between the ridges is adequate to allow sun clearance. If the buildings are 25' high, buildings should be at least 56' apart on ridges of equal altitude to prevent complete winter shading. Distances of 100' would prevent most shading. Building on these highpoints allows low vegetation to be placed in the front yards without causing shading of north-side units, and allows units on both sides to drain to the road.

If the altitude of the south ridge is lower than the northern ridge, less distance is required between the ridges for winter sun clearance. Likewise, a higher southern ridge compounds the clearance problems and requires large distances for sun clearance.

By waving the ridge line from east to west, as done in the pattern diagram, irregular unit layouts can be achieved while following this pattern. Placing units along a "rippled" ridge line helps define enclosed spaces as shown.

On property that is basically flat, where some grading is possible to lower the road and raise ridges to either side, this design allows all

units to be on south-facing slopes, have adequate sunlight clearance,
define enclosed spaces, drain properly, and otherwise work very well
from many points of view.

Problems are possible with winds, since this groundform and
building layout can likely affect local wind conditions, making them
less predictable and more difficult to block. It may be necessary to
build the units, and then experiment on the site to determine the best
location for windblocks.

PATTERNS FOR NON-EAST-WEST DEVELOPMENT

Patterns to this point have been applicable to development along east-west roads. To use the dimensions of a land parcel efficiently, it may be necessary to have development in other direcitons. Patterns for handling this problem are suggested below:

   PATTERN:
             "Linear development on diagonal (NE-SW, SE-NW) strips can be analogous to that on E-W strips of land."
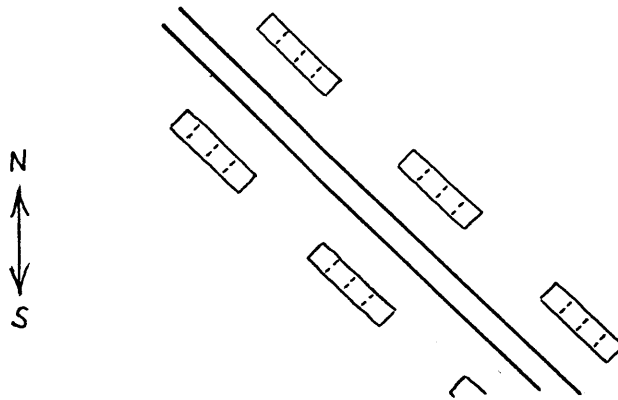
Because of the flexibilities of orientation to within 45° of south, development can occur on diagonal strips with small losses in winter sun radiation. Similar care must be taken to that of E-W strips to prevent shading across the street, either by staggering the units, or by maintaining adequate clearance distances. It is interesting to note that units can be directly opposite each other across a diagonal street, and yet be staggered with reference to southern sunlight.

An alternative to this arrangement is the following:

PATTERN:

"Angle units to the street to achieve southern exposure
on a diagonal street."
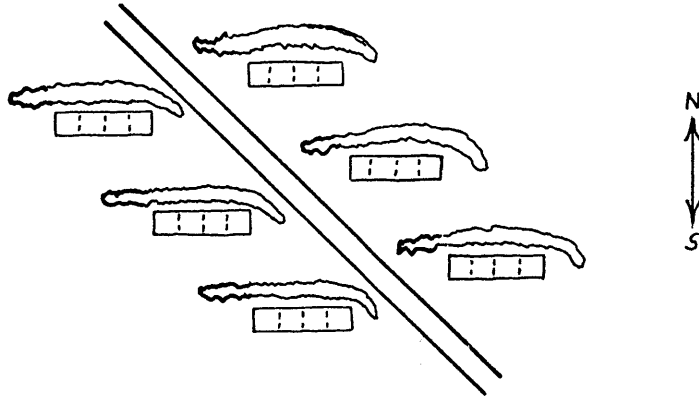
By angling the units, they can remain at an optimal sun orientation
on a diagonal street. This pattern also requires less road frontage per
unit than development paralleling the street.

It is possible to define the south face of units as the front, even
of the south side of the street, with this pattern. Careful placing of
hedges and access can lessen the problems of the front facing slightly
away from the street. The advantage is that a designer can use similar
building form and architecture on both sides of the street, which is
simpler and may be aesthetically desireable.

In addition, wind blocking can be easier with this design. If the
south face of units is defined as the front on the south side of the street,
then high hedges can be placed, without blocking fronts, to the north of
each unit, resulting in strong wind blocks.

This pattern will therefore result in better solar performance than
the first pattern, less road frontage, and easier wind protection than
the first diagonal pattern.

PATTERN:
>"Use similar devices to E-W development to enclose
>spaces on diagonal development."
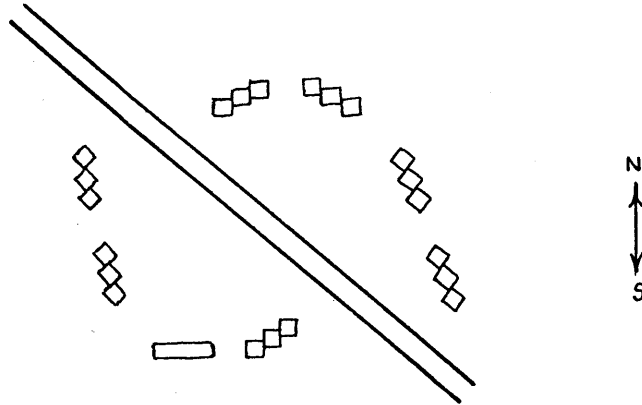
Enclosing space is possible, but more difficult on diagonal development. Enclosing the space on the east side is more difficult north of the road, as is enclosing the west side of the space south of the road, since units cannot be placed on these sides without being oriented greatly from south (see diagram). Using varied setbacks and staggered units, these sides can be formed with some inefficiency and shading, but without losing most radiation advantages.

PATTERN:
>"Maintain adequate clearance distances on a north-south
>street."
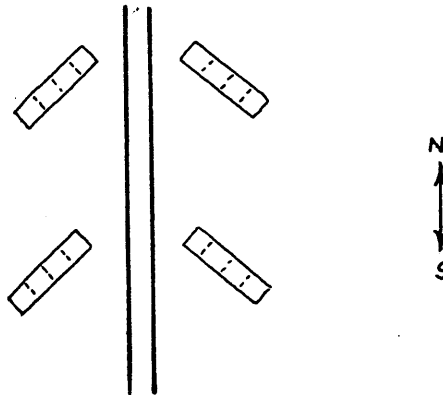
While the orientation flexibilities discussed previously can suggest methods of placing units along N-S streets, it is difficult to give units clearance from obstruction to the south. It is best to assume that N-S development is disadvantageous and should be avoided due to the problem of achieving this clearance.

Since there will be buildings to the south, sun clearance can only be provided by having adequate distance between units on the same side of the street. Pattern #21 suggests methods for reducing that distance, such as building on south-facing slopes, placing windows and collectors high on buildings, and using a low building form.

PATTERN:
"Enclosed spaces can be formed along N-S strips using hedges to enclose the south side."
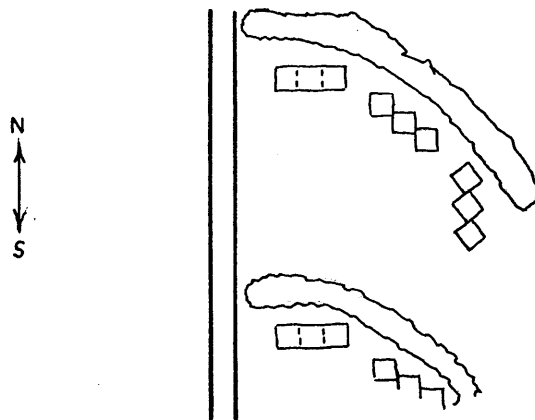
If there were units on the south edge of the cluster described above, they would have their north-side facades facing a cluster of south-side facades. They would have radically different front architecture, or would have the rear of their unit facing the community space. Therefore, units on the south side would have an awkward spatial relationship to the other units in the cluster.

Placing a hedge on the south side of the enclosed space acts to define the space. The hedge, in turn, acts as the windblock for the next cluster, allowing reasonably dense use of the site.

PATTERNS FOR NORTH-FACING SLOPES

A north-facing slope possesses a significant problem to energy-efficient development because sun clearance problems may be increased substantially, depending on the extent of the slope (as described in pattern #21). On a 10% northern slope, the required clearance for mid-day winter sun is 100', compared with 56' on flat ground and 37' on a 10% southern slope. Clearances for morning and afternoon sun need larger distances than these.

Although it may be possible to clear enough area on a sparcely developed site, large vegetation removal may be necessary, causing microclimatic changes on the site that may result in higher heating loads. The changes may also cause environmental degradation by altering the microclimate, and may have undesireable aesthetic consequences.

The recommendation for north-facing slopes is therefore reiterated from pattern #21 : avoid them wherever possible. If it is absolutely necessary to build on such slopes, the following patterns are recommended:

PATTERN:
"Place window areas and collectors high on units on north-facing slopes."

S ← → N
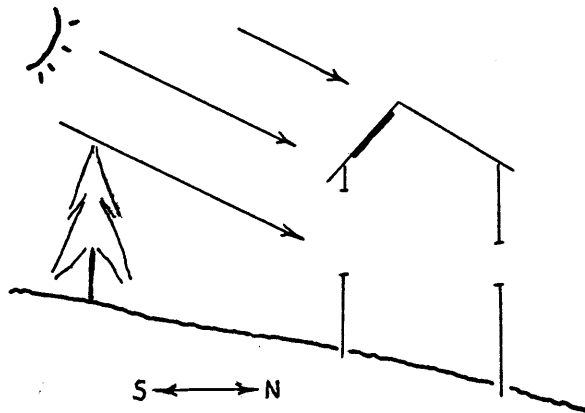
High windows and collector surfaces allow sunlight to enter

above some vegetation, and requires less clearance from buildings.

This pattern suggests an advantage to taller buildings, which

allow collector areas to be placed at higher points. Tall buildings,

however, cast longer shadows, and may increase clearance problems of

other buildings on the site.

PATTERN:
"Cluster collectors, or separate them from units."
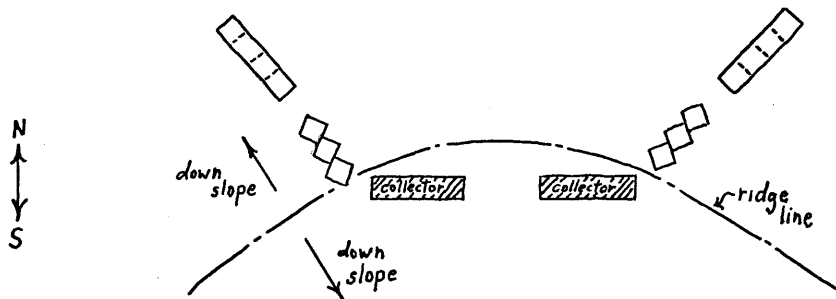
If it is too difficult or expensive to admit radiation throughout

the winter to all units, an alternative of placing disproportionate col-

lector areas on a few units that have clearance, or on separate structures

(such as garages) should be considered. There will be increased costs

due to required ducting from a centralized facility, but there are econ-

omies of scale in the centralized collector storage system to offset these

costs, as described in pattern #22 .

VII.   GOVERNMENT STRATEGIES FOR PROMOTING ENERGY-EFFICIENCY

The intent of this chapter is to survey possible federal government

strategies that will improve the efficiency of dwelling units for space

heating. The strategies will try to promote the use of the energy-saving

techniques previously described. In this chapter, previous techniques will

be summarized, with evaluation made on whether government action on them

is desireable or necessary. Proposals for government action will then be

made in areas where government intervention was considered necessary. Likely

benefits and costs of proposals from the perspective of government will be

outlined, although this paper will not analyse its proposals with in-depth

benefit-cost studies. At the conclusion, however, it is hoped that certain

recommendations will be shown to be highly desireable and deserving of

further study. These recommendations should indicate clear directions for

national domestic energy policies yielding the greatest benefits with the

least risks and costs.

Government's Objectives

As previously described, it is in the national interest to reduce

the long-term consumption of fossil fuels. The reasons mentioned for this

include the following:

- The nation's dependence on fossil fuels for all energy needs has

grown very strong in a period when fossil fuels have been readily available

and inexpensive. It now appears that the world's supply of these fuels is

limited. The known reserves of oil and natural gas, for example, are less than 20 years. If the actual reserves are twice that much, and there is adaquate fossil fuels for 40 years, this end-to-fuel-supply point is still within the lifetime of dwellings built today.

- Even before fuel supplies run out, shortages may continue to occur for political reasons, with nations threatening others with fuel embargoes, or selling to adversary nations at exorbitant prices. Because production in the United States has not kept pace with demand, our dependence on energy sources beyond our political control may be a threat to national security. Reducing our energy consumption can reduce (or end) our dependence on foreign energy supplies.

- Fossil-fuel burning generally produces externalities of air pollution, water pollution, and other environmental problems. Reducing fossil-fuel usage promises to alleviate this.

One proposed method of reducing fuel consumption is to destroy the ability of the economy to purchase fuel by making it expensive through taxes and other means. This approach was regarded as undesireable because of the hardship and stress placed on the nation by such a program.

The method that will be explored here is the promotion of the use of the energy-conserving techniques outlined in this thesis. The energy-saving site planning techniques involving building insulation, microclimate control, and advantageous use of winter sun have been shown to be of significant benefit, and often without major costs. Solar-energy heating was shown to have much promise. The use of these techniques can result in dwellings with 25% or less of the fuel consumption of comparable present dwellings. In the long term, when these techniques would be used on the majority of the housing stock, the possible aggregate savings of the use of these

techniques would be a 15% reduction in national fossil fuel consumption.

Approaches to the Promotion of Energy-Efficiency Techniques

The government should consider three broad approaches to the promotion of these techniques, which are the following:

1) Do nothing. The null alternative should always be examined. It may be that the natural economic forces, and the natural rate of information dissemination will be adequate to promote the use of energy-efficiency techniques rapidly, without government intervention.

2) Assist or coerce the developer and homeowner. It may be that the housing market will respond to energy-saving techniques, but that response will be slow because of conservative constraints on the building industry, because of a slow rate of information dispersal, and because of a slow growth in consumer demand.

Also, the benefits of energy-efficiency to society may be greater than to a particular developer or homeowner. From the point of view of the private developer or homeowner, his rate of consumption of fossil fuels has no significant impact on national goals, whether or not he is concerned with them. He must make his decisions on the basis of his own concerns, mainly economic. Because energy-efficiency may be more valuable to the nation as a whole than to the private individual, action by government to affect private energy economics may be required. In these cases, the government should undertake programs that are catalysts to the use of energy-saving techniques. Incentive programs and regulatory legislation would be such catalysts.

3) Do it yourself. The far end of the spectrum is for government

to finance and manage the development of energy-efficient housing. It
is a necessary approach if energy-efficiency is desireable for the public
good, but not adaquately profitable for private development.

Evaluation of energy-efficiency proposals will be presented from
the points of view of the developer and dwelling-unit purchaser. The
position of the renter will not explicitly be presented. It is felt that
their positions can be omitted because the goals of the renters and the
landlords and those of the nation, developers, and homeowners are non-
conflicting concerning energy-efficiency. If energy efficiency is desireable
from the standpoint of the housing market, it will be desireable to the
rental market as well, as follows:

If the renter pays separately for heat, he will show the same
concern for energy-efficiency that a home-buyer would. If the renter has
heat included in the rent, then it is true that efficiency savings belong
to the landlord, and the renter may or may not benefit from the savings,
depending on market conditions. Even when savings are not passed along,
energy-efficiency will be profitable to the landlord, but not disadvantageous
to the renter.

Will Energy-Efficiency Require Government Action?

A. ECONOMIC OUTLOOK FOR SOLAR ENERGY:

As previously described in Chapter 4, the economic arguments for
solar-energy collection for space heating are generally unfavorable at
present, but seem likely to improve.

We estimated net present costs for a solar collector system at $7 per
therm (one gallon of fuel oil) saved per year by its use. Using the present

price of $.40 for a gallon of fuel oil, a 10 to 15 year life expectancy

for collector equipment, and a 14% capitalization rate on yearly savings, we

determined that the maximum collector cost that could be justified

economically was $2.80 per therm saved per year.

For water heating, the collector equipment is twice as efficient, due

to year-round use, and the present estimated cost per therm savings

for hot water heating is $3.50, much closer to the "break-even" point of

$2.80 per therm.

In the near future, however, it is forseeable that collector

equipment will become more efficient and less expensive, while fuel-oil

will rise in price. In our analysis of benefits and costs in ten years,

we estimated the cost of a unit in ten years to be under $3 per therm

saved, while the benefit of saving one therm per year at a 14% discount

rate was estimated at $8! This is a hypothetical guess, but is indicated

by present trends and research.

Planning for solar energy use in the future therefore seems to be

good practice, although its economic feasibility at present is doubtful.

B. ECONOMIC OUTLOOK FOR SITE PLANNING TECHNIQUES INVOLVING HEAT

RETENTION, MICROCLIMATE, AND PASSIVE USE OF SUN RADIATION:

As described in the design patterns, these techniques can have

great savings, easily summing to 50% energy savings over common modern

construction.

This requires more discriminating choice and use of sites, more

restricted architectural design, and less use of free-standing, single

family housing. These requirements may be convenient for a specific

site program, and therefore costless. For another site, implementation

of the design patterns may be more difficult, requireing building variances

or zoning changes, massive grading, loss of site yield in housing units, and

possibly loss of market appeal through undesireable architecture. In these

cases, implementation of the design patterns may far exceed their economic

benefits. The general approach suggested for this problem was to promote

these techniques in such a way that they would be used only where advantageous.

C. PROBLEMS OTHER THAN COSTS:

Besides possible economic hurdles, the following problems stand in

the way of energy-efficient development:

- Ignorance by the developer of energy-saving techniques and their

possible benefits. Although there may be simple, inexpensive ways to

reduce the fuel consumption of his units, a developer may not know about

them.

- Ignorance by housing residents of energy-saving techniques and

benefits. Ways of improving energy-efficiency in existing units are often

unknown by housing residents.

- Lack of demand for energy-efficient housing by the market.

Although fuel savings may be large enough to justify a higher initial housing

cost, buyers may be reluctant to pay this additional initial cost.

- Risks to the developer and homeowner. Energy-efficient construction

requires developers to risk development for an untried market. Also, the

buyer is asked to pay for unproven fuel savings. With solar energy

equipment, both the housing buyer and the developer must take risks on the

longevity and performance of unproven equipment. These risks are therefore

significant hurdles to solar energy development.

- Financing. Along with increased risks comes greater financing

difficulties, since the banks, as well, are assuming greater risks. These

risks result in higher interest rates, and therefore, greater costs.

It therefore appears that energy-efficiency may have economic

promise as well as serve the national interest, but may need government

prodding and promotion to overcome the conservative tendencies of the

housing market in America and to fill information gaps. It seems likely that

these programs can be of limited time span; that once energy-efficient

construction is proven and accepted, energy-efficiency will continue without

government help.

Outline of Proposals for Government Action

A. TO THE PROBLEM OF LACK OF INFORMATION:

Information helps to improve rational economic behavior by home

buyers and developers. For promotion of cost-effective energy-saving

techniques, improved information transfer may be all that is necessary.

Approaches to improved information include the following:

1) Demonstrations and publications. One obvious way to inform both

the developer and the public is through demonstration programs and preparation

of publications. At present there are some demonstration programs, notably

the "Solar Heating and Cooling Demonstration Act of 1974", which authorizes

$60 million in discretionary funds for demonstrations in fiscal years

1975-1979. Additional programs for non-solar techniques should be implemented,

as well.

The benefits of dissemination of such information in this way are

as follows:

- A "market" for energy-efficiency is created. People become aware

of the benefits, and desire them. Builders offering energy-efficient

units will thereby experience greater demand.

- Energy-efficiency techniques become common knowledge. The

developers and homeowners are informed of probable returns on investment in

energy-efficiency. Architects and engineers will become acquainted with

these techniques in response to the demand, and once they are familiar with

them, they will suggest them to their clients on projects where energy-efficiency

techniques may be desireable.

The costs of demonstration programs are minor when compared with

possible benefits. Improved information may promote energy-efficiency in a

shorter period of time. If the energy-efficiency of housing is improved by

5% over 10 years, rather than in 20 years without demonstration programs, the

savings would be at least 1 billion gallons of fuel oil, or equivalent in

other energy forms, over the twenty years. This would seem to justify the

present $60 million program.

2) Energy-efficiency ratings. Government could provide a mechanism for

"scoring" dwelling units in the marketplace for energy-efficiency. In much

the same way that the Environmental Protection Agency publishes miles-per-

gallon ratings for motor vehicles, H.U.D. could provide an energy-efficiency

rating service for housing.

The "fuel consumption index" for housing could be in units of

BTU's of fuel consumed, per sq. ft. of floor area, per degree day, per

heating season. This would be a good unit for comparison among units,

because it is energy consumption controlled for energy source, unit size,

and climate. Therefore, the rating would give no advantage to southern
development, small development, or to one energy source over another. The unit
would refer to energy-efficiency quality alone.

Such a measure presently exists in Federal Housing Administration
guidelines for mortgages, with a requirement that housing eligibility be
limited to units under a determined "fuel consumption index" specified for
each particular region and climate. In Boston, the maximum "fuel consumption
index" is 19 .[2]

By compiling the actual "fuel consumption index" for all new housing
units, home buyers would be able to use the concept of energy-efficiency
in their decision-making, by making simple comparisons among the indexes
listed for the various dwellings.

Each unit drop in the index would represent approximately 5% less
energy consumption, equivalent to $20 saved per season per 1000 sq. ft. of floor
area (comparison based on oil heat at $.40 per gallon). Energy-efficient
units would thereby have a clear market advantage, and all cost-effective
techniques would be promoted.

The only costs of this proposal are administrative. Initially,
the government may have to pay for the rating service, but once accepted
and popular, developers could be required to subscribe to it and pay
all expenses.

B. TO THE PROBLEM OF COSTS:

New energy-saving techniques may be deemed desireable by the
public sector, but may be unused by developers and homeowners where it
is not cost-effective, or where uncertainties of performance are too great.

In such cases, it may be advantageous for government to reduce the costs

of energy-saving improvements. Proposed methods are as follows:

1) <u>Tax benefits to homeowners for additional insulation or solar</u>

<u>equipment.</u> For improving energy-efficiency of existing housing, it has

been proposed that homeowners be offered a tax deduction for capital

investment in energy-saving equipment. This would serve to offset the

costs of the equipment for the homeowner.

A problem with tax-deduction subsidization is that the benefits tend

to be regressive, since the wealthy are in higher tax brackets and benefit

most from reduced taxable income. A tax credit, allowing individuals to

take a portion of their investment in energy-saving equipment off of

their tax payments is less regressive, since everyone would save the

same amount, provided they owed at least as much tax as their eligible

tax credit.

The benefits of this subsidization are the promotion of the use

of better insulation and solar collectors by homeowners. Notably, all

energy-saving techniques involving microclimate control and windblocks,

which could be undertaken by a homeowner, will not be promoted by this

approach since they do not require the use of specific energy-saving

equipment.

The fuel savings of such a program would be hard to estimate. If

solar technology was readily available and subsidizations adaquate, it

would be reasonable to expect that much existing housing, perhaps 10 - 20%,

could use additional insulation or solar equipment to lower their fuel

consumption 25 - 50%. These estimates would suggest national fuel savings

of ½ of 1%, to 2%.

In addition, the tax credit would inform the public and popularize

the concept of energy-efficiency, as people tend to research possible tax

breaks. It would also spur research, production, marketing, and competition

in the energy equipment industry, as a result of expected demand growth.

This could work to reduce equipment costs, and decrease the need for subsidy.

Once the benefits of initial interest were achieved by this program,

the program could possibly be discontinued without reducing consumer

demand for energy-efficiency products. Therefore the benefit stream

may outlast the cost stream with this program.

The major cost would be the forgone taxes. This cost would vary

depending on the size of the subsidy and the popularity of the program.

Another national cost would be the fuel consumption of industries

producing energy-saving equipment. Although figures vary depending on the

construction, solar collectors may use substantial amounts of fossil fuels

in their production. For example, an aluminum collector plate will require

at least as much fuel in production as the collector will save in a year,

and this is but one of many energy inputs to the production and installation

of a solar collector system.

2) <u>Tax benefits of housing developers</u>. If energy-saving equipment does

not add as much value to housing as it costs, it is unlikely that developers

will consider using them. Subsidies, such as those described for homeowners,

may be advantageous from the public viewpoint and for developers as well.

Energy-saving techniques other than solar collectors are difficult

to promote with this method. Microclimate, passive radiation, and wind

reduction have no special equipment that developers could claim as special

energy-efficiency costs. Insulation, of course, could not be regarded as

an extra expense in the public interest. Therefore, only solar collection can be reasonably promoted with this method.

Benefits and costs are similar to the homeowner tax benefit proposal, with the addition that new development will more likely have solar equipment, and that developers will become educated about energy-efficiency, as well.

3) Link energy-efficiency to subsidization programs. Government programs to subsidize housing costs have been implemented in the past. HUD Section 236 mortgage subsidization is a recent example, although it is not operating at present. Should subsidization programs of this type re-occur, they should promote the national energy objectives as well as any other stated goals.

A method of doing this would be to require a low "fuel consumption index", described in the information proposals. For example, the government could require a maximum index of 9½ in the Boston area, half the present building standard of 19. To be eligible for subsidies, the developer would seek out the least expensive ways to reduce his fuel consumption to this level in his development.

The benefits are reduced energy consumption in all government subsidized units, and promotion of initial private attempts at energy efficiency, in an attempt to "break the ice". Once the energy-saving techniques are tried, they may prove themselves to be economically feasible, and will be used outside the subsidized housing programs.

C. TO THE PROBLEM OF RISK:

Risks of radically new energy-saving techniques were described as blocks to their acceptance by developers and the housing market. The following approaches to this problem are offered:

1) <u>Government acts as the first developer</u>. Since the housing industry
may be unwilling to accept the uncertainties (both financial and maintenence)
of solar collector systems or radical site planning, it may be necessary
for government to take the initiative. While heavy subsidization may get
the private sector to take risks, as suggested in the cost-reduction proposals,
it may be less expensive for government to develop housing itself rather
than "bribe" the private sector with subsidies into taking the first step.
A disadvantage of government-run development, however, is that the private
sector may remain unconvinced of the ability of non-government developers to
profit from energy-saving techniques.

The benefits are the provision of some energy-efficient housing units,
and the promotion of initial energy-efficient construction to quiet fears
of home buyers, developers, and banks.

The costs are minimal, limited only to any losses in housing development
(none would be planned), administrative and advertising costs.

2) <u>Establish a government-regulated solar energy utility.</u> Once the
technology of solar collection is perfected, utilities could be formed that
would install, maintain, and replace solar heating equipment for a basic
rental fee. Homeowners would therefore be offered perfect information on
monthly savings vs. monthly costs for solar collection equipment, and would
not have to assume any initial capital expense. The homeowner would also
be relieved of any of the risks of a solar system, including non-performance,
maintenence, and replacement, since this service would be provided by
the utility company, and performance would be guaranteed.

The rental fee would reflect the size of the system, and thereby
it would also be proportional to the fuel savings. The utility would

therefore only make sense when the economics of solar collectors were favorable enough that the systems could be built, installed, and maintained for less than the fuel savings provided by the collector system.

Benefits include reduced risks to the homeowner, and removal of the requirement of large initial investment for collector systems, spreading equipment expenses over the same time span as savings.

The costs include the following:

- The collector system will be added on to dwellings, rather than integrated into building design, resulting in some inefficiencies. Exterior building surfaces will have been provided where collectors will cover them, and probably less planning for collector systems will occur in building design and in site planning. This lack of planning during construction could result in greater space costs, installation costs, and poorer performance.

- The utility would be an additional middleman in the solar collector industry, adding additional costs to solar collector systems.

D. TO THE PROBLEM OF FINANCING:

1) Require improved energy-efficiency standards for FHA- insured mortgages. At present the government is a major insurer of financing of home mortgages. If the government will assume the risks of solar energy systems and other energy-efficiency techniques, the banks will not be afraid to offer low-cost mortgages to owners of energy-efficient dwelling units.

The process for promoting energy-efficiency could be periodic reduction in the standard for fuel consumption in dwelling units, repre-sented by the proposed "fuel consumption index". This maximum consumption

level could be reduced over time, by a fixed timetable, promoting rapid

evolution in the energy-efficiency of housing. The timetable would be

designed to correspond to the ability of the housing industry to improve

the energy-efficiency of its units without major expense. The program

would be analogous to the EPA's timetable for the reduction of air pollution

in new automobile production.

The benefits of the program would include the following:

- Greater availability of financing for energy-efficient construction.

- Spurred interest in energy-efficiency to achieve requirements

inexpensively. Research and production of energy-saving equipment would

also be stimulated.

- Forced reduction in fuel consumption of dwelling units in the

near future, resulting in significant national energy savings.

The costs of applying decreasing energy-consumption standards may

be small. It may be limited to increased administrative costs in determining

accurate "fuel consumption index" measurements.

However, it is clearly possible that housing may be made more

expensive if the standard is reduced faster than the ability of the

housing industry to establish cost-effective measures in energy conservation.

If the index is so low that non-cost-effective measures must be implemented

to qualify for mortgage guarantees, then housing costs will go up for those

that require mortgage guarantees the most: poorer homeowners.

This program should therefore be coordinated with technological

improvements and with information dispersal programs. If carefully done,

the regulations can provide strong impetus to the use of energy-saving

techniques, without increases in housing costs.

Conclusions

Information dispersal is the most essential action to be undertaken at present. If developers and homeowners are aware of the energy-saving techniques presently available, much would already be happening to reduce domestic fuel consumption. Despite some government efforts, there are few information sources that seek to provide energy-saving information in terms usable by average homeowners and small developers. These information sources should be available. Indeed, one of the intentions of this thesis was to be such a source.

The concept of a standardized "fuel consumption rating" would seem to go far towards achievement of efficiency goals at this time. It informs the public, and makes it easier for them to shop for energy-efficient housing. It thereby improves the energy-efficient housing market, pressuring developers to attempt energy-saving techniques. It's application as a standard in federal housing programs gives the government some strength in coercing the housing industry to attempt fuel-conserving design and planning. In addition, the "fuel consumption index" can stand as a measure of a national goal; and perhaps we should explicitly set a goal for reducing fuel consumption in housing. Perhaps, for example, we should make a national goal of 50% reduction in the "fuel consumption index" within ten years. The results would be more meaningful and important to Americal society than achievement of the goals of the space race, although perhaps less exciting.

Use of solar energy

It seems clear that government should not coerce the housing industry into use of solar collector systems at present. Overzealous

promotion of solar energy has resulted in a backlash once before, silencing

the field for 15 years. Although technology has improved, solar energy

still suffers from being too expensive, lacking trademen to provide

maintenence and service, and containing hidden energy costs in production

that lower its effectiveness for achieving national objectives. In short,

we are not yet ready to go large-scale.

But the day for solar energy is approaching. Technology is

improving collector systems and cutting costs while alternative energy

sources continue to rise in price.

What is presently needed is experimentation, therefore, with

government supporting small-scale solar energy development, even at a

loss. Government housing programs could provide a limited testing ground.

These experiments will teach us about what to expect in a solar-heated

home, and will result in increased research by potential manufacturers,

creation of trades for servicing collectors, and "folk knowledge" of

the solar collector system's existence, its appearance, and its benefits.

At the same time, promotional government programs, such as those

outlined in this chapter, should be studied and prepared by congress

and consultants in anticipation of technological improvements. These

studies should establish effective strategies for promoting the use of solar

energy, at low government expense, when they become feasible.

In addition, new housing should be designed in anticipation of

collector systems. Buildings should be oriented properly, and space

should be provided for ducts and storage, so that dwellings can be

converted to solar energy as soon as the technology arrives.

Footnotes

Chapter I

1) Environmental Information Corperation, <u>The Energy Index</u>, p. 43.

2) Weaver, "Search For Tomorrow's Power, p. 653.

3) and 4) Anderson, <u>Solar Energy and Shelter Design</u>, p. 6.

5) Rocks and Runyun, <u>The Energy Crisis</u>, p.7.

6) <u>The Energy Index</u>, p.20.

7) Rocks and Runyun, <u>The Energy Crisis</u>, p.9,16.

8) <u>Ibid</u>.,p.22.

9) Vansant, <u>Strategic Energy Supply and National Security</u>.

10) <u>Ibid</u>.

11) Fisher, <u>Energy Crisis In Perspective</u>, p.4.

12) Rocks and Runyun, <u>The Energy Crisis</u>, p. 18.

13) Anderson, <u>Solar Energy and Shelter Design</u>, p.6.

Chapter II.

1) Developer objectives based on development principles in
     David, Philip, <u>Urban Land Development</u>; and taught by Philip David
     in M.I.T. course 11.232, spring 1975.

Chapter III

1) and 2)   Anderson, Solar Energy and Shelter Design, p. 43.

3)   All climatic information directly or indirectly from
     U.S. National Climatic Atlas.

4)   From class notes in "Solar Architecture and Integrated Utility
         Systems", M.I.T. course 4.46, taught by Sean Wellesley-Miller,
         spring, 1975.

5)   From discussion with Prof. Tunney Lee, 3/31/75.

6)   American Institute of Architects, "Ten Ways to Control Climate", p.27.

7)   Calculations performed in appendix. Information from Anderson,
         Solar Energy and Shelter Design, p.48.

8)   Class notes, "Solar Architecture....",Sean Wellesley-Miller.

9)   Olgyay, Design With Climate, p.54.

10) Chart from Total Environmental Action, Solar Energy Housing Design, p.77.

11) Microclimate information predominantly from
         Geiger, The Climate Near The Ground.

12) Ibid., p. 80.

13) Ibid., p. 352.

14) Ibid., p. 138.

15) Ibid., p. 110.

16) Ibid., p. 149.

Chapter IV

1) Basic information from class notes in "Solar Architecture...",
   Sean Wellesley-Miller.

2), 3), and 4) Anderson, Solar Energy and Shelter Design, p.77.

5) From class notes, Wellesley-Miller.

6), 7), and 8) See appendix.

9) See p. 21.

10) From class notes, Wellesley-Miller.

11), 12), 13), and 14) Anderson, speaking at Energy Utilization Conference,
   Feb. 1975.

15) Brown, Martin S., The Production, Marketing, and Consumption of
   Copper and Aluminum.

16) Anderson, at Energy Utilization Conference, Feb. 1975.

Chapter V

1) and 2) See appendix.

3) Anderson, at Energy Utilization Conference. See appendix.

4) Anderson, Solar Energy and Shelter Design, p.46.

5), 6), 7) See appendix.

8) AIA, "Ten Ways To Control Climate", p. 27.

9) See appendix.

10) Geiger, The Climate Near The Ground, p. 80-82, 352.

11) AIA, "Ten Ways...", p. 27; Geiger, p. 195.

12) Geiger, p. 206.

Chapter V (continued)

13)   Geiger, The Climate Near The Ground, p. 78.

14)   Ibid., p. 28, 138, 398.

15)   Ibid., p. 149.

16)   Ibid., p. 353.

17)   Ibid., p. 110.

18)   See appendix

19)   From insolation chart in appendix, reprinted from Total Environmental
         Action, Solar Energy Housing Design, p. 77.

20)   See appendix.

21)   T.E.A., Solar Energy Housing Design, p. 113.

22)   See appendix.

23)   A.I.A., "Ten Ways To Control Climate", p. 28.

24), 25)   See appendix.

26), 27)   T.E.A., Solar Energy Housing Design, p. 97, 98.

28)   See appendix.

Chapter VI

1)   See appendix.

Chapter VII

1) Phillips, "Solar Power Systems Receive $60 million Development Push",
       p. 1331.

2) FHA fuel consumption index, as reported for Boston Area in
       Total Environmental Action, Solar Energy Housing Design, p. 10.

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Appendix

Appendix arranged by chapter, indexed by the footnote citing the appendix where appropriate.

Chapter I.

Charts on pages 138 and 139 from The Energy Index, p. 43, 44. The charts show the sources of U.S energy consumption, and the pattern of growth to 1973 (publishing date).

US Energy Consumption by Source from 1971 to 2000

	1971	1975	1980	1985	2000
Petroleum (includes natural gas liquids)					
Million bbls	5,523	6,340	7,615	9,140	12,985
Million bbls per day	15.1	17.4	20.9	25.0	35.6
Trillion Btu	30,492	35,090	42,190	50,700	71,380
% of gross energy inputs	44.1	43.8	43.9	43.5	37.2
Natural Gas					
Billion cubic feet	22,050	24,462	26,169	27,537	32,959
Trillion Btu	22,734	25,220	26,980	28,390	33,980
% of gross energy inputs	33.0	31.4	28.1	24.3	17.7
Coal (bituminous, anthracite, lignite)					
Thousand short tons	510,800	565,000	665,000	893,000	1,310,000
Trillion Btu	12,560	13,825	16,140	21,470	31,360
% of gross energy inputs	18.2	17.2	16.8	18.4	16.3
Hydropower					
Billion kwh	266.3	350	420	470	700
Trillion Btu	2,798	3,570	3,990	4,320	5,950
% of gross energy inputs	4.1	4.4	4.2	3.7	3.1
Nuclear power					
Billion kwh	37.9	240	630	1,130	5,470
Trillion Btu	405	2,560	6,720	11,750	49,230
% of gross energy inputs	0.6	3.2	7.0	10.1	25.7
Total Gross Energy Inputs					
Trillion Btu	68,989	80,265	96,020	116,630	191,900

Source: Coal Age, Mid-April 1973, p. 59.

Per Capita Income and Energy Consumption, 1968
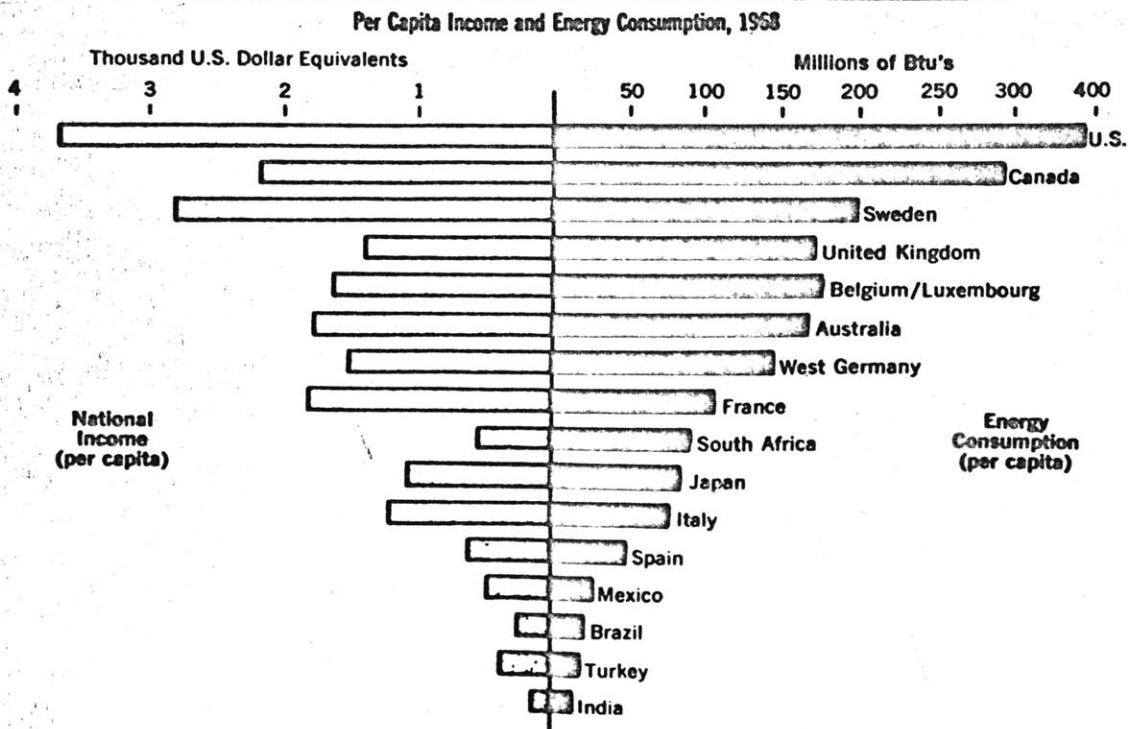
Source: United States Energy — A Summary Review (USDI), 1972, p. 2.
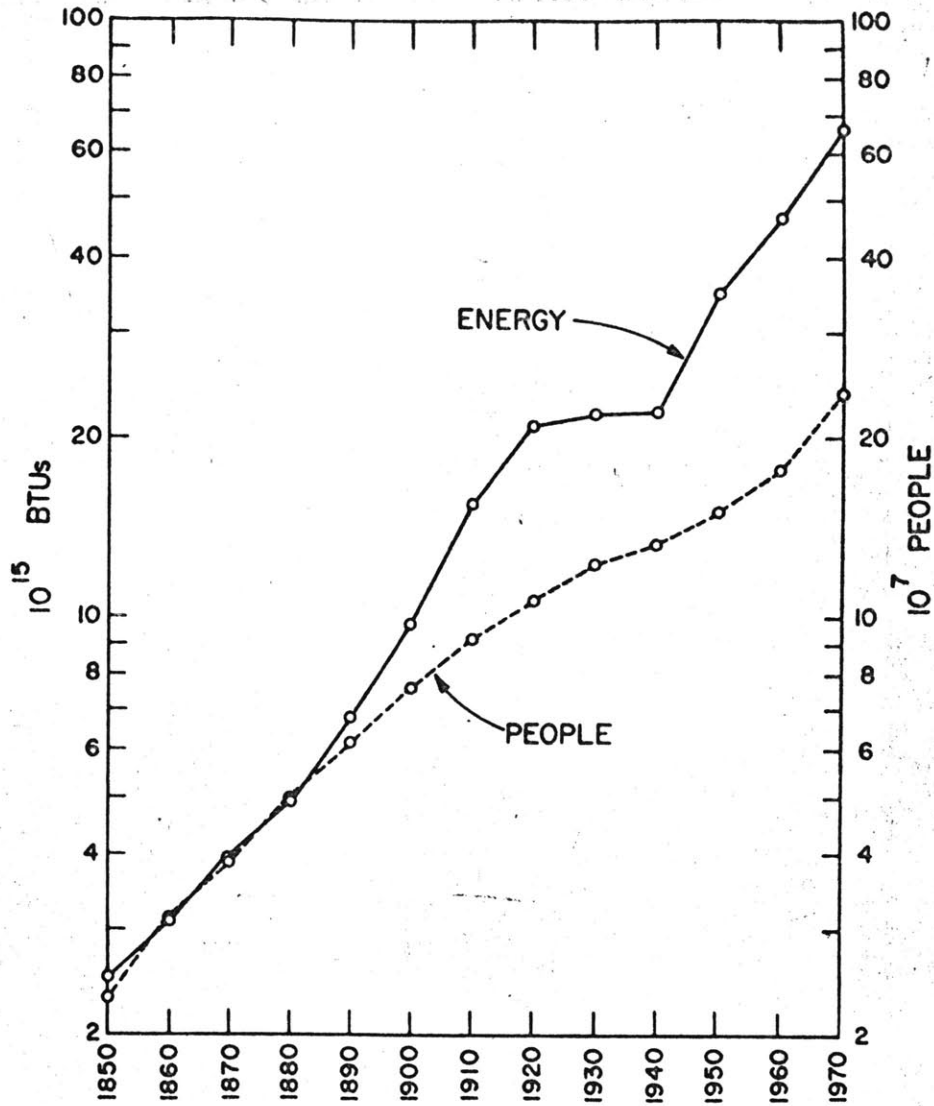
Comparison of energy and population growth, United States, 1850-1960.

Source: Energy and the Environment (ESSO Education Foundation), 1973, p. 2.
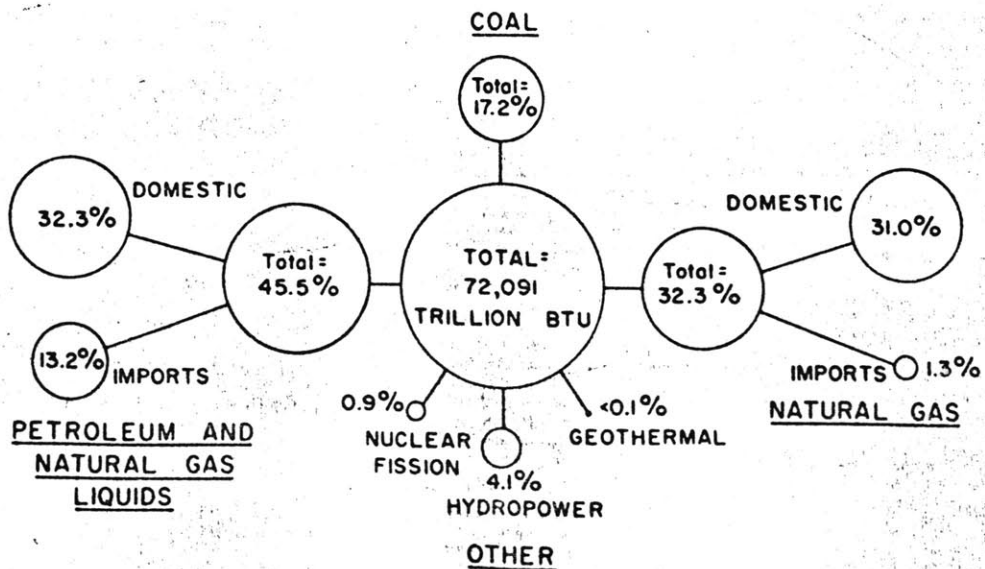
Major sources of the energy consumed in the United States in 1972. Size of circle is proportional to the quantity of energy supplied by each source.

Chapter III.

7)   Calculation of savings from weatherstripping:

From Anderson, Solar Energy and Shelter Design: air infiltration
        chart, p. 48:

        Infiltration per foot of crack per hour, through well-built,
double-hung, wood frame window, with 15 MPH winds   = 39 cu. ft.

                        39 cu. ft.
        times   15 ft. (crack length in average window)
        times   24   hours per day
                14040 cu. ft. per window per day of air infiltration

        times   .018 BTU,per cu. ft., per $^{\circ}$F (thermal capacity of air)
        times   5700   degree days per season (boston climate)
                1440504 BTU,per window, per season   = 14.4 therms.

        From same chart, infiltration per foot of crack per hour, through
same window with weatherstripping   = 24 cu. ft.

        24/39 = .615; therefore weatherstripping lowers infiltration
to 61.5% of non-weatherstripped heat loss, a reduction of 38.5%, and
total heat loss from a weatherstripped window   = 8.85 therms.

$ savings: 14.4 - 8.8 = 5.6 therms.

                        5.6 therms
        times   1 gallon oil saved per therm saved*
        times $.40 per gallon of oil
                   $2.24 saved per year

Savings per foot of crack: 5.6 therms / 15 ft.   = .37 therms.

$ savings per foot for 5 years:

                        .37 therm saved,per season, per foot.
        times   5 years
        times   1 gallon per therm*
        times $.40 per gallon
                   $.74 per ft. weatherstripped is saved.

$ savings if electric heat is used:

```
              .37  therm per ft. per season
     times    5    years
     times    30   KWH per therm
     times   $.03  per KWH
            $1.66  per ft. weatherstripped, is saved.
```

* 1 gallon fuel oil per therm, derived from common burner efficiency
    of 70%, times 1.4 therms per gallon actual chemical potential = .98 therms.

Chapter IV.

6)   Calculation of fuel savings per sq. ft. of collector:

From class notes, Sean Wellesley-Miller, "Solar Architecture...",
    M.I.T. course 4.46, spring 1975. Boston area climatic data.

250 to 275 BTU per sq. ft. per hour of radiation will strike
a collector plate perpendicular to the sun's rays in Boston. It is
reasonable to assume 6 hours of radiation will strike a fixed
collector over the course of a day. "6 hours" considers day
length, and varied angles of incidence to the plate during the
day.

Common cloud coverage in Boston is 50%, meaning that only
half of the available solar radiation will reach the plate, on the
average.

Collector efficiency is placed at 70% for a 140° collector,
30° outside temperature.

The heating season in Boston is 6 months, considering spring
and fall months as partially heated, contributing fractional months
to the heating season.

```
            260    average BTU, per sq. ft., per hour radiation
    times   6      hours per day
    times   365    days per year
          569,400  BTU's would strike a sq. ft. of collector, per
                   year, except for:

    times   .5     for 50% cloud cover
          284,700  BTU's striking collector, per year
```

```
          284,700   BTU's per year
times         .7    for 70% efficient collector system
times         .5    for 6 month (½ year) heating season
           99,645   BTU's per sq. ft. of collector, per heating season
                                                        = .996 therms.
```

7)   Average home heating demand;

      Based on FHA standard maximum heat loss of 19 BTU, per sq. ft.
per degree day, in Boston area.

```
              19
times       5500   degree days
          104,500 BTU per sq. ft.                    = 1.04 therms.
```

8)   Collector size:

      Based on information on page 15.

```
1 cu. ft. rock storage/sq. ft. collector   X   250 sq.  ft.=250 cu.  ft.
.5 cu. ft. water storage/ sq. ft. collector  "   "   "   "  =125 cu.  ft.
1/15 cu. ft. salt   "       "     "     "      "   "   "   "  =16.7 "   "
              (plus a little extra for imperfect phase change)
                                                     =20 cu.  ft.
```

Chapter V.

      Charts on pages 143 and 144 from Total Environmental Action,
Solar Energy Housing Design, p. 72, 77. The charts summarize
Boston- area climatic data, and insolation gains through windows
of each compass orientation.

DESIGN INFORMATION - 1

Region: II   BOSTON AREA   Climate: TEMPERATE   Latitude: 42°-2' N. LAT.
Regions with similar climate characteristics: MID-OHIO REGION - Columbus, Ohio - 40°-0' N. LAT.

CLIMATIC DATA

| MONTH OF YEAR | HEATING DEGREE DAYS | COOLING DEGREE DAYS | % POSS. SUNSHINE | SUNSHINE HOURS | AVERAGE TEMPERATURE | | | WIND | | RELATIVE HUMIDITY |
| | | | | | MO. | DAY | NIGHT | SPEED | FROM | |
	DD/MO	DD/MO	Decimal	HRS/MO	°F	°F	°F	mph	dir.	%
AUG	15		.63	280	72	76	67.5	10	WSW	70
SEP	98		.61	232	65	69	61	11	WSW	78
OCT	316		.58	207	55	59	51.5	12	WSW	70
NOV	603		.48	152	45	48.5	41.5	13	WSW	70
DEC	983		.48	148	33	36.5	30	17	N	70
JAN	1088		.47	148	30	33.5	26.5	17	W	68
FEB	972		.56	168	30	33.5	27.5	14	NW	69
MAR	846		.57	212	38	41.5	34.5	14	NW	65
APR	513		.56	222	48	52	44	14	WSW	67
MAY	208		.59	263	59	63.5	54.5	12	SW	70
JUN	66		.62	283	68	72	63.5	11	SW	70
JUL	7		.64	300	74	78	69.5	10	WSW	70
TOTALS	5715		.57	2615	50	55	48	15	W	69

(COOLING DEGREE DATA IS NOT AVAILABLE. N.A.H.B. INSULATION MANUAL GIVES 400 HRS. ABOVE 80° F ANNUALLY.)

HEATING SEASON

DD indicates Degree Days

Region: II BOSTON AREA Climate: TEMPERATE Latitude: 42°-2' N. LAT.
Regions with similar climate characteristics: MID-OHIO REGION-Columbus, Ohio - 40°-0' N.LAT.

HEAT GAIN THROUGH VERTICAL WINDOWS OF SINGLE PANE GLASS: MULTIPLY BY .86 FOR DOUBLE GLASS

MONTH OF YEAR	SUNNY DAYS			ORIENTATION OF WINDOW															
	A DAYS MO.	B %POSS SUN	AxB DAYS MO.	N S.H.G.F.* BTU/FT²		NE		E		SE		S		SW		W		NW		HORIZ. WINDOW	
				DAY	MO.	DAY	MO	DAY	MO	DAY	MO	DAY	MO	DAY	MO	DAY	MO	DAY	MO	DAY	MO
JAN	31	.47	14.6	109	1590	122	1780	481	7020	1144	16700	1595	23300	1144	16700	481	7020	122	1780	706	10300
FEB	28	.56	15.7	151	2370	210	3300	683	10700	1269	19900	1632	25600	1269	19900	683	10700	210	3300	1092	17100
MAR	31	.57	17.7	209	3700	410	7260	948	16800	1334	23600	1432	25300	1334	23600	948	16800	410	7260	1528	27000
APR	30	.56	16.8	291	4890	642	10800	1112	18700	1228	20600	1037	17400	1228	20600	1112	18700	642	10800	1924	32300
MAY	31	.59	18.3	394	7200	810	14800	1185	21700	1106	20200	776	14200	1106	20200	1185	21700	810	14800	2166	39600
JUN	30	.62	18.6	470	8740	907	16900	1230	22900	1055	19600	687	12800	1055	19600	1230	22900	907	16900	2242	41700
JUL	31	.64	19.8	410	8120	819	16200	1177	23300	1088	21500	762	15100	1088	21500	1177	23300	819	16200	2148	42500
AUG	31	.63	19.5	307	5990	648	12600	1092	21300	1194	23300	1008	19600	1194	23300	1092	21300	648	12600	1890	36900
SEP	30	.61	18.3	217	3970	403	7370	907	16600	1278	23400	1383	25300	1278	23400	907	16600	403	7370	1476	27000
OCT	31	.58	18.0	155	2790	214	3850	663	11900	1223	22000	1570	28300	1223	22000	663	11990	214	3850	1070	19300
NOV	30	.48	14.4	113	1630	124	1790	475	6840	1123	16200	1563	22500	1123	16200	475	6840	124	1790	706	10200
DEC	31	.48	14.9	90	1340	99	1480	396	5900	1057	15700	1501	22400	1057	15700	396	5900	99	1480	564	8400
TOTALS#	365	.57	207.	51930		98130		183660		242700		251800		242700		183660		98130		312300	
COOLING SEASON #				22450		45700		67500		64400		47500		64400		67500		45700		121100	
HEATING SEASON #				29480		52430		116160		178300		204300		178300		116160		52430		191200	

* S.H.G.F. indicates Solar Heat Gain Factor   # Yearly totals are indicated   o : Best orientation for a given month
SOURCES: ASHRAE, Kool Shade, Climatic Atlas of the U.S.   m : Best month for a given orientation

-144-

From Geiger, <u>The Climate Near the Ground</u>, p. 82.

The chart shows some data on surface air temperature differences, by time of day, and date. in degrees Centigrade.
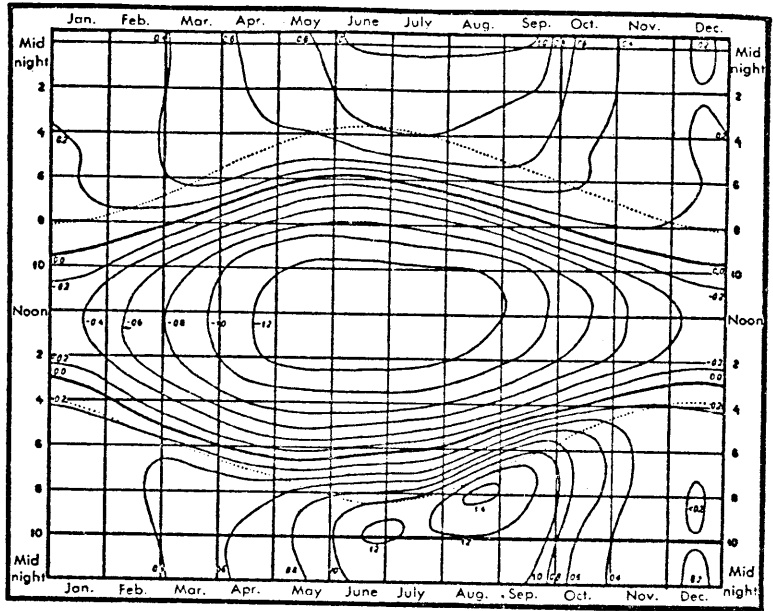

FIG. 38. Difference of the air temperature at 2 and 34 meters height in Potsdam 1893–1904. (After K. Knoch)

Also from Geiger, p. 353. The chart shows data from six clearings, indicating the effect of clearings on surface temperature.
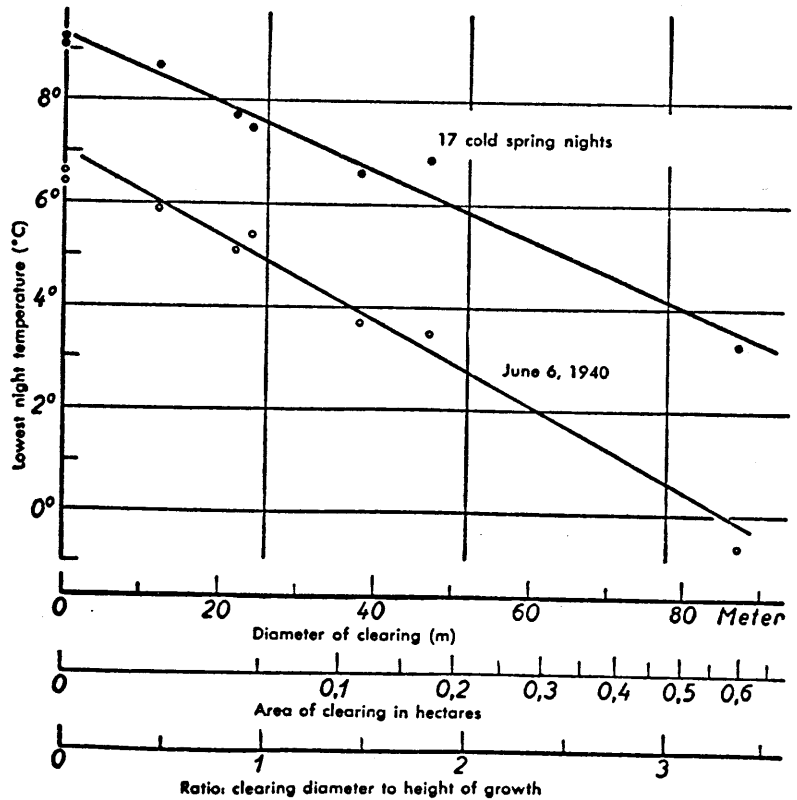
FIG. 164. Increase of frost danger in clearings of increasing size

Chapter V (continued)

1) Heat loss per season of 3' X 5' window:
    (infiltration and radiation loses excluded)

        Boston climate- 5700 degree days per season.

        - Single-glass window; u-value = 1.13

                    1.13 BTU/^{o}f, hr, sq. ft.
        times   24   hours per day
        times   5700 degree days
        times   15   sq. ft. of window
                2,318,760 BTU heat loss per season   = 23.2 therms.

        - Wall; U-value = .07

        Same calculation as above yields   1.4 therms.

    Savings: 21.8 therms.

        See Chapter III for source of U-values, and see chapter III
        appendix for therms-to gallons fuel oil conversion.

2) Heat losses per season of single glass, double glass, triple glass:

    -Single-glass (U=1.13)

                    1.13 BTU/^{o}F, hr., sq.ft.
        times   24   hours per day
        times   5700 degree days
                 157,000 BTU heat loss per sq. ft.   =1.57 therms.

    - Double-glass (U=.55)
            Same calculation as above with U = .55 yields   .76 therms.

    - Triple-glass (U=.36)
            Same calculation as above with U = .36 yields   .49 therms.

    Savings: .82 therms/sq.ft./season with double-glazing rather
                  than single glazing.

    $ savings: with oil heat
                    .82 therms
        times   1 gallon saved/therm saved
        times $.40 per gallon
                    $.33 per year savings, per sq. ft. double-glazed.

    With 10% discount rate, worth $3.30 initial investment.

3) <u>Heat savings with shuttered window:</u>

Shutter assumed 80% as effective as wall. Double-glass window U =.55, wall U=.07. Hypothesized window with shutter U = .17.

Assume shutter closed for 50% of the heat loss during the heating season. Since it is coldest at night, when shutters will be closed, shutters need only be closed 8 to 10 hours per day to be closed for 50% of the potential heat loss.

- Heat loss through a double-glass window(U=.55)   =.76 therms.

- Heat loss with shutter:
    while shutter open(50% of loss, U=.55)   =.38 therms.
    while shutter closed(50% of loss, U=.17)   =.11 therms.
    total   .49 therms.

Savings: .27 therms per sq. ft.
          For 15 sq. ft. window (per season)   = 4.05 therms.

4) <u>Savings from insulation of a basement wall:</u>

Reference: Anderson, <u>Solar Energy and Shelter Design</u>

-Heat loss from above-ground insulated wall (U=.07)   =.095 therms
    (calculation: U X 24 hr./day X 5700 dd)
    (per sq. ft., per season)

From reference: typical 8" concrete basement wall
        loses twice as much,   =.18 therms.

From reference: typical insulated basement wall
        loses half as much   =.045 therms.

Insulation savings: (.19 - .045)   =.146 therms.

8' X 25' wall savings: 200 sq. ft. X .146   =29.2 therms.

5) <u>Heat loss through door exposed to wind</u>:

-3' X 7' doorway   =21 sq. ft.

- infiltration rate, hypothesized to be 5 MPH   =7.33 ft/sec

- door opened for 5 sec., 5 times daily by each family
member, 4 family members. Total infiltration time   =100 sec/day

-Heat loss calculation:

$$
\begin{array}{ll}
& 21 \quad \text{sq. ft. doorway} \\
\text{times} & 7.33 \quad \text{ft/sec infiltration rate} \\
\text{times} & 100 \quad \text{sec/day door open} \\
\text{times} & .018 \quad \text{BTU/cu. ft./}^\circ\text{F} \quad \text{(thermal capacity of air)} \\
\text{times} & 24 \quad \text{hours/day} \\
\text{times} & \underline{5700} \quad \text{degree days} \\
& 15.7 \quad \text{therms lost, per door, per season.}
\end{array}
$$

6) <u>Heat savings of placing wall below ground</u>:

Losses figured in pattern #4.

loss/sq. ft./season of above-grade wall (U=.07)   =.095 therms.

loss/sq. ft./season of below-grade wall   =.045 therms.

Savings: (.09 - .045)   =.05 therms.

7) <u>Heat savings by connecting units along common walls</u>:

- Loss/sq. ft./season of exterior wall   =.095 therms.
                                                (approximately .1 therm)

-Area of shared walls;(2 walls, 2 stories high, 40' long)
        2 X 16' X 40'   =1280 sq. ft .

Savings over exterior walls:
        1280 X .1   = 128 therms.

8) <u>Evaluation notes</u>:

Calculation 3: Shuttered window loses .49 therms/sq. ft.(from 3)

        -Wall loses approx. .09 therms/sq. ft.

        Savings of wall =.4 therms/sq.ft.; X 15 sq. ft.   = 6 therms.

Calculation 4: Area of basement walls
   (20'+35' +20' +35') X 8' high   =880sq. ft.

  Heat savings from insulation(from 4)= 1/6 X 880 =145 therms.
                       (approx.)

Calculation 5: (from 5) 10- MPH wind would yield 5 MPH average
   wind directly entering through doorway, which was the
   rate used in "5". 16 therms, from "5", expanded to 20 to
 account for occasional carelessness in closing door.

Calculation 6: Connecting units:

  Connecting the 4 units on 35' walls produces 3 shared walls,
  each producing a 0 heat-loss wall for the unit to either
  side.

  35' X 16' (2 stories) X 6 walls   = 3360 sq. ft.

  Heat loss of wall (U = .07) , per sq. ft. =.096 therms.

  Total heat loss = 3360 X .096   =320 therms.

  For 4 units: 320 / 4 = 80 therms per unit average.

Calculation 7 and 7a:

  Placing 4 ft. underground on single unit(from 6)
  Area underground = 20 X 4'   .   = 80 sq. ft.
  Plus triangular areas on side walls
     (35' X 2' avg. depth X 2 walls)   = 140 sq. ft.
              Total 220 sq. ft.
Savings: 220 sq. ft. X .05 therm/sq. ft.
                 = 11 therms.

  On connected units, only end units have triangular side wall
  areas underground.
  Area underground = 20' X 4' X 4 units   = 320 sq. ft.
  Plus 2 triangular areas, as above   = 140 sq. ft.
             Total 460 sq. ft.

Savings: 460 sq. ft. X .05 therm/sq.ft. =23 therms.
     Average per unit   approx.= 6 therms.

Calculation 8:
  Maximum wind block effectiveness(from 8) placed at 50%.
  Assuming a semi-effective wind block, irregular winds, etc.,
  effectiveness should still be at least 10%.
     10% X 1100 therms/unit   =110 therms/unit.

18)   Percent heat savings per degree temperature rise:
          (Microclimate savings)

1° average temperature rise should reduce heat load by 1 degree-day
on 180 to 240 days per year in northeast regions. Therefore, causing
a reduction of 180 to 240 degree-days per year:

      For Boston area (5700 degree days)

      Reduction of 180 degree days
           (180/5700)   heat load reduction of   =3.1%

      Reduction of 240 degree days
           (240/5700)   heat load reduction of   =4.2%

20)   Calculations of window heat gains:

      References: insolation chart and climate chart, in appendix,
          from Total Environmental Action, Solar Energy Housing Design, p. 72,77.

      Example calculation:
          -heat gain per sq. ft. through south window in January
                 (from insolation chart)
                 (X .86 for double-glazing)   =.20 therms.

             -heat loss (U=.55) in January
                 (1088 dd in Jan., from climate chart)   =.14 therms.
                        Net heat gain in January   .06 therms.

      Similar process for Dec. - March yields .33 therm savings.

      All other results found similarly from comparison of charts.

22)   Result found by same process as above, only adding net heat gains
      from months of November and April, as well.

24)   Percent heat load reduction from windows:

      Using figure of .6 therm/sq. ft./ season, from pattern #19,
      for fuel savings from south windows;
                .6 X 15 sq. ft. avg. window = 9 therms/season saved.

      Considering the typical unit discussed in"9", with a heat load of
      1100 therms per season; 9/1100 = .81% heat load reduction per window.

25) <u>Storage savings through combining units:</u>

From Chapter IV, "8";

250 cu. ft. of rock storage required per dwelling unit.
Hypothesized container: 5' X 5' X 10'
        -surface area of container   =250 sq. ft.
        -surface area of 4 separate units   =1000 sq. ft.

For 4 combined units, 1000 cu. ft. of rock storage required.
Hypothesized container: 10' X 10' X 10'
        -surface area of container   =600 sq. ft.

Savings: 400 sq. ft., 40% reduction.

28) <u>Economy of scale in storage:</u>
        (from above)

        -separate units (5' X 5' X 10' storage)   =250 sq. ft./unit
        - 4 unit systems(10' X 10' X10' storage)   =150 sq. ft./unit
        -16 unit systems(20' X 20' X 10' storage)   =100 sq. ft./unit
        -32 unit systems(20' X 20' X 20' storage)   =67 sq. ft./unit.

<u>Chapter VI.</u>

1) <u>Calculation of 50% heat load reduction:</u>
        (from calculations in Chapter V)

Savings:

    1)   Minimizing windows (2 less than usual on E,W,N sides)
                                 savings = 2%

    2)   North wall 4' below grade   savings = 1%

    3)   Protected entranceways   savings = 2 to 3%

    4)   Connected units   savings = 8%

    5)   Good wind block   savings = 20% to 30%

    6)   Large south windows(45 sq. ft. more than usual)
                                   savings = 3%

    7)   Good planning for microclimate
        (perhaps 2° to 5° higher average temperature)
                             savings = <u>8% to 20%</u>
                 Total savings   <u>44% to 67%</u>

Possible savings not included:

1) double glazing (additional 6% to 8%)
2) shutters   (additional 2% to 3%)
3) insulating basement walls (additional 15%)
4) building in warm bands(perhaps 2 degrees warmer, additional 8%)
5) conductive soils
6) winter drainage (5) and 6), perhaps adding 1°, additional 3 to 4%)
7) summer cooling savings from overhang
8) financial savings for combined storage.