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U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Office of Building & Community Systems
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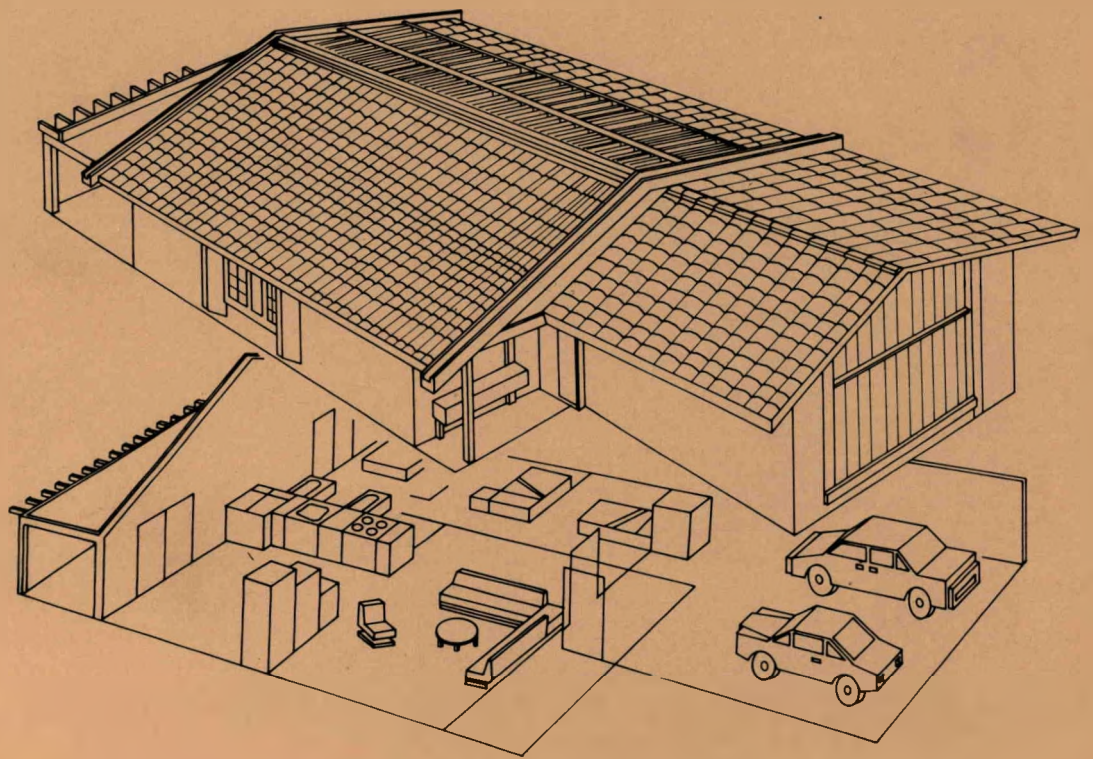

Minimum Energy Dwelling Mini-Workbook

July 1981

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July 1981

Prepared by a Joint Venture of:
Southern California Gas Company and Mission Viejo Company

Bur t Hill Kosar Rittelmann Associates
Washington, D.C. 20001

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introduction

The Minimum Energy Dwelling (MED) began as a research project in 1975. It was conceived by the Southern California Gas Company, as a means to investigate methods of energy conservation and solar techniques in a single family dwelling. This progressive attitude in support of energy conservation and related research is an ongoing policy at the Southern California Gas Company. The Minimum Energy Dwelling Workbook, the original publication of which this is a condensed version, was written by the architectural firm Burt Hill Kosar Rittelmann Associates, as a documentation of the conservation methods explored during the design of the MED house. This "Mini-Workbook" was prepared by the designers for Southern California Gas Company with the purpose of communicating the total scope of residential energy conservation techniques as well as larger considerations of a community and regional level. While the methods discussed have been developed and included in the workbook specifically for use in Southern California, nearly all can be used with suitable modification in other climates of the country.

The success of this project is a result of a combined effort of the Southern California Gas Company and the Mission Viejo Company, a progressive residential developer. The Mission Viejo Company added its experience and skills in construction, marketing and cost control to the project. The two MED homes were constructed in the Mission Viejo community and are actually modifications of a standard home model built by the developer.

Once the working relationship between Mission Viejo and Southern California Gas had been arranged, a contract with the Department of Energy (DOE) was secured. This government agency is dedicted to energy conservation and to the advancement of the solar industry. Funding for the Minimum Energy Dwelling project was provided by Southern California Gas, DOE and Mission Viejo.

The goal set in 1975 was to reduce the energy consumption of a typical Southern California home by 50%. Now, after sophisticated testing and analysis of data collected on an hourly basis over the past two years, we can say that the Minimum Energy Dwelling is a success. The original 50% energy reduction goal was exceeded. This reduction is due to the appropriate use of the design and construction concepts presented in this "Mini Workbook".

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community relationship 1

the costs of sprawl

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attitudes that merge user and system

The basic decision of how the land will be used is the first and often the most important link in the chain of events that determine how much energy the residents of any modern community will require. Fortunately careful study has been given to the way land use effects energy requirements. In April, 1974, the Council of Environmental Quality, HUD, and the Environmental Protectional Agency received a 271-page report, The Costs of Sprawl[1], prepared for them by the Real Estate Research Corporation, an organization respected by the building industry. The study outlines in detail the dollar, energy, and personal costs of different neighborhood and community models that are intended to simulate real-world situations.

the costs of sprawl

The conclusions of this study indicate that planned development is less costly than sprawl in terms of environmental cost, personal cost, and energy consumption. Better planning results in a 4 per cent savings in costs of housing, roads, utilities, and land over sprawl development with the same housing mix. Costs borne by local government are reduced by one-third because a larger portion of land and facilities for open space, roads and utilities is likely to be provided by developers. Environmental advantages are also significant. Through careful planning, fewer roads are likely to fall within areas with poor air movement or on poor soils. Drainage and erosion problems would be minimized as no development need be planned on steep slope sites or flood plains. Planning would provide the preservation of more vacant land and therefore clearing of wooded areas can be controlled, minimizing the effects of development on vegetation and wildlife. Finally, energy consumption because of reduced automobile travel would be from 4 percent to 8 percent less in planned development than in unplanned development.

1. Real Estate Research Corporation, The Costs of Sprawl, U.S. Government Printing Office, Washington, D.C., April, 1974.

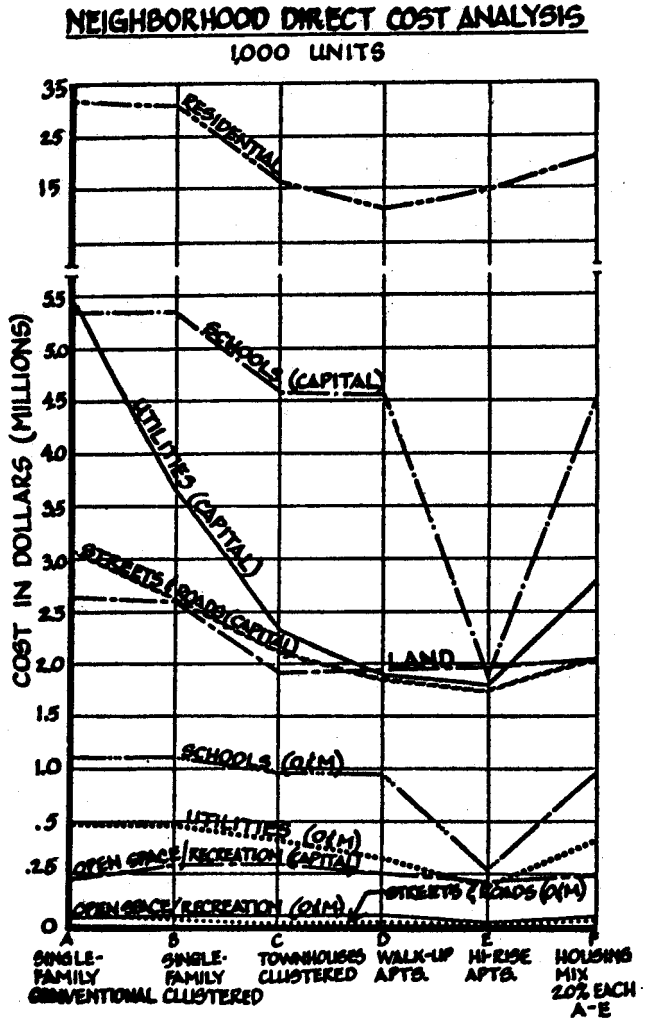


Figure 1

Another very important finding of this study is that for a planned community of 1,000 households, increasing the density will result in an additional reduction in environmental and resource consumption. (Figure 1). Total costs as calculated in the study for a high density planned community are 56% of those for the conventional low density community. Specific areas of savings would be housing, land, roads, utilities, transportation, energy and costs to the environment. According to the study, total cost per dwelling unit (identical inside living area assumed) would range from $48,900 for single family conventional housing at two units per acre to $20,700 for high-rise apartments at ten units per acre. The cost of a high-rise dwelling unit then is 47% of the cost of a conventional single family unit. The cost of housing is least for the walk-up apartment. At 5 units per acre, its cost is only 37% of housing costs at a density of two units per acre. As would be expected, the amount of land required decreases as the density of development increases. Therefore, more land can remain in a natural state for recreational use. Operating and maintenance costs are approximately 11 percent less per year than the low density sprawl community. These savings are largely due to decreased road and utility pipe lengths and reduced gas and electric consumption. Total energy consumption is also decreased by 44%. This is primarily due to the reduced heating and cooling requirements of mass housing types and also reduced automobile transportation in a more compact, better organized community. Environmental costs are similarly reduced. Air pollutants from automobiles are reduced 50%. Those pollutants associated with space heating and other natural gas uses are reduced 40%. Sediment is reduced 30% and total storm water runoff 20%.

There are, however, increases in certain personal costs in the high density community. At higher densities, noise impacts are likely to be more severe and overall satisfaction with the residential environment tends to decrease. Also, psychological problems, such as those associated with a loss of privacy may increase with higher density. However, resolutions to these problems may be achieved through conscientious design. Noise sources can be identified early in the design phase and appropriate solutions can be included in the design. The aesthetic qualities of the built environment should be of extreme importance to insure not only satisfaction but pride in the residential

environment. Attention should be given to the creation of a very pleasant pedestrian environment through landscaping, shading and isolation from automobile traffic. Obviously the design problems presented by the high density planned community are considerable. However, in view of the environmental, economic and natural resource savings that can be realized through land use planning design and higher population densities we cannot afford to continue to develop new residential areas in an unplanned manner.

The research information presented in The Costs of Sprawl is a valuable description of an inefficient system that can be greatly improved. It represents, however, only the first step of a two-fold effort of research and implementation that is necessary to bring about energy conservation. It must be recognized that direct comparisons between the prototype and specific projects should be made with caution -- the prototypes can only suggest the dollar, environmental and personal costs of a real building project.

inovative energy legislation

Implementation of land use planning in new residential communities can be more ideally achieved than in existing communities of a single family detached housing context. However, certain policy changes developed for new housing, may also be used to alter existing community policies. The city of Davis, California is one such community that is setting an example by demanding energy conservation at all levels. The residents of Davis have responded positively to the need for energy conservation by consuming less gas and electricity per capita. The new awareness has also fostered an energy conservation building code for new housing based on the local micro-climate. It is estimated that the new code will save approximately 50 percent of the energy ordinarily needed to heat and cool buildings. It is also recognized that an even greater savings could accrue if certain policy changes in city planning and administration procedures were instituted. These proposed changes have been published in a report[2] drafted by Living Systems. If implemented, the resolutions

2. Living Systems, Planning For Energy Conservation, Draft Report, prepared for the City of Davis, California, June, 1976.

in the report cannot compact the city into a maximum energy conserving system as might be ideally conceived, but would take major steps to improve efficiencies within the given planning context of detached single family housing.

The suggested policy changes are organized into five different areas:

- Land use planning
- Transportation
- Landscaping
- Administration programs
- Home Environment

land use planning

In this category, the planners wish to complement the new building code by adding new ordinances and resolutions which minimize suburban sprawl and foster natural space heating and cooling and solar hot water heating. The new ordinances proposed at Davis deal with these situations in three ways:

- Establishing solar rights for each owner.
- Increasing *setback* flexibility.
- De-regulating fence setback requirements.

If made law, the ordinances could require developers to build all new houses within the boundary of a space envelope that eliminates or minimizes shading of nearby properties. In order to achieve this throughout an entire development, certain houses may have to be built on the extreme edge of their lots. For this reason, building and fence setback requirements have been loosened.

Hand in hand with reducing lot sizes, the recommended code proposes narrower streets in the future (from 34' to 16'). The energy investment in streets for construction and maintenance is significant but only a small part of their total energy costs. The material resource investment, however. is quite high.

An even greater cost can be attributed to the effect of streets on

the micro-climate during the summer. On a sunny 90° day, pavement temperatures can reach 140°. The effect on nearby buildings and cars is an increased conditioning load. It is estimated that by narrowing the streets, air temperatures could drop about 10° and thus improve the pedestrian environment and reduce air conditioning requirements. The energy and resource costs in extra material and maintenance could also be saved.

transportation

Approximately 45 percent of the energy consumed in California is used to move automobiles, airplanes, trains, busses, trucks, motor scooters, and motorcycles. With dwindling oil reserves and increased reliance on foreign supplies, Americans must orient themselves toward means of transportation other than the automobile. Two alternatives are walking and cycling. The city of Davis is encouraging the use of bicycles and pedestrian paths to save energy and decrease pollution. Several more ordinances have been imposed to improve these alternative pathways.

Pedestrian In the future, walking will assume increasing value as an energy-efficient, non-polluting means of transportation. Walking can be encouraged if the pedestrian pathways are convenient, pleasant and secure. Specially designed walkways with easements, signals, benches and landscaping are in the planning stage.

Bike Ways Already Davis has a network of bike ways that handle 25 percent of the total travel in Davis. In order to increase this percentage, further steps should be taken to improve routing, provide more racks and wind breaks, and improve the micro-climate to increase use in the summer. The resolution requires that 25 percent ot the city's total street expenditure be used for developing the bike ways system.

Hazards of Street Trash Placement of trash in the street and gutters pose a threat for bicyclists. The ordinance would prohibit trash placement in the street until the day of trash pickup.

Bicycle Access to Sacramento Since Sacramento is only 12 miles away, many Davis residents would like to bicycle the distance. However, high speed traffic, debris and

expansion joints in the road create significant hazards to bicyclists. The local government resolution asks the state legislature to provide and improve a bicycle route to Sacramento.

landscaping

Landscaping is a significant part of the plan to encourage walking, cycling and natural cooling. Shading and landscaping may be a determining factor in an individual's decision to walk, cycle, or use an air conditioned car. The glaring, hot unshaded, asphalt can turn a street or parking lot into a desert micro-climate that discourages cyclists and pedestrians. Therefore, the planners drafted four resolutions supporting increased tree shading in streets and parking lots. It should be pointed out that the program to shade streets may conflict with sun rights.

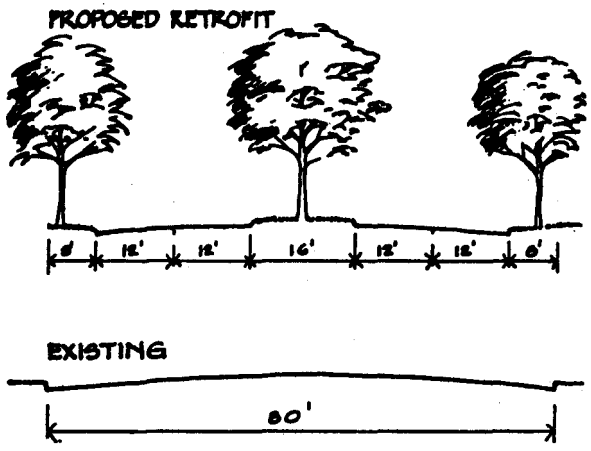


Figure 2

Existing Developments Existing wide, unshaded streets would be improved by planting with decidous trees along their edges and in islands in the middle of the street. (Figure 2). The goal is to achieve 50 percent shading on all existing streets within 50 years.

Parking Lots The thermal effects on people, cars and buildings will be reduced by shading parking lots. A minimum of 50 percent shading on August 21 within 15 years of planting will be the target. Trees used for shading must meet longevity, density, pollution tolerance, and maintenance requirements.

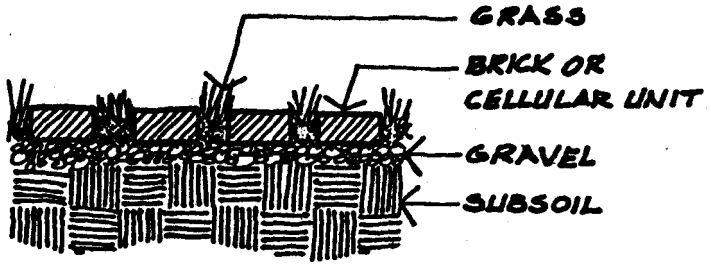


Figure 3

Since parking lots are low speed traffic zones, less friction between road and tread is required, and thus less area of contact. Because of this, it would be appropriate to use alternative paving materials that are not continuous but modular, having joints and grooves between to support growing turf and allow water to flow between. Bricks or turf blocks fit into this category, although gravel and cobbles are also recommended. (Figure 3.)

Landscaping in New Commercial Developments It is suggested that builders of new commercial developments be required to provide extensive landscaping for potential energy benefits rather than installing token shrubbery with

minimum maintenance. The landscaping should cover 10 percent of the site within an expected 15-year growth projection. The method of compliance required submission of a landscaping plan showing the amount of shading on August 21st at 8 a.m., 12 noon, snd 4 p.m. An average of 50 percent shading of all exposed horizontal surfaces (excluding roof) is required within 15 years.

aministration programs

Besides requiring new residential and commercial development to be more energy conscious, the municipal government can rationalize its own use of energy. In Davis 5 percent of the electricity consumed is for pumping water and 1 percent for street lighting. The local government uses additional energy to heat and cool its own buildings and operate its fleet of police and fire vehicles. The new proposals suggest ways to rationalize municipal energy use but go a step further to promote education in the field of energy conservation. Three ordinances are proposed:

Education Technically, the first resolution would require that money saved through energy conservation in the city's operation be used in the promotion of further energy conservation. The money would be used to distribute literature, maintain an energy-conservation library, and fund research and demonstration projects.

Energy Committee The present Environmental Advisory Committee would be renamed the Environmental Advisory and Energy Conservation Committee. It would be charged with the gathering and disbursement of literature on energy-saving techniques.

City Vehicle Fleet This resolution is simply a policy statement on the types of vehicles the city should purchase to minimize energy use and operational costs. If the recommendations are followed, it is estimated that ten to twenty thousand dollars can be saved per year.

home environment

Most of the Neighborhood Planning Program stresses urban design, but this final section emphasizes careful energy use in the home to maximize savings. Homeowners are encouraged to turn off lights, purchase efficient appliances and equipment and avoid using

unneeded household appliances. These conservation measures cannot be legislated, but the researchers do propose three more ordnances which supplement the plea for moderation in the home:

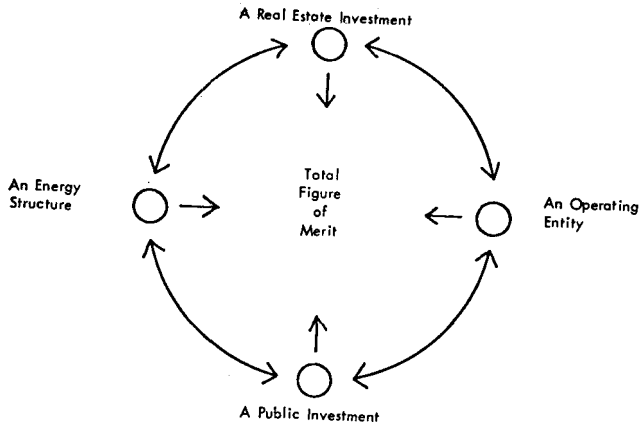
Clothes Drying Most clothes drying is presently accomplished with electric or gas dryers because the use of clothes lines has been restricted by law for aesthetic reasons. The new ordinance would nullify all laws, regulations and covenants which ban clothes lines ahd would require all new multi-unit developments to provide facilities for clothes drying by the sun.

Swimming Pool Heaters The second proposal regards the use of fossil-fuel burning swimming.pool heaters as a blatant waste of energy and would ban their use in all new pools. Since solar heaters for pools have proven their efficiency, are available, and are more economical than other systems, the only heat source allowed for swimming pools would be solar energy.

Work at Home The last resolution encourages the use of the home as a working environment. Since 50 percent of the energy used in Davis is used by the automobile, it makes sense to move parts and paper rather than people. Therefore, it supports the widest possible use of residential areas for working and small businesses.

attitudes that merge user and system

The state government of California is headed on the same track toward energy conservation as Davis. Its proposed methods for attacking the problems are found in Building Value, Energy Design Guidelines for State Buildings by Bender/deMoll, prepared in November 1976 for the Office of the State Architect. It offers many suggestions for improvement at all levels. Most significantly, it illustrates novel means of clearly picturing the way an incremental unit of consumption passes through the system. The authors replace "initial cost" valuation of buildings with four new economic performance measures: Valuation as a real estate investment, as an energy structure, as a total operating entity, and as a public investment. See Figure 4. These are innovative methods of valuation that can force public and private builders to account for the energy costs they generate throughout the



1) As a Real Estate Investment: Looking at the costs of constructing, owning, and operating the building over its lifetime.

2) As an Energy Structure: looking at the physical quantities of energy supplied, as well as the efficiency of using that energy to light, heat, cool, and ventilate the building over its lifetime.

3) As a Total Operating Entity: Looking at the building's effect on the performance and well-being of the people who will occupy the building as well as the costs and energy used in constructing and operating the building itself.

4) As a Public Investment: looking at the contribution and costs to public systems and the "common good."

Figure 4

community. Each method uses a different analysis to find the real costs of what we build. But the four methods can be used to complement and reinforce each other. For instance, when using "evaluation as an operating entity," the cost of a building is viewed as some portion of the total cost of the activities it shelters. In these terms, building and maintenance cost are 2 percent and 6 percent respectively of the total costs. More than 90 percent of all costs go for salaries of the personnel using the building and their supplies and equipment. Obviously, the building costs could be greatly increased without significantly affecting the costs of the entire entity. In fact, a better working environment that improved worker effectiveness by only 6-1/2 percent would be cost-effective even if it quadrupled building cost! Of course this enlarged building budget could be used to improve its value as an "energy structure" or "public investment".

comfort and climate

2

climate and architecture

comfort standards

energy and comfort zones

The sun, source of most of the earth's heat, is a sphere of gases, 93 million miles away. (Figure 1). Despite this incredible distance, the sun has enough energy to heat the earth's enormous ocean and atmospheric masses to the extent that their movement, together with the sun's impact on the earth's land masses and daily rotation, combine to create a constant dynamic state which is responsible on a global scale for seasonal changes and an infinite variety of climatic conditions. These world climatic conditions may be ordered into five basic climatic zones[1]: (Figure 2)

- Hot and Humid
- Hot and Arid
- Temperate
- Cool
- Cold

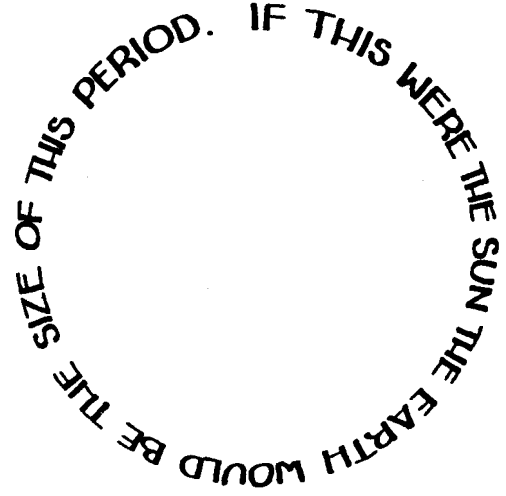


Figure 1

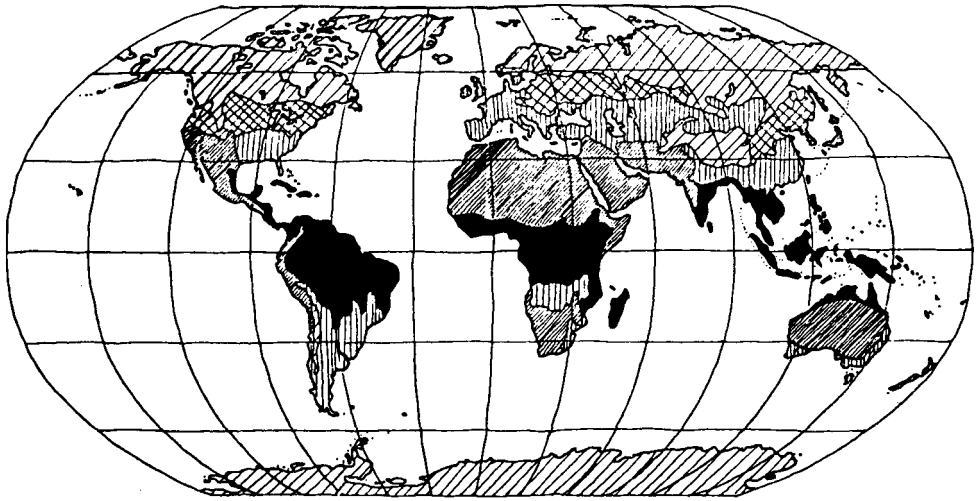


Figure 2

1. Olgyay, Victor, Design With Climate: Bioclimatic Approach To Architectural Regionalism, Princeton University Press, New Jersey, 1963.

Figure 3

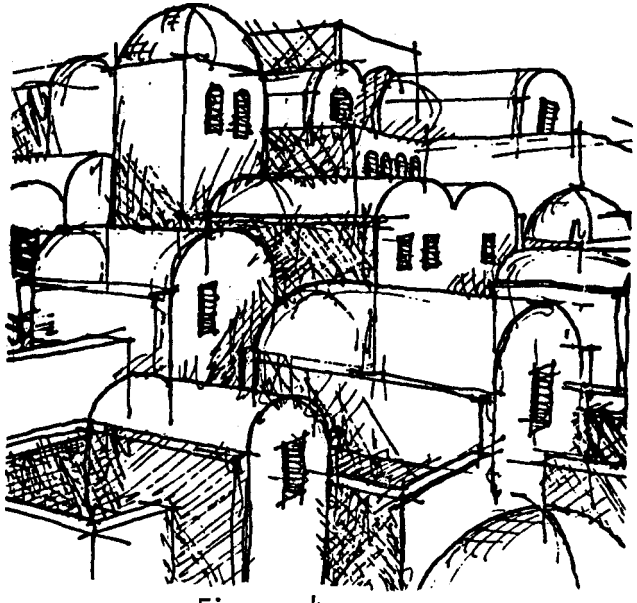


Figure 4

Each of these zones tests man's ingenuity to develop building types that maintain human comfort. In recent times, our society has provided the technical means to build without careful consideration of climate. However, in the past and today in primitive societies around the world there are examples of dwelling types that maintain human comfort without benefit of mechanical equipment. In effect, man has learned to do by "brute force" what was once done by "finesse".

climate and architecture

A study of primitive housing types around the world indicates that dwelling types are more a product of climate than national or cultural boundaries.[2] The dwellings of primitive peoples around the world are simple responses to the natural forces that effect human comfort. Consequently, dwelling types found in tropical regions of Africa, Asia, Australia, Polynesia and South America are very similar in design. (Figure 3). They incorporate a sturdy thatch roof to provide protection from both torrential rains and intense sun. Side walls are minimal or non-existant and floors are elevated to permit maximum air movement for natural cooling. Similarly the hot, arid regions of the world present another special type of dwelling. (Figure 4) The absence of moisture in these regions results in intense sun, extreme temperature ranges and dehydrating winds. These conditions are countered by massive walls to provide insulation and *thermal lag*. Close grouping of dwelling units is frequently employed to minimize exposure of walls and narrow streets to direct impact of the sun. Dwellings of the temperate climates incorporated devices which compensated for the moderate seasonal changes and daily weather variations. In the lodges of the eastern woodsmen, these were found in the form of operable flaps used as doors and walls which could be opened or closed at will. The rich diversity of building materials made a wide variety of shapes possible, with the structures being sited carefully in order to maximize the use of sunlight for utilitarian purposes. Similarly, man has adapted his dwelling types to the cool snow belt regions by joining or grouping dwellings together to conserve heat. By minimizing exposed surfaces the

2. Dolltus, Jean, les Aspects de L'Architecture Populaire dan le Monde, Albert Norance, Paris 1954.

chilling impact of northern winds and cold air masses was reduced. Mutual benefit was derived by locating the firepits along a center aisle creating a concentrated heat source. Finally man has seen fit to inhabit the polar regions of the earth -- perhaps the most hostile environment this planet has to offer. It is ironic that under conditions of extreme stress and complete hostility a solution as simple and elegant as the igloo presents itself as the answer to man's survival in the elements. It is notable that the key to that survival is due primarily to the use of ice and snow which are themselves unusual and uncompromising and yet are, in fact, the only materials found in any readily available quantity in the Artic. The igloo with its dome shape and low profile serves to deflect the Artic wind. Entrances are oriented away from prevailing winds and are often buried and sloped up into the igloo to retain heat and protect from drafts. A thin film of ice forms on the inside of the dome from body heat and heat from the cooking lamp providing a critical defense against infiltration of Artic winds.

Even with these brief descriptions of the earth's basic climatic zones and man's adaptation to each, it is apparent that the role of climate has in the past, been a strong influence on society and dwellings. Because no mechanical means of environmental conditioning was available, man was forced to develop dwelling types for specific climates using imaginative building techniques combined with proper wind and solar orientation, to minimize the thermal effects of a given climate. This approach, known as "passive" is what man relied on for thermal comfort until the dawning of the industrial age. In contrast, modern man has come to depend almost entirely on mechanical heating and cooling for human comfort. Our ability to perceive the environmental effects of building has been dampened by our dependence on mechanical devices. It is possible today to disregard such given conditions as prevailing wind, sun angles, as well as the nature of the materials we build with and instead substitute larger and more complex mechanical equipment.

comfort standards

In 1961, studies by R. G. Nevins[3] revealed a gradual increase in

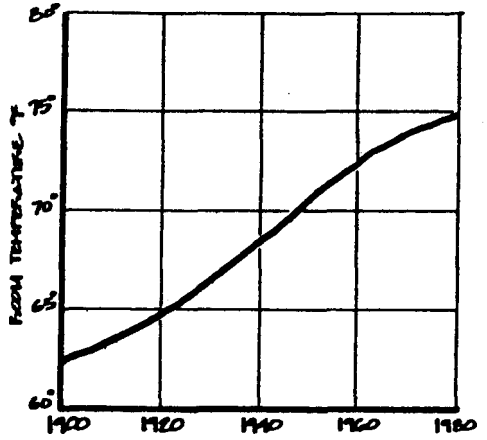


Figure 5

3. Nevins, R.G., Psychrometrics and Modern Comfort, (Presented at the joint ASHRAE-ASMC meeting, Nov. 28-29, 1961).

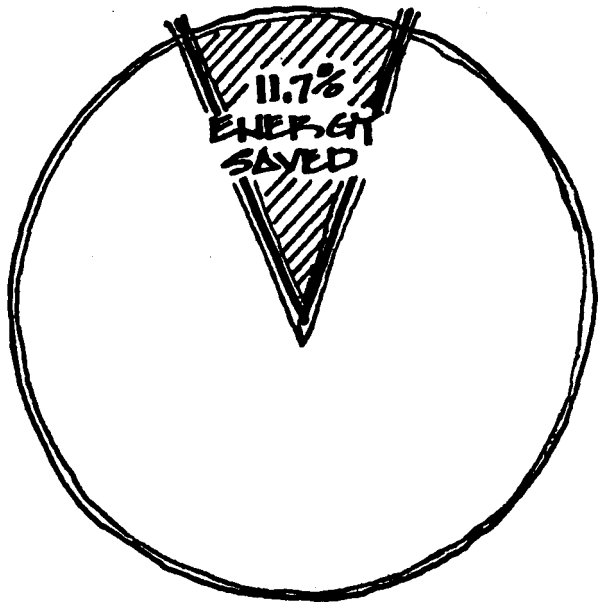


Figure 6

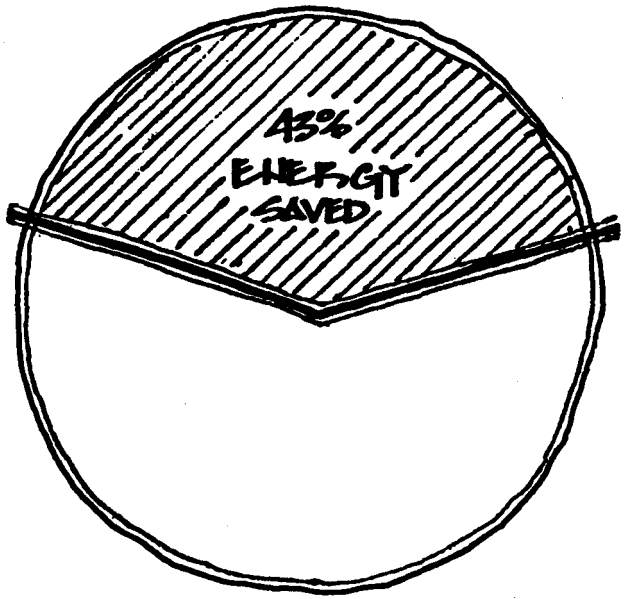


Figure 7

temperature and thermal comfort criteria from 1900 when 65°F to 70°F was accepted, to 1960 when the design limits were between 75° F and 78°F. (Figure 5) This was due in part to trends resulting in lightweight clothing as well as changing living patterns, diets and comfort expectations of a society which had evolved into dependency on mechanically controlled environments. In the same period a marked increase in energy consumption per capita has also taken place.

energy and comfort zones

The concept of "*comfort zone*" implies a range of thermal conditions under which man can survive comfortably. The limits of comfort are a matter of personal tolerance. Being less demanding about how warm or cool one feels results in a natural extension of the comfort zone. The conditions which determine a satisfactory comfort zone vary considerably for different individuals.

A computer analysis of the minimum energy dwelling at Mission Viejo proved the logical assumption that maintaining a specific temperature of 75° was the most energy intensive task. Allowing the conditioning equipment no leeway resulted in a maximum cooling load of 160,000 BTU's/Day in July and a maximum heating load of 120,000 BTU's/Day in December. This is a result of the equipment trying to react instantly to varying internal loads and natural climatic phenomenon such as infiltration, solar gain, dry bulb and wet bulb temperature, etc., all of which vary constantly on a day and night basis. Extending the upper and lower limits to 77° F and 72.5°F respectively resulted in an average savings of 11.7 percent when compared to the point comfort zone at 75°F. (Figure 6) A temperature fluctuation of 4-1/2°F would not be easily discernable to the individual but would result in enough idle time in the mechanical equipment operation to realize the 11.7 percent energy reduction.

A further enlargement of the comfort zone to 68°F minimum and 80°F maximum would not be definitely noticeable to most individuals but not necessarily uncomfortable. Allowing a 12°F range in the home may be tolerated quite well by dressing to suit conditions. In the winter when the inside temperature would most likely tend to drop to 68°F, the resident may opt to put on more clothes. In the summer, the tendency for inside temperatures to

rise to the 80°F upper limit may be offset by wearing lighter clothing. Allowing a 12°F range between 68° and 80°F would produce a 46 percent energy savings compared to that consumed to maintain 75°F. (Figure 7) Varying the upper and lower temperature limits through the day is another approach to energy conservation. By allowing warmer temperatures during the day and cooler temperatures at night, the mechanical system "rolls with the punch of the thermal heating and cooling loads.

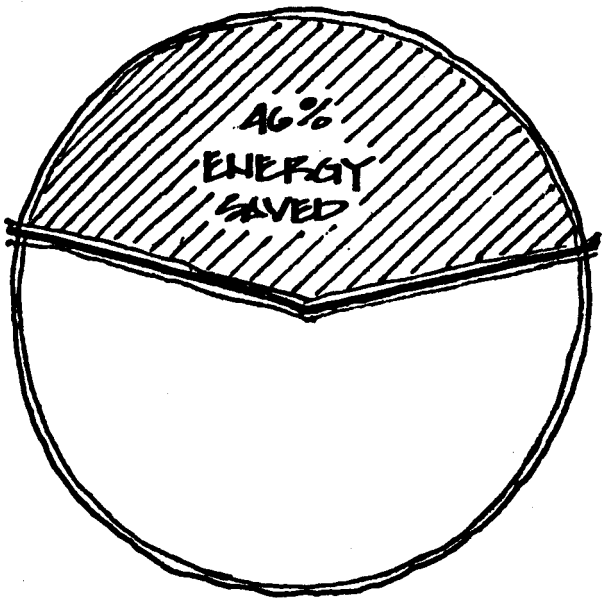


Figure 8

As stated earlier, warmer indoor temperatures may be accommodated simply by wearing appropriate clothing. In instances where entire families are away for the day, the residence simply heats up and the equipment is excused from conditioning an uninhabited space. In addition, by allowing indoor air temperatures closer to these outside, cooler outdoor air may be used to assist on conditioning indoor spaces a greater portion of the time. The more similar indoor conditioning demands are to outdoor conditions, the longer outdoor air can be used for cooling. (Figure 8) An average savings of 43% of the total energy required to maintain a point comfort zone at 75°F can be realized by using daytime set up and nighttime set back. As illustrated in Figure 9 , the requirement for energy varies throughout the year. The lines shown are representative of the Southern California comfort zone. The theory of moving comfort zones and adjusting thermostat settings may be extended to include variations on a seasonal as well as a daily basis. Lower thermostat settings in winter and higher settings in summer will have a similar result, reducing energy consumption considerably.

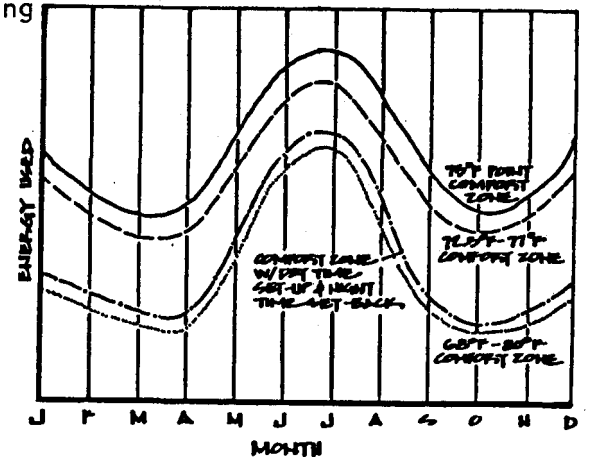


Figure 9

Man decides where he lives and the conditions under which he exists. When he chooses to create and inhabit a particular building, he submits himself to the thermal conditions of that climate as altered by the building skin. If the stresses are minimal, intelligent design will enable the majority of comfort conditioning to be accomplished by passive means. If the stresses are severe and passive systems cannot overcome the loads, mechanical conditioning is required. Under such conditions, man determines at what rate energy will be consumed to provide that which the building skin cannot.

residential energy use

3

national energy use

MED energy use

residential energy use

The American public will buy and use an appliance seldom considering the vast energy production industry required to support it. Each morning when we arise to dress and bathe, we are more likely to relate our electric toothbrushes to clean teeth than to the lumps of coal that fire steam engines at the power station.

In the past, splitting a cord of firewood had a directness to it, but flipping switches to "on" and turning keys to "start" are activities of a different sort -- we enjoy instant results and are blind to their origins. In some instances, we are totally removed and unaware of energy being used in our behalf. The furnace in a basement which activates itself is a good example. Our consciousness about energy consumption, though, must go beyond pondering lumps of coal early in the morning. There is a need to establish a clear view of the relationships between all forms of residential energy uses. This is the first step toward the determination of the best opportunities for energy conservation.

national energy use

The use of home appliances or the family car implies the consumption of a primary fuel such as oil, gas or coal. To compare the consumption of all appliances uniformly, the fuel quantities should be converted to a common thermal unit. An informative booklet, Patterns of Energy Cosumption in the United States[1], does just that. The book divides the total United States energy consumption into four sectors:

- Residential
- Commercial
- Industrial
- Transportation

Within these sectors, detailed estimates of energy usage for

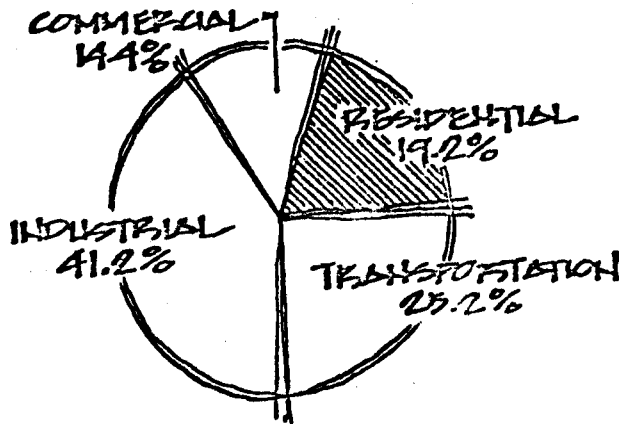


Figure 1

1. Patterns of Energy Consumption in the United States, Office of Science and Technology, Executive Office of the President, Washington, D.C., January, 1972.

different end uses, applications were made. The primary sources of information were the year by year energy consumption data developed by the United States Bureau of Mines and contact with personnel of major consuming industries.

(Figure 1) In 1968 the residential sector accounted for 19.2 percent of the total energy consumption in the United States or 11,616 trillion BTU. The residential sector is divided into the most common end uses and listed below and shown graphically in Figure 2. Their relative importance is shown as percentages of the total residential consumption in the United States.

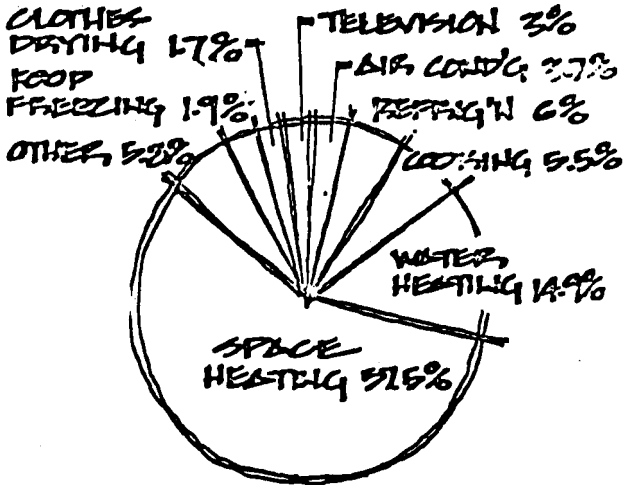


Figure 2

Space Heating	57.3%
Water Heating	14.9%
Cooking	5.5%
Refrigeration	6.0%
Air Conditioning	3.7%
Television	3.0%
Clothes Dryer	1.7%
Food Freezing	1.9%
Other	5.8%
	100.0%

Four applications -- space heating, water heating, cooking and refrigeration -- account for more than 80 percent of the energy used in households. This immediately suggests that these are the areas where the greatest impact on energy consumption can be made if conservation measures are implemented.

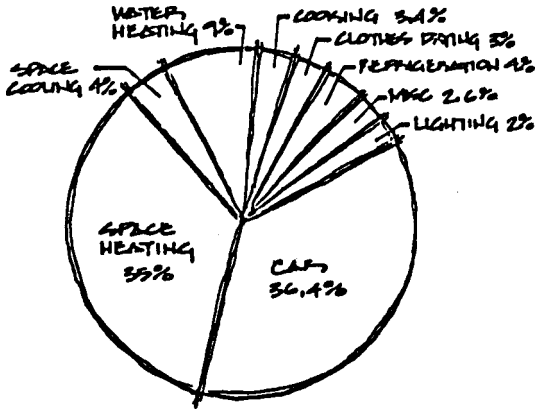


Figure 3

A more comprehensive picture of residential energy usage is illustrated in Figure 3, as it also includes the automobile. In this profile, the average of 848 gallons of gasoline consumption per year is assumed for the typical one car family. Even though two or more cars are standard for nearly half the country -- in this profile showing only one car, the largest portion of energy usage is related to the automobile, closely followed by space heating. Further below in importance is water heating, refrigeration and cooking. Because of their small contribution to energy consumption, the color television, dishwasher and washing machine have been included in the miscellaneous category. In terms of absolute energy consumed, this figure represents a total of 308,000,000 BTU per year per average household. The percentage generated for each category in the energy profile is the result of an averaging of

many different types and climate areas of the country. Realistically, the individual components can vary greatly, for instance, the space heating requirements of Minnesota are much different than those for California.

MED energy use

In the design of the MED house for the Mission Viejo development in Southern California, the designers felt it was necessary to establish an energy profile representative of the typical household in that area. The profile that was developed (Figure 4) differs considerably from the national average. The differences are primarily in the shift of emphasis due to the mild climate from space heating to space cooling and increased gasoline consumption. Due to the location of Mission Viejo, it is necessary to drive to both work and shopping areas. It was also found that 58 percent of the wives in Mission Viejo are employed and therefore a second car is practically mandatory. Because of this, the typical Mission Viejo household is likely to consume 1300 gallons of gasoline per year, compared with the national average of 848 gallons per year. In spite of these differences, the total yearly BTU consumption is 304 million BTU per Mission Viejo household or within 1.3% of the national average.

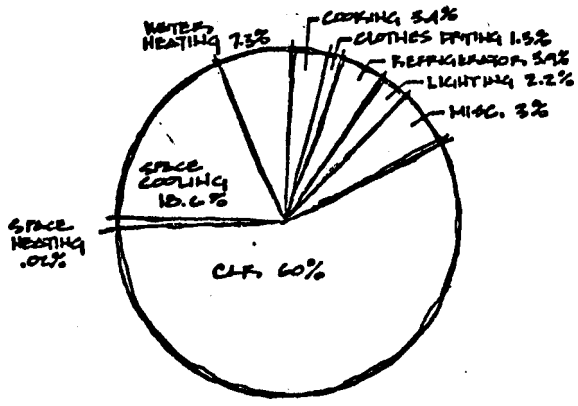


Figure 4

As a result of this study, the emphasis of the MED design effort was placed on space cooling and domestic hot water heating. These two uses are 64% of all energy consumed in a Mission Viejo household, and are therefore the areas where the greatest savings can be realized. The other areas are appliance related and were handled simply through the selection of the most energy and water conserving appliances available. The small amount of heating required was easily accommodated with heat from the solar system. The energy conserving methods presented in the following discussions are those that were explored during the design process of the MED houses.

The success of the Minimum Energy Dwelling has now been measured. A complex instrumentation system was installed to measure the effectiveness of each energy conservation method. Indications are that the goal of 50% reduction of household energy usage was achieved. Virtually 100% of the domestic hot water need was provided by the solar system. The need for mechanical cooling was nearly eliminated through the use of

shading devices, reduced infiltration, insulation, mass, reduced internal heat and the economizer cycle. In fact, cooling need has been reduced to the point that one begins to question the value of mechanical cooling in certain areas of Southern California. A valuable continuation of the MED studies would be to determine if mechanical cooling could be eliminated through the further development of techniques such as those presented in the discussion of Mass in this workbook.

insulation

4

thermal transmission

types of insulation

the effectiveness of insulation

problem areas

insulation

Insulation is the basic component in the building's shell necessary to protect an enclosed space from the fluctuation of temperature during daily and yearly cycles. If properly designed and installed, the insulation system can greatly contribute to a reduction in energy consumption. Making the best decisions about insulation requires a basic knowledge of its thermal behavior in conjunction with an extended view of the entire energy system operating within a building.

Thermal insulations are those materials which retard the flow of heat by three modes of heat transfer:

- *Radiation*
- *Convection*
- *Conduction*

The purposes of insulation then are to reflect electromagnetic waves of radiation, and to trap air or other gas to prevent its displacement by moving air which will convect heat away. Achieving and maintaining effective air entrapment in a material will provide a high resistance to heat transfer by conduction.

thermal transmission

The most important thermal control characteristic of any material is its transmission rate or its ability to resist heat flow across its thickness. When heat impacts one side of a material, its effect on the other side is dampened by the insulative value of the material or its "U" value. The overall heat transfer coefficient is expressed in BTU/(Hr.)(Sq.ft.)(^{o}F). The absolute amount of heat that would pass through a wall depends on the temperature difference across the wall. This temperature difference can be visualized as a "pressure" forcing heat to flow to the cold side. As the temperature difference increases, the pressure increases and heat excapes more rapidly to the cold side. The heat passing through the wall is measured in *British Thermal Units* (BTU). One BTU is equal to the amount of heat it takes to raise one pound of water through one degree Farenheit temperature rise. This is approximately the same amount of heat given off by the complete burning of one match.

Because heat is measured in these units, the measure of the temp-

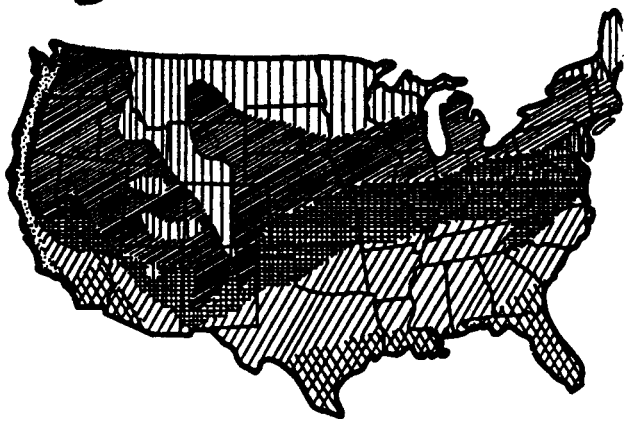


Figure 1

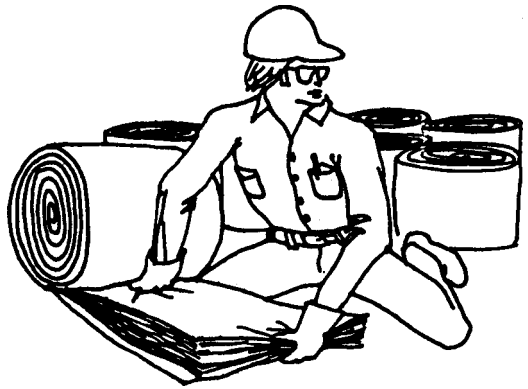


Figure 2

erature differences (ΔT) in degrees Fahrenheit can be used as that factor which when multiplied by the "U" value and square foot area yields the absolute heat flow through a wall: $(\Delta T)(U)(Sq.ft.)$ = Heat Loss. Besides the "U" value, two other variations -- k and C are used to indicate heat transfer and also a third -- "R" which is the reciprocal of any of the other values ($\frac{1}{U}$, $\frac{1}{k}$, or $\frac{1}{C}$). The value for conductance "k" rates the passage of heat through 1" of material, and "C" being the rate for the total thickness of the given material and is found by $C = k/x$ where x is the thickness. To establish the total resistance (R) of a wall assembly consisting of two or more materials, the conductance of each material is first converted to "R" values $\frac{1}{C}$ which can then be added together. Total "U" value is then equal to $\frac{1}{R}$.

Recent studies have indicated that the most effective amount of insulation is not necessarily the most that can possibly be installed in a given structure. In fact, the popular notion of "the more the better" does not apply. For instance in certain climates at certain times, some buildings should be lightly insulated in order to leak internal heat to the exterior. Recommended insulation thicknesses for the various regions of the country are illustrated in Figure 1. Using this as a guide, integration of insulation with structure can be made to provide the optimum insulation "R" value.

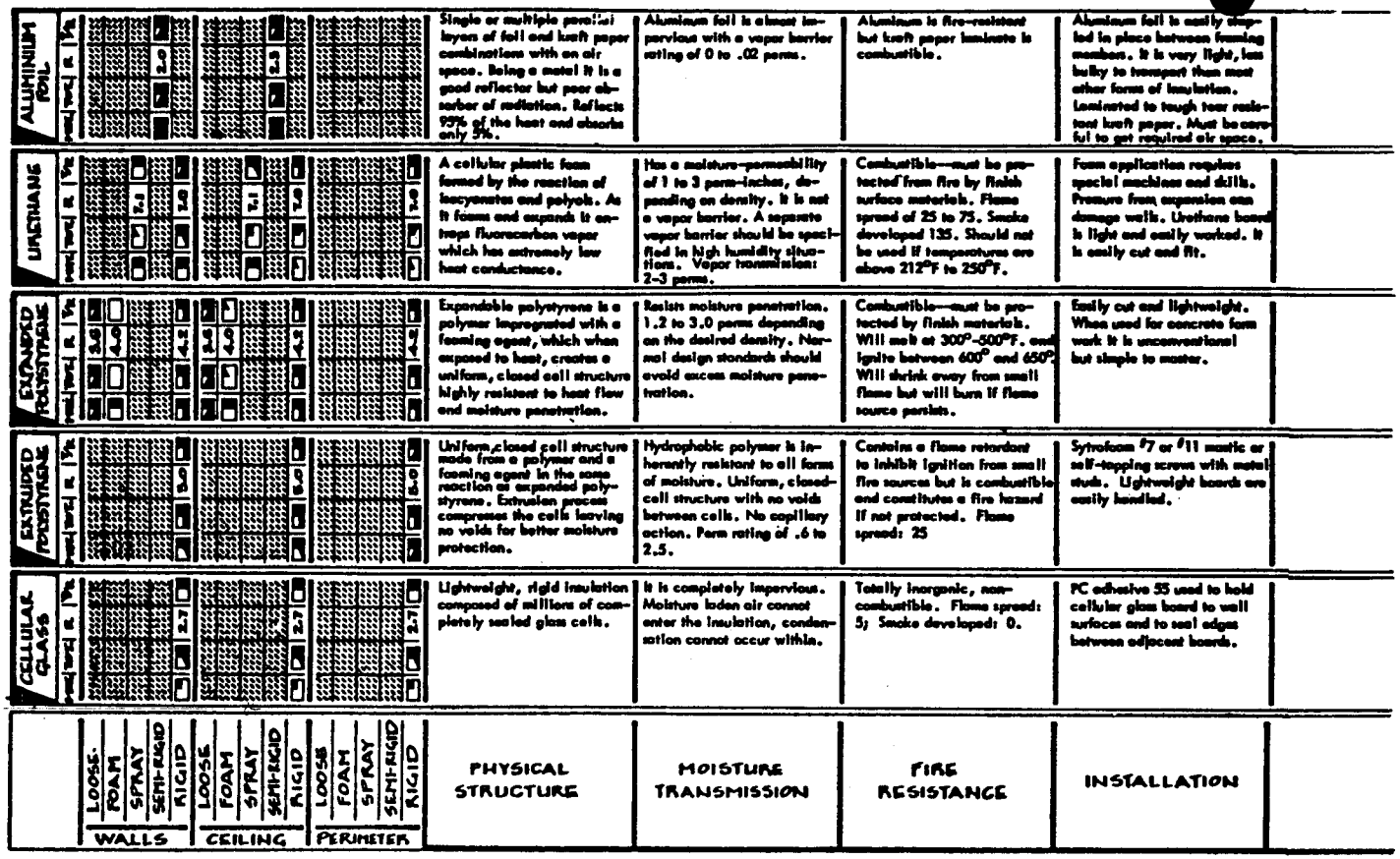
types of insulation

All insulation is rated according to its "U" value but is more conveniently classified according to its physical structure and form. It is separated in divisions of flexible and semi-rigid, rigid, pellet or loose fill, foamed, foil and other special types of insulation. These various types of insulation have been developed to conveniently coordinate with different types of construction, or to facilitate quick, easy and thorough application. The following is a description of the various types of insulation. Also, included in the discussion is an insulation "matrix" to provide a quick comparison of the various insulation types.

flexible and semi rigid insulation

These types of insulation are specifically for use in wood frame construction, are characterized by their extremely low density, but high compressibility. They are usually made from glass or mineral wool or felt and wood fiber. The fibers have individual

structural integrity, resist breakage, and retain their flexure strength in order to form voids. The vast majority of the volume that the insulation displaces are trapped between the individual fibers. The insulation material is usually covered or faced on one or both sides by paper, reflective material, vapor barriers or a finished covering. (Figure 2) This combination of materials forms blankets or batts available in sheets or rolls whose widths are coordinated with conventional framing construction and have thicknesses which vary between 2" and 12". Raw, unattached unformed glass or mineral wool, in a "clumpy" consistency, can be "poured" to any thickness, and is used in walls and attics. To be effective these insulations should completely fill the void in the walls where they are disposed. Fiberglass batts should also fill the void in the space between stud framing to prevent convective air currents from circulating around batts to transfer heat.



KEY	
MAT.	The relative cost of an inch of each insulation type.[1]
TOT.	The total cost of one inch of the insulation and the cost of the labor to have it installed.
R	The insulation's R-Value; the resistance of one inch of the insulation to the flow of heat or energy. (Btu)/(Hr)(°F.)(Sq.Ft.)
T/R	A ratio comparing the total cost of the installed insulation divided by the R-Value. Although a particular type of insulation may be more expensive, it may have an excellent R-Value, thereby requiring less material than another less resistive material. The resultant ratio could show that the insulation is a comparable value to a cheaper material with a low R-Value that would require a greater thickness to get an equal total R-Value.

[1] Building Construction Cost Data 1977, 35th Annual Edition, Robert Snow, Means Company, Inc., Massachusetts, 1976

rigid insulation

The members in this category are stiff in their consistency and manufactured as boards, blocks, or sheets of standard dimensions to

	RANGE OF USE	DURABILITY	SUBSTRATE	AVAILABLE SIZES	BRAND NAMES	
	In wood frame construction between ceiling and wall framing; it also can be suspended between metal joists in pre-fabricated industrial type buildings.	The foil is laminated to tough, tear-resistant kraft paper. Heavy liner board dividers and stapling flanges assure parallel air spaces. Loss of air space diminishes value of insulation.	Must have drywall or lath and plaster type finish. It is not a finish material in its own right.	25" wide for rafters, joists or studs on 24" centers; 33" wide for 16" centers; and 36" wide for 16" centers where insulation is to be recessed.	Infra-Foil Metallation	ALUMINUM FOIL
	Tapered roofing insulation boards, lightweight sandwich wall panels, sprayed in frame or masonry cavity walls. Used in combination with fireproof material as composite slabs. Under concrete floor slabs.	Must be protected from direct sunlight to prevent degradation of the surface of the material. Should not be used at temperatures above 212°F. to 250°F.	Gyp. bd., asbestos cement or plaster to give fire protection. Can be sprayed on conc. & conc. blk., wood, mtl. & ptd. surfaces. If sprayed on outdoor storage tanks coat w/protective layer. Top w/fiber glass mesh and stucco for exterior finish.	Foam expands to fit any shape or size space. Tapered roofing sections usually of 2'x4' or 3'x4' boards tapered 1/16", 1/8", or 1/4". Can also be a pre-expanded froth.	Rubicon, Unirayal Upjohn North Carolina Foam Industries Owens-Corning Apache Celotex Chemetics Systems Inc.	URETHANE
	Walls, in built-up roofs, in masonry cavity walls as board or loose fill beads. In wood frame wall construction and under floor decking.	Must be protected from direct sunlight which degrades the materials surface. Will resist rot and vermin but should be protected from fire. Should not be used above a temperature of 300°F.	Good surface for plaster base. Drywall for interior finish. Stucco with self-furring lath and fiber glass mesh for exterior finish.	Boards in lengths of 4', 6', & 8' widths of 12", 16", 24" and 48", thickness of 1/2" to 19" in 1/8" increments. Billets of 55 lbs. Tapered roof insulation.	Styropor Baylite Benoit Foam-Form	EXPANDED POLYSTYRENE
	In masonry cavity walls, foundation perimeters, tongue and groove sheathing for walls and roof.	Resistant to rot and vermin, surface cell structure will deteriorate if not protected from prolonged exposure to the sun. Fire protection should also guard against impact. Should not be used if temp. exceeds 300°F.	Drywall is usually used for interior finish. Stucco with self-furring lath or fiber glass mesh for exterior finish.	8" boards, 24" wide; 3/4", 1", and 2" thick. Tongue and groove sheathing 8' long, 16" or 24" wide 3/4", 1", and 2" thick. Roofing boards 24"x48", 1", 1-1/2", 2" and 3" thick.	Styrofoam TG (Dow) Zonolite Thermo-Stud	EXTRUDED POLYSTYRENE
	Can be used as construction material as part of slabs, in masonry cavity walls, and in built-up roof construction as tapered boards.	Is dimensionally stable. Will not swell, warp, shrink, or otherwise distort. Will not rot, resists vermin and termites. Does not lose insulative value with time.	Will accept finishes by gluing. Has great strength and rigidity. The high compressive strength makes it an ideal construction material, while being lightweight (8.5 lbs. per cu. ft.).	24"x48" boards in 1-1/2" to 4" thickness. 12"x18" and 18"x24" flat blocks in thicknesses from 1-1/2" to 4". Tapered roof blocks 18"x24" with tapers of 1/16", 1/8", or 1/4".	Foamglass (Pittsburgh Corning)	CELLULAR GLASS

The graphic representation used for the relative material cost, total cost, and cost to R-Value ratio, is a rectangle with portions darkened in. The larger the dark portion, the better. Lower costs are darker, a ratio showing a better comparative cost value is darker.

Portions of the chart which do not have values are either insulation types which do not exist or do not have readily available information to enable a fair comparison.

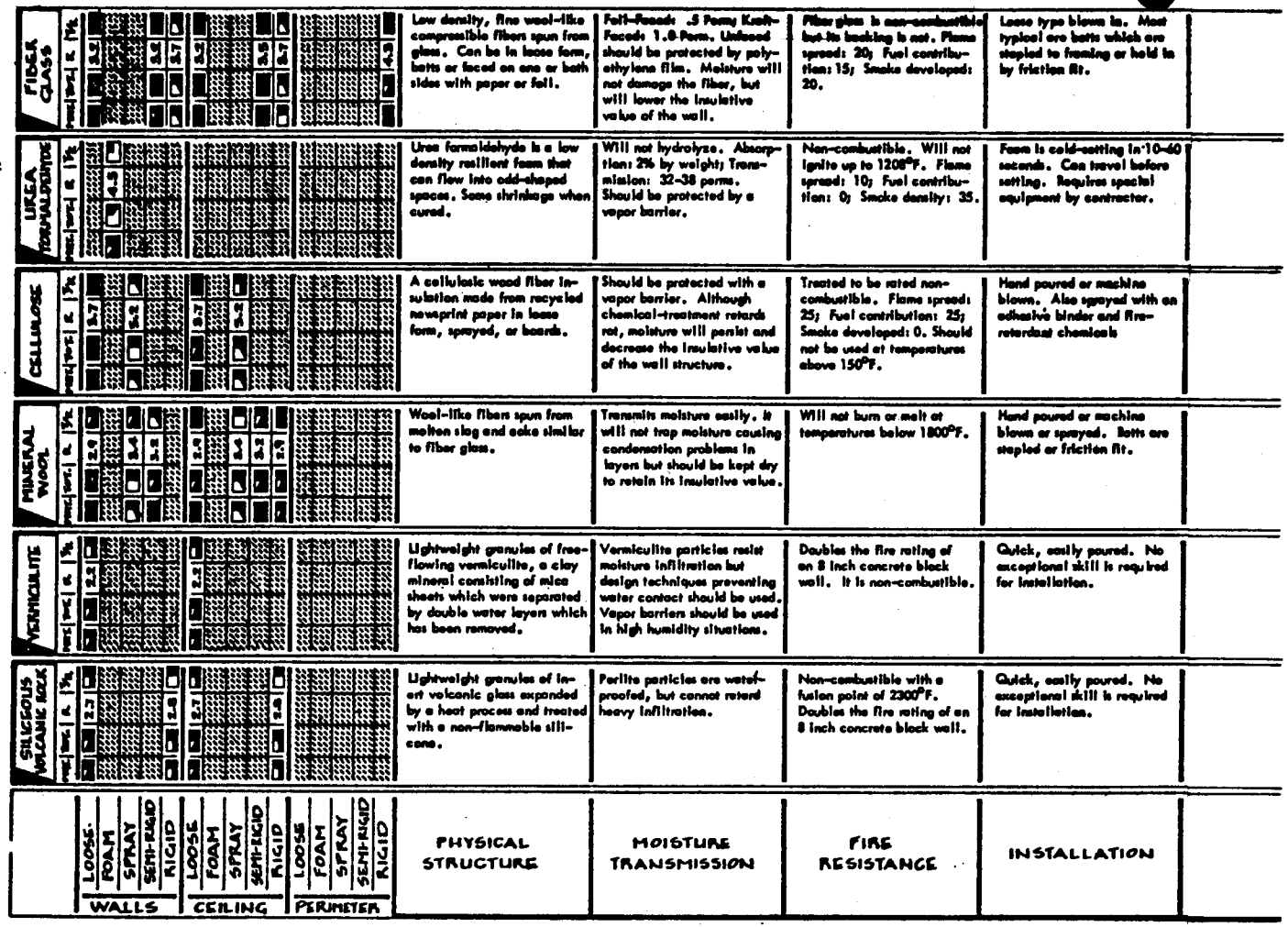
coordinate with standard construction. They are used mainly in masonry construction where they can be placed or glued rather than mechanically fastened as with the flexible types. They also have applications below grade for slab insulation where they can resist earth pressures and water penetration. The most common types of rigid insulation are made from expanded polystyrene, urethane, urea-formaldehyde, or cellular glass. (Figure 3)

loose fill insulation

The nature of this insulation, granulated low density pellets, allows quick, easy installation by pouring. (Figure 4) It can fill the voids in the cavity of masonry walls or framed walls and ceilings (if sufficiently leakproof). Care must be taken to fill all voids, minimize settling and prevent leakage. Most types carry a fire rating in addition to their insulation value.

The most common form is made from Perlite, a volcanic glass. After being crushed, screened, and graded, perlite ore is heated in excess of 1600°F., whereupon the ore expands to nearly 20 times its original volume. Each separate perlite particle contains a large number of cells formed during expansion and are responsible for its low conductivity. Another type is made from

recycled wood fiber (cellulose) usually derived from old newsprint. Chemically treated, they can resist mold, mildew, and achieve a respectable fire rating. Special equipment has been designed to also enable successful spray application. Water is mixed with the cellulose fibers at the spray nozzle and binders within the cellulose provide internal cohesion among the fibers. The finished product is a built-up thickness and has a texture similar to that of egg cartons. The sprayed fibers, offering a very low conductivity, will adhere to nearly every surface and are compatible with nearly all construction types.



FIBER GLASS	Low density, fine wool-like compressible fibers spun from glass. Can be in loose form, batts or faced on one or both sides with paper or foil.	Foil-Faced: .5 Perm; Kraft-Faced: 1.0 Perm. Unfaced should be protected by polyethylene film. Moisture will not damage the fiber, but will lower the insulative value of the wall.	Fiber glass is non-combustible but its backing is not. Flame spread: 20; Fuel contribution: 15; Smoke developed: 20.	Loose type blown in. Most typical are batts which are stapled to framing or held in by friction fit.
UREA FORMALDEHYDE	Urea formaldehyde is a low density resilient foam that can flow into odd-shaped spaces. Some shrinkage when cured.	Will not hydrolyze. Absorption: 2% by weight; Transmission: 32-38 perms. Should be protected by a vapor barrier.	Non-combustible. Will not ignite up to 1208°F. Flame spread: 10; Fuel contribution: 0; Smoke density: 35.	Foam is cold-setting in 10-60 seconds. Can travel before setting. Requires special equipment by contractor.
CELLULOSE	A cellulosic wood fiber insulation made from recycled newsprint paper in loose form, sprayed, or boards.	Should be protected with a vapor barrier. Although chemical-treatment retards rot, moisture will persist and decrease the insulative value of the wall structure.	Treated to be rated non-combustible. Flame spread: 25; Fuel contribution: 25; Smoke developed: 0. Should not be used at temperatures above 150°F.	Hand poured or machine blown. Also sprayed with an adhesive binder and fire-retardant chemicals
MINERAL WOOL	Wool-like fibers spun from molten slag and coke similar to fiber glass.	Transmits moisture easily. It will not trap moisture causing condensation problems in layers but should be kept dry to retain its insulative value.	Will not burn or melt at temperatures below 1800°F.	Hand poured or machine blown or sprayed. Batts are stapled or friction fit.
VERMICULITE	Lightweight granules of free-flowing vermiculite, a clay mineral consisting of mica sheets which were separated by double water layers which has been removed.	Vermiculite particles resist moisture infiltration but design techniques preventing water contact should be used. Vapor barriers should be used in high humidity situations.	Doubles the fire rating of an 8 inch concrete block wall. It is non-combustible.	Quick, easily poured. No exceptional skill is required for installation.
SILICEOUS VOLCANIC ROCK	Lightweight granules of inert volcanic glass expanded by a heat process and treated with a non-flammable silicone.	Perlite particles are waterproofed, but cannot retard heavy infiltration.	Non-combustible with a fusion point of 2300°F. Doubles the fire rating of an 8 inch concrete block wall.	Quick, easily poured. No exceptional skill is required for installation.
	LOOSE-FOAM SPRAY SEMI-RIGID RIGID — WALLS; LOOSE FOAM SPRAY SEMI-RIGID RIGID — CEILING; LOOSE FOAM SPRAY SEMI-RIGID RIGID — PERIMETER	PHYSICAL STRUCTURE	MOISTURE TRANSMISSION	FIRE RESISTANCE	INSTALLATION

foamed insulation

These insulations are formed at the site by the mixture of two liquid chemical reactants. As the two combine, they rapidly expand into a froth or foam and then stiffen into a solid. The physical structure of this lightweight material is millions of voids of open or closed structure. A closed structure, as opposed to an open structure, prevents the absorption of moisture. Those types of foam with closed structure often contain fluorcarbon gases, the product of the rapid chemical reaction. These gases, which may have very low conductivity, remain trapped in the cells for a long time, but eventually escape over a period of years to be displaced by air molecules of higher conductivity values.

RANGE OF USE	DURABILITY	SUBSTRATE	AVAILABLE SIZES	BRAND NAMES	
In ceilings and walls. In frame construction, attic floor and roof, sill sealer between top of masonry foundation wall and wood framing plate. Used between wood furring strips on masonry walls.	Long lasting if protected from moisture. Moisture will not damage the glass fibers but will lessen its insulative value. It resists slumping and tearing. Resists rot and vermin.	Cannot be used as finished surface. Must be sheathed over except in non-use areas such as attic spaces.	Great variety of shapes and sizes. Batts in 16" or 24" widths, 4 feet long and 3-1/2", 6", or 9" rolls of 32' lengths. Still sealer of 1"x6"x50". Loose in 4 cu. ft. bags.	Owens-Corning Johns-Manville	FIBER GLASS
Floors, walls, partitions, pipe chases and other building cavities.	Is rot and vermin resistant. Exposed surfaces should be protected. Should not be subjected to temperatures in excess of 210°F. for prolonged periods.	Will support only light loads. Usually sheathed over to protect from bumping or chipping.	Foam spreads to fit any shape or size space.	Rapco-Foam Tripolymer	UREA FORMALDEHYDE
Poured—limited to frame construction; Sprayed—all construction types.	Organic, chemically treated to resist rot, vermin and fire. Should be protected by a vapor barrier and not used at temperatures above 150°F.	If sprayed, it can be used as the finish surface. Can be painted.	4 cu. ft. or 15 and 20 pound bags. 3.3 cu. ft. - 40 pound bales.	Cellin Man-Therm K-13 Celotex	CELLULOSE
With wood or metal framing. Walls and ceiling construction.	Inorganic, long-lasting if kept dry and undisturbed. Moisture will decrease its insulative value quickly.	Similar to fiber glass in that is cannot be used as a finish surface. It must be sheathed over except in non-use areas such as attic spaces.	26 pound bags. Batts with or without kraft or foil backing in 3-5/8", 6", 6-1/2" thickness, 16" and 24" widths, 48" lengths.	Premium Brand (Rockwool Indus.) Sprayden Sprayed Mineset Fiber Spraycraft Thermofiber	MINERAL WOOL
Masonry units Veneer walls Masonry cavity walls Free pours up to 20 feet Also in ceiling construction	Will not rot, settle, attract vermin, or lose insulative value with time. Moisture will decrease its insulative value quickly.	Must be contained within an envelope of building materials	4 cu. ft. bags.	Zonolite	VERMICULITE
Masonry units Veneer walls Masonry cavity walls Also in ceiling construction	Is organic, resists rot, vermin and termites. Will not decompose. Moisture will decrease its insulative value quickly.	Must be contained within an envelope of building materials.	4 cu. ft. bags or 1" and 2" rigid board.	Perlite Institute Inc.	SILICEOUS VOLCANIC ROCK

These types of foams were developed for their high thermal performance and ease of installation. They can be poured into odd shaped, irregular cavities to expand completely into all the voids, or rapidly sprayed on the flat surfaces or into difficult spaces where no other insulation can be placed. Some foams, such as polyurethane should not be sprayed or poured into finished walls. Their expansion may crack masonry walls, or cause wallboard to split away from the studs if no opening is allowed for expansion.

Since application requires the skill and experience of a trained operator who can manipulate the specialized spraying apparatus to adjust the mixture. (Figure 5) He must also be able to judge which amount of sprayed liquid produces which thickness of expanded rigid foam. The outside temperature affects the quality of the result and must be accounted for during application. Hot walls on the southern exposure may cause over expansion, while the coolness of the northern exposed walls will retard the proper expansion of the foam to its full thickness and lowest density.

Another negative attribute of certain foamed insulation such as polyurethane is that they are dimensionally unstable; over a period

of time, they shrink and crack, and may allow infiltration of air. They also expand and contract according to the moisture content of the air. Some manufacturers market urea-formaldehyde instead of polyurethane and claim that it will not expand once it has been foamed in place. It will, however, shrink 1.8%-3% linearly during its drying period.

Polyurethane can also burn rapidly contributing to combustion and release of toxic gases. It can, however, be coated with fire retardant chemicals. In places where potential fire hazards exist, the appropriate precautionary and safety measures should be taken. Nevertheless, this insulation type has high performance values, and should be used under controlled conditions if their maximum potential is to be reached.

foil insulation

These types combine reflective power with trapped air spaces to achieve an insulative effect. (Figure 6) They are usually made of multiple layers of aluminum foil or metalized paper, and come in rolls with widths corresponding to framing dimensions. The layers are separated from one another to form pockets of trapped air. Usually one outer layer functions as a vapor barrier. Reflective barriers require skillful installation to prevent punctures and ensure that the layers fully separate to the proper distance.

the effectiveness of insulation

When manufactured, the density of an insulating material is intended to be uniform to assure the building industry of dependable and even performance from one installation to the next. Yet, after leaving the factory where careful control was imposed on its manufacture to insure maximum insulating quality, the product becomes vulnerable to environmental factors which could drastically reduce the thermal benefits it could theoretically provide for a building.

The first environmental factor responsible for this is low quality installation procedures which allow discontinuity across the insulated section. The second deleterious effect is the increased densities caused by the presence of condensed water vapor within the insulation. Since the conductivity of water is many more times that of the insulation, any building section afflicted in this way will permit rapid escape of heat.

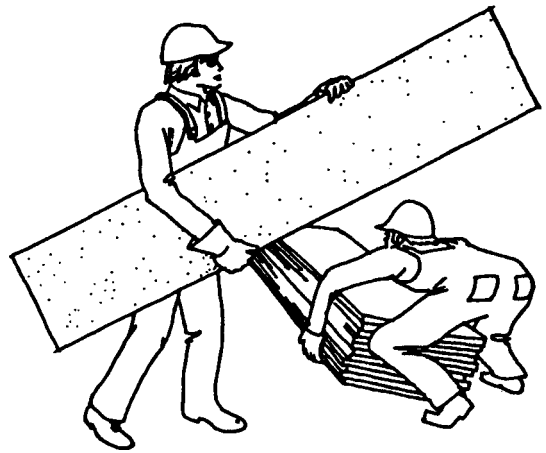


Figure 3

Figure 4

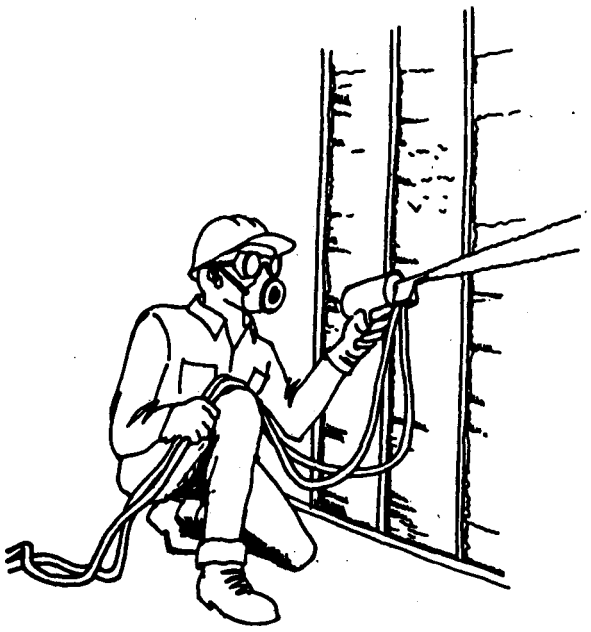
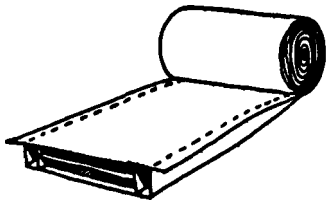


Figure 5



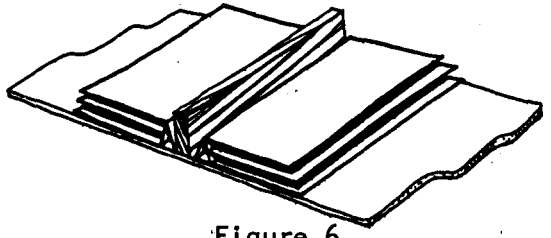


Figure 6

vapor barriers

The *vapor barrier* is nearly always used in conjunction with insulation. A vapor barrier, properly installed will effectively prevent the occurrence of condensation within the wall section. If warm moist air is permitted to pass into materials with temperatures below the dew point, the water vapor would condense on the cool surfaces. The material could be insulation, structural members or painted wood, all of which should remain dry once they are a part of the building. Thus, vapor barriers function to:

- Keep insulation dry to prevent deterioration, and increased thermal conductance, thereby maintaining its effectiveness.
- Prevent damage to structural members by rot, corrosion, or the action of freezing and thawing.
- Reduce paint problems by preventing moisture from passing from the building's interior, through the wood, and condensing underneath the paint. This expansion to a gaseous state causes delamination of paint, formation of bubbles, and peeling.

Structural -- a barrier which is an integral part of the enclosing shell of the building or a stiff rigid board-like material which is self-supporting structural integrity. Sheets of reinforced plastic, aluminum, stainless steel, and closed cell insulation, which are relatively impervious to water, fall into this category.

Membrane -- a thin film of material of low permeability, usually metal foils, laminated foils, and treated papers, coated felts, and plastic films and sheets. The membrane films that are supplied as an integral part of glass, wool or mineral insulations are also included. These thin membranes, usually available in rolls, are dispensed across a wall, roof, or floor area and held in place by gluing or mechanical fasteners, or in the case of a poured slab, simply in place by the weight of the concrete.

Coatings -- coating barriers divide into two groups: semi-fluid mastic types and the more fluid paint-like barriers called surface coatings. Their composition may be asphaltic, resinous, and polymeric and can be applied by a mop, dip, roller, trowel, brush, or spray depending on the type of coating or insulation to be

protected.

Besides their ability to retard the flow of moisture, other properties may be important according to particular applications or aspects that each type of barrier can offer. These include mechanical strength in tension, shear, impact and flexure; adhesion, elasticity, thermal stability, fire and flammability resistance; inertness to other deteriorating elements and ease of fabrication, application and joint sealing.

problem areas

Once the optimum insulation levels and types of insulation and vapor barriers have been determined the next area of concern should be to check a few problem areas that could possibly reduce the effectiveness of insulation:

Convection In Wood Frame Construction -- Convection is the circulation of air within the stud space due to a difference in outside and inside wall temperatures. (Figure 7) This circulation of air will greatly increase heat transfer through the wall. Convection can be prevented by carefully selecting and installating insulation so that all gaps between wood framing, sheathing boards and batts or blankets are closed. An exception to this is foil-faced insulation which is designed to be recessed slightly within the stud space to provide a bonus insulating air space with reflective surface.

Blow Back In Frame Construction -- In conventional frame construction, the attic space is most often ventilated by soffit vents and gable and/or ridge vents. The problem here occurs when the insulation (poured or batt) is blown back toward the attic interior by incoming air. This exposes the upper side of the ceiling of the space below to outside air. This can be prevented as shown in Figure (8) by inserting a piece of rigid foam insulation board snugly between the rafters and tacked into place. A piece of wood lath nailed at the jointure of the rafter and joist, supports the board. This permits free air circulation and keeps the insulation still.

Overhangs -- Uninsulated overhanging floors reduce thermal efficiency and could result in frozen pipes if any are located

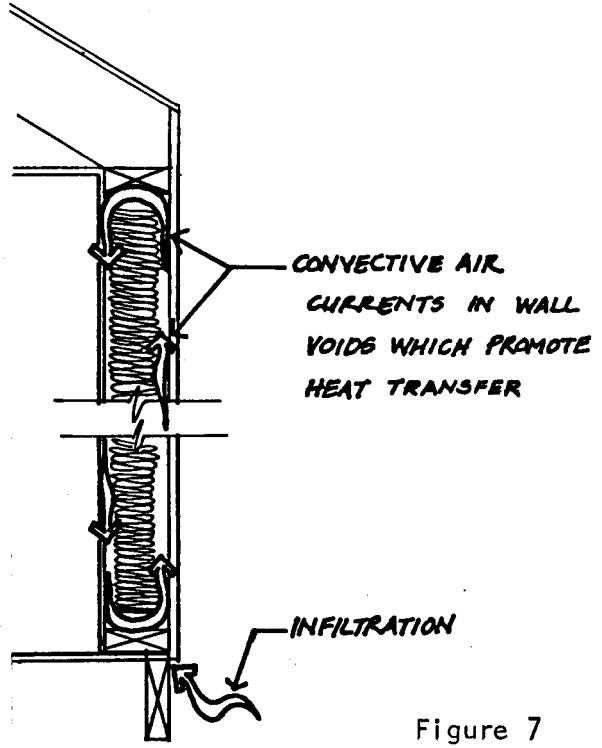


Figure 7

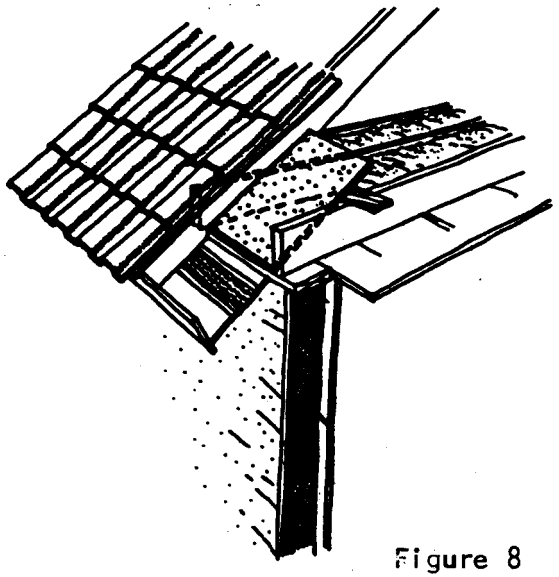


Figure 8

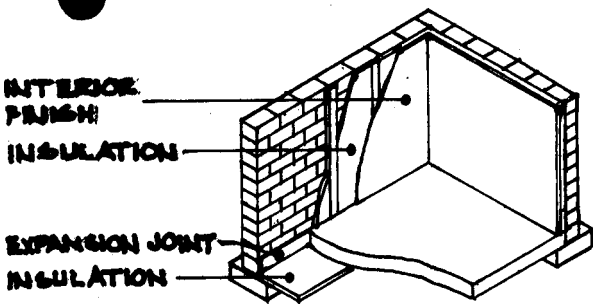


Figure 9

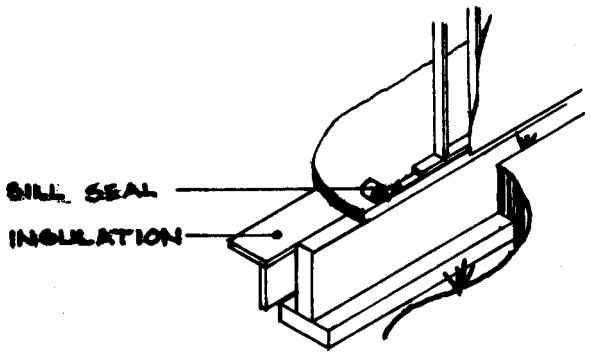


Figure 10

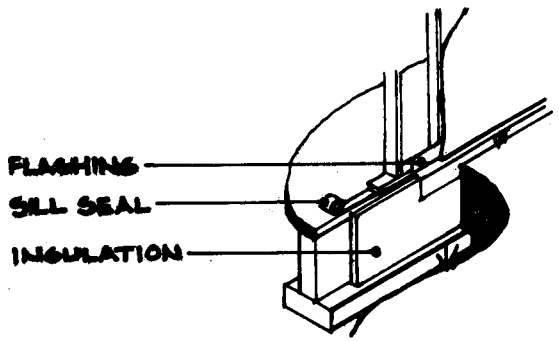


Figure 11

in the overhang. Also, the interior of the house is affected when cold air travels from the uninsulated overhang through the floor and down the interior walls. Even here, plumbing may be vulnerable to below freezing infiltrating air.

Windows -- Since windows are a source of infiltrating air, care must be taken to install strips of insulation around their perimeters. Besides plugging air leaks, this procedure insulates the gap between the rough framing opening in the wall and the window. If windows project, all wall, ceiling, and floor areas surrounding the window must be insulated.

Slab Edge -- For slab-on-grade construction, a 1" thick by 24" wide edge of rigid, closed cell type insulation should be installed under the slab edge. (Figure 9) Also, a strip of insulation or expansion material should be installed as a thermal break between the external masonry wall and the floor slab. In Figure 10 a solution is shown for the situation where the floor slab rests on the foundation wall. The rigid boards are placed vertically along the inside of the foundation wall, gravel is backfilled against it, and then horizontal pieces are wired to the verticals at the corner. A problem with this solution is that there is no thermal break at the slab edge. An alternative solution (Figure 11) is to install the insulation board on the outside of the foundation wall and extend it up to the bottom edge of the sill plate. This placement eliminates the thermal bridge and may be simpler to install. To protect the insulation, a continuous metal flashing should be installed that fits underneath the exterior siding and is slipped underneath at ground level.

Sill Plate -- Another insulating problem occurs at the sill plate where infiltration air may penetrate the joint between the wood frame and the masonry. The solution is to install a special batt of fiberglass or a putty-like sill sealer. (Figures 9, 10) Either of these products will effectively stop air infiltration and also provide a thermal break.

mass

5

combining mass and insulation

calculating time lag

using mass in residences

Mass, the property of density, can have a great effect on the energy consumption of buildings. Although this property is little understood by most people in the building industry, the amount of mass can be as important as insulation in the conservation of energy. If mass is properly included in the total energy system of a building a further reduction of energy consumption is possible. While insulation resists heat flow, mass has the ability to store heat energy and delay its impact on interior spaces, until it is possible to provide cooling by natural ventilation or by simply circulating cool nighttime air.

Imagine the start of a day in late spring. Upon awakening, the outside is bright and sunny, and there is still a night chill in the air and inside your home. Deciding to enjoy the day outside, the house is closed for the day. During the afternoon the outside temperature warms up from 85° to 90°F. Returning home about 6:00 PM, the house is still cool and comfortable. A few hours later, though, changes have occurred. Feeling uncomfortable, the window is opened to let in some cool evening air. The mass has delayed the effects of the outdoor temperature cycle. This property of *time lag* is uncommon in most homes that are built of lightweight materials such as wood or metal having little ability to delay the flow of energy.

The ability to delay heat flow can be as important and sometimes more important than the ability to resist heat flow. In a climate with large day-night temperature variation, this can be especially true. The sun's energy which normally adds to the need for air conditioning can be stored and delayed and used to provide heat at night. A house without insulation or mass in such a climate would require a great deal of energy for heat at night and cooling during the day. A house with insulation in such a climate would still require heating and cooling although in lesser quantities. With mass and a 12 hour time lag, the home may not require any heating or cooling.

Mass, like insulation, can be a disadvantage if used improperly. A building with infrequent and changing use such as a church or a theater is a good example. A church may only be used for four hours on the weekend. To save energy, it may not require heating

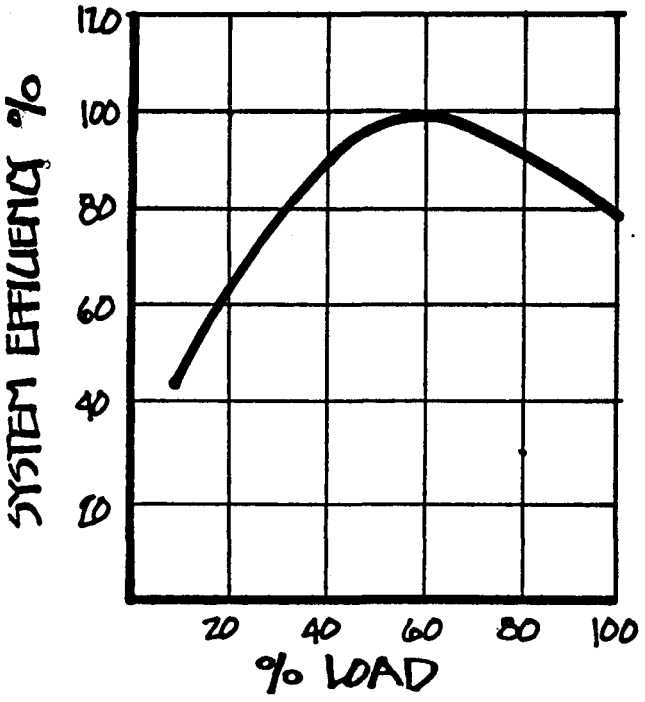


Figure 1

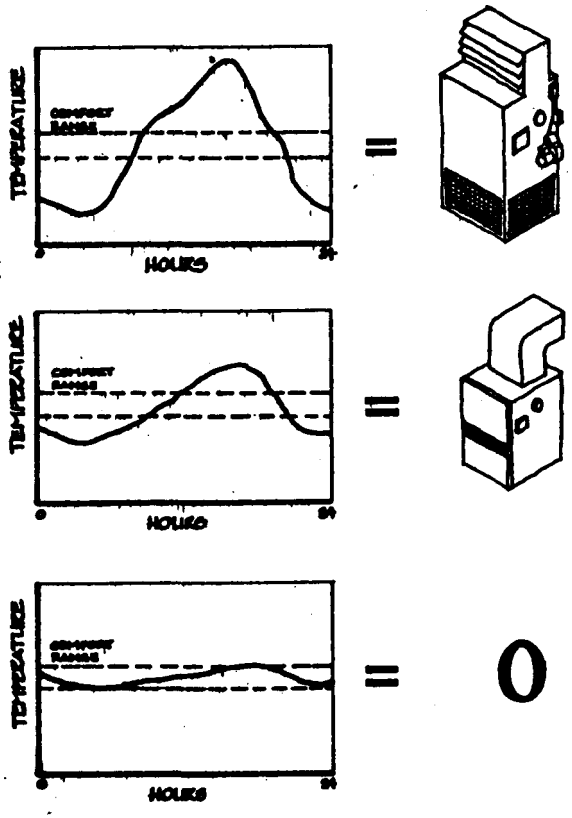


Figure 2

to the comfort zone the other 164 hours in the week. Two hours before the church service, the lights are turned on and the thermostat turned up. If the building is of massive construction, it may remain cool throughout the duration of the church service only to become comfortable after everyone has gone. Mass is hard to control. You can't just turn it off and on. Mass has sometimes been referred to as a thermal flywheel. If a building is in a heating mode and is suddenly transferred to a cooling mode the mass will respond very slowly. A control system in such a building must be able to anticipate thermal conditions hours in advance.

This "Flywheel" effect can have an influence on mechanical equipment size. The equipment can be smaller since the peak load has been reduced significantly. Thus, the initial costs and the operating costs of the mechanical system will be lower. These savings are due to a smaller, more consistent load. (Figure 1)

The operating efficiency for a piece of equipment can vary significantly when conditioning requirements change drastically as seen in (Figure 2). Mechanical equipment is sized to meet the maximum load requirements that rarely occur. Usually the mechanical equipment operates at 50% to 70% of the maximum load. Manufacturers understanding this principal have designed their equipment to operate most efficiently at part load requirements. The part load efficiencies of equipment change depending on the specific type of equipment investigated. The performance curve shown in Figure 1 is for a centrifugal chiller. The part-load characteristics can usually be obtained from equipment manufacturers. Even so, at lower percentages of the load, the system's efficiency drops off significantly. If the mechanical equipment could operate continuously at high operating efficiencies, greater fuel savings would occur although the building requirements remain the same.

combining mass and insulation

In view of the energy savings to be realized by adding the proper amounts of mass to a building's shell, it is first necessary to be able to evaluate building materials and their combinations so that they can be selected to provide a desired time lag. Two material characteristics essential to this evaluation are energy resistance (R) and energy capacity(C). (Figure 3) A third pro-

	Energy Resist. btu/in(hr)(sq.ft.) (°F)	Energy Cap. btu/144 (in^3) (°F)		Energy Resist. btu/in(hr)(sq.ft.) (°F)	Energy Cap. btu/144 (in^3) (°F)
Acous. Ceiling Tile	2.381	.128	Insul. Min. W. Bat	3.125	.040
Air Space	.909*	0	Insul. Roof Deck	2.632	.208
Aluminum	.0007	2.089	Insul. - CAFCO	3.846	1.670
Asbestos Cement Brd	.250	2.500	Insulrock	1.961	.780
Brick Common 4 Inch	.700	2.200	Kawnfer	3.226	.160
Brick Face 4 Inch	.111	2.383	Linoleum	.637	2.330
Carpet	2.222	.333	Marble	.049	2.835
Ceramic	2.222	.306	Membrane	3.125	.040
Celotex	4.000	.133	Paper, Regular	1.111	1.813
Clay Tile 4 Inch	.278	1.307	Perlite	.667	.750
Clay Tile 6 Inch	.253	1.307	Plaster	.172	2.320
Clay Tile 8 Inch	.231	1.307	Plaster, Metal Lath	.172	1.750
Clay Tile 12 Inch	.208	1.307	Plaster, Cement	.200	2.767
Concrete Blk - LW 4 In.	.373	.817	Plaster, GYP LW AGG	.625	.638
Concrete Blk - LW 6 In.	.298	.617	Plaster, GYP SAND AGG	.179	1.750
Concrete Blk - LW 8 In.	.250	.817	Plywood	1.250	1.842
Concrete Blk - LW 12 In.	.208	.817	Porcelain	.003	4.900
Concrete Blk - RW 4 In.	.179	1.833	Rockwool Batt	3.704	.067
Concrete Blk - RW 6 In.	.145	1.833	Roofing Asphalt Roll	.154	1.925
Concrete Blk - RW 8 In.	.139	1.833	Roofing Built Up	.885	2.217
Concrete Blk - RW 12 In.	.107	1.833	Sand	.188	1.742
Concrete Standard	.083	3.267	Sheathing Fiber Resin	2.632	.412
Copper	.0004	4.301	Shingles Asphalt	3.333	2.740
Coral Rock	.083	1.367	Shingles Wood	2.500	2.640
Door Core	2.381	.975	Slate	.100	2.330
Drywall	.303	.750	Steel	.003	4.790
Earth	.154	1.833	Stone 4 Inch	.080	2.330
Felt	.752	2.333	Stucco	.200	2.710
Glass Block (Wall)	2.500	1.667	Styrofoam	1.667	.043
Glass Plate (Door)	.060	1.610	Tectum Deck	1.818	.367
Glass (Painted)	.400	2.690	Terrazzo	.080	2.500
Glass Spand Solarbrnz	.060	1.610	Tile Asphalt	.400	3.500
Granite	.076	2.692	Tile Floor (Vinyl)	.050	4.800
Gypsum Deck	.625	.850	Transite	.250	2.000
Gypsum Lath (Plaster Board)	.870	1.083	Urethane Foam	5.882	.048
Hard Board	.714	.933	Varmiculite-Loose	3.333	.067
Haydite Block	.250	.817	White Quartx	.083	2.500
Insulation Fibre	5.882	.144	Wood, Hard	.909	2.513
Insulation Rigid	2.778	.347	Wood, Soft	1.250	1.733
Insulation Glass Bd.	4.000	.128	Zonolite (Loose)	2.564	.058

* The energy resistance remains constant regardless of the number of inches beyond one. Therefore, for a 4" air space, the resistance remains .909 btu/(in)(hr)(sq.ft.)(°F).

Figure 3

perty, energy conductance (U) can be determined by inverting the energy resistance ($\frac{1}{R}$ see insulation discussion).

Consider two materials, 3" of rigid insulation and 8" of concrete block. Separately, (Figure 4) the insulation has a thermal conductivity or "U" value of .107 and a time lag of 1.6 hours. (Figure 5) The concrete block has a U value of .90 and a time lag of 5 hours. The challenge begins when two materials are combined. (Figure 6) First consider putting the insulation inside of the dwelling and the concrete block on the outside. If the calculation method were easy, the time lag of the composite construction would be the simple addition of the two individual time lags. Unfortunately, it doesn't occur that way and instead turns out to be approximately 7 hours.

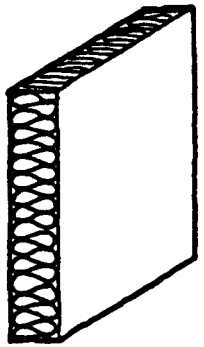


Figure 4

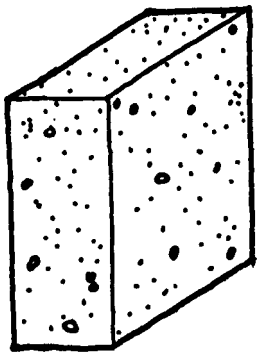


Figure 5

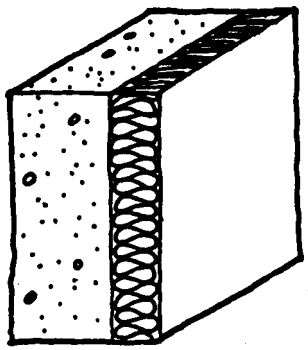


Figure 6

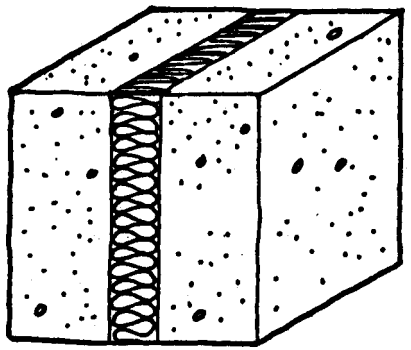


Figure 7

The placement of insulation can have a great effect on the time lag of the composite wall. (Figure 7) If, for instance, the insulation is placed in the middle with a 4" concrete block on both sides the time lag becomes 10 hours. If the insulation is placed on the outside, the time lag becomes 15 hours. The placement of insulation has such an effect because of the movement of heat into and out of the wall construction. In a homogeneous wall construction, the heat flow into and out is of an equal magnitude. However, within a wall with an exterior insulation layer, the properties of heat flow become more selective. (Figure 8) The insulation restricts the flow into the massive heat absorbing material and therefore, more time elapses before the storage capacity of the massive material is filled, increasing the time lag.

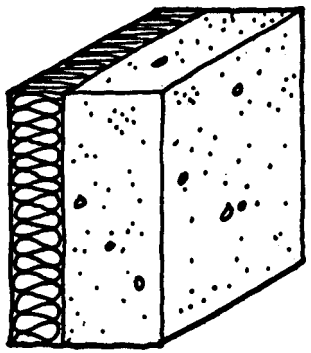


Figure 8

calculating time lag

Time lag is very simple to determine for a wall of a single homogeneous material. As an example, take a simple wall constructed of 8" concrete block. Determine the energy resistance and energy capacity values from the chart given in Figure 3. The values are .139 (Hr.)(Sq.ft.)(^{o}F)(BTU/In.) and 1.833 BTU/(144 In.^{3})(^{o}F) respectively. Multiplying these values by the thickness of the wall modifies the characteristics for a given wall thickness. In this case:

$$R = (.139)(8'') = 1.112 \text{ (BTU/IN)(Hr.)(Sq.Ft.)}(^{o}\text{F})$$

$$\text{or } \frac{1}{R} \text{ therefore } U = \frac{1}{R} = \frac{1}{1.112} = .899$$

The time lag can be determined with the use of the chart in Figure 9. The chart is constructed with "U" value across the horizontal axis and time lag on the vertical axis. The sloping lines across the graph are UC values that are determined by multiplying the U value and Energy Capacity determined above.

UC = "U" value x Energy Capacity = .899 x 14.664 = 13.2

Then, reading the UC line of 13.2 and its intersection with the "U" value line of .899, a time lag line of 5 hours can be located.

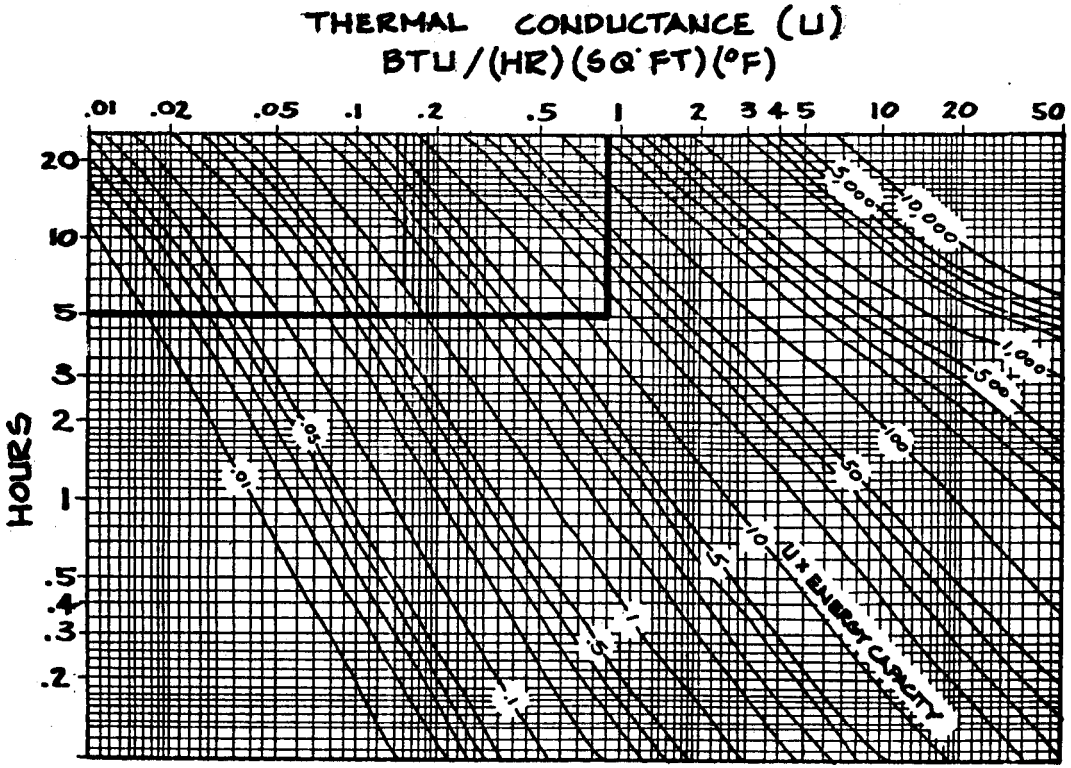

THERMAL CONDUCTANCE (U)
BTU/(HR)(SQ FT)(°F)
.01
.02
.05
.1
.2
.5
1
2
3
4
5
10
20
50
HOURS
20
10
5
3
2
1
.5
.4
.3
.2
5,000
10,000
1,000
500
100
50
10
5
1
.5
.1
.05
.01
U x ENERGY CAPACITY

Figure 9

The characteristics of a composite wall having two or more layers of materials are harder to determine. For example, take the previously discussed wall section in Figure 7, of a wall consisting of 2 layers of 4" concrete block with 2" of rigid insulation between. First, assemble the required resistance and energy capacity values for all three materials:

		Wall Component Characteristics		
	Symbol	Outside	M_1	Inside
Material Characteristics		Conc. Block	Rigid Insul.	Conc. Block
Energy Resistance/Inch		.179	2.778	.139
Energy Capacity/Inch		1.833	.347	1.833
Thickness in Inches		4.000	3.000	8.000
Energy Res. for Given Thickness	R	.716	8.330	1.110
Energy Cap. for Given Thickness	C	7.332	1.04	14.664
Energy Capacity/Energy Resistance	A	10.240		

The energy resistance for the composite wall is the addition of the resistance of the individual parts. Energy resistance of the composite wall:

$$Rc = .716 + 8.33 + .716 = 6.99$$

The calculation of the UC value for a composite wall requires the following formula[1] using the given information.

Energy capacity of the composite wall, where:

Ci = Energy capacity of the interior layer
Cm_1 = Energy capacity of the 1st middle layer (if any exist)
Cm_2 = Energy capacity of the 2nd middle layer (if any exist)
Ao = The ratio of the energy capacity of the outer layer to the resistance of the outer layer.

1. Mackey, C.O. and Wright, L.T., "Periodic Heat Flow - Homogeneous Walls or Roofs," Heating, Piping and Air Conditioning, September, 1944.

Ro = Energy resistance of the outside layer
Rm_1 = Energy resistance of the 1st middle layer (if any exist)
Rm_2 = Energy resistance of the 2nd middle layer (if any exist)
Ri = Energy resistance of the interior layer
Rc = Energy resistance to the composite wall.
(The sum of the resistances of all layers)

$$UC = \frac{1.1\ (Ci+Cm_1+Cm_2+....+Cm_n)}{Rc} + \frac{Ao\ [(Ro-.1(Ri+Rm_1+Rm_2+....+Rm_n)]}{Rc} =$$

$$\frac{1.1(7.33+1.04)}{6.99} + \frac{10.24\ [.716-.1(5.56+.716)]}{6.99} = \frac{9.21 + (-1.93)}{6.99}$$

Note: When the second half of the numerator is a negative number, it is ignored and assumed to be equal to zero, therefore:

$$\frac{8.83 + 0}{6.99} = 1.31$$

U value = .102
Time Lag = 12 hours

Now having the ability to calculate time lag, it is possible to compare the time lag of different wall constructions. This can be of importance after having determined the time lag desired for the walls and roof of a given structure. By the variation of building materials, a given time lag can be incorporated into a structure with the least cost.

using mass in residences

The ultimate in mass, is a dwelling built in a cave. The time lag becomes infinitely large and the indoor temperature is little affected by the daily cycles of the outside air temperature. The dwelling remains at a constant ground temperature throughout the day. In practical terms, the ultimate is difficult if not impossible to achieve at low cost for the standard home. Mass, like insulation, has an economic optimum where the benefit of improved performance is not worth the additional first cost.

The easiest amount of mass to justify is an amount providing a time lag from 8 to 12 hours. It takes relatively small amounts of heavy materials when combined with external insulation to obtain a

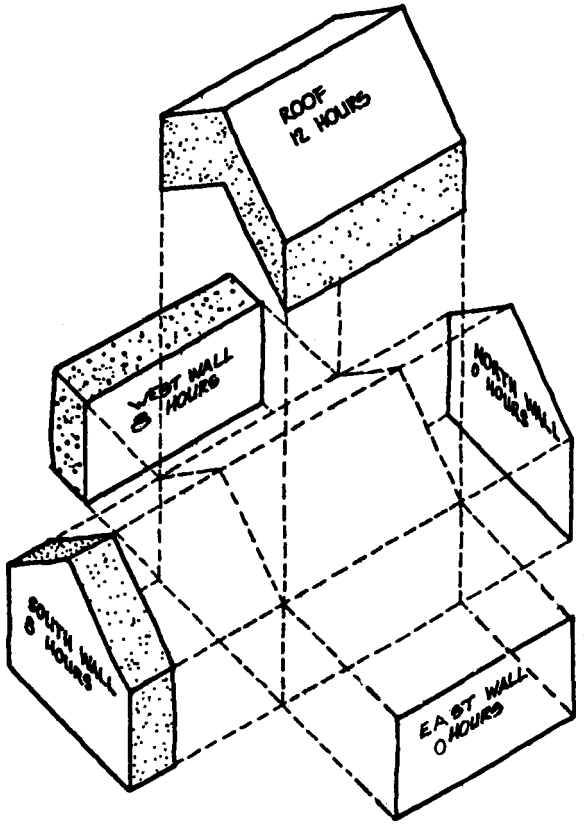


Figure 10

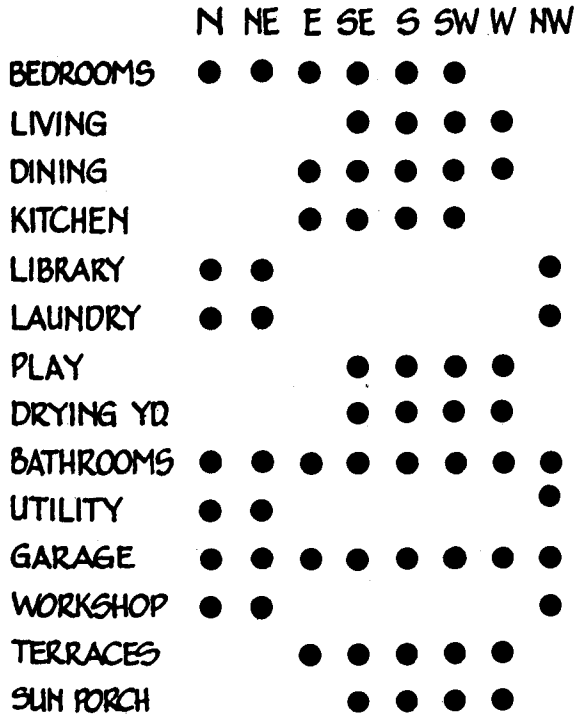


Figure 11

reasonable time lag. The effect of the sun on different orientations and the timing of its energy impact on the interior spaces determine the appropriate time lag for exterior walls.

The energy input for a typical home varies widely throughout a day. Just before sunrise, it is the lowest. The lights are off, the people are asleep; it is dark and cool. During the day, the energy input rises steadily to a peak at about dinner time. Everyone is home, dinner is cooking, the television and lights are on and outside it is still relatively warm and sunny. The most inappropriate time to add additional heat input is during the late afternoon because this would increase the amount of cooling required during peak hours of the day and do nothing for the peak heating load early in the morning during the heating season. Increased energy usage during peak hours implies larger mechanical equipment to meet the load.

Illustrated in Figure 10 are recommended time lags for different wall orientations. The time lag of the east wall, for example, is 0 hours. The reason being that, if the time lag is less than 18 hours, the heat of the sun which strikes in the morning will enter the dwelling at a worse time than if it entered while the home is still relatively cool. To have a time lag greater than 18 hours could be useful but would probably prove uneconomical to build. The west wall is the exact opposite and the sun strikes the wall during the afternoon. A time lag of 8 hours is just enough to delay the heat impact until the late evening hours. The system at this time may be able to use cool evening air in what is known as an *economizer* cycle in which the cool evening air is circulated through the existing air conditioning duct system in place of mechanically cooled air.

Recommendations for other orientations are shown in Figure 11. Along with time lag, the home can have its rooms oriented in a manner described in the accompanying chart. Although hard to predict and quantify in energy savings, the matching of time lag and room orientations should be considered. The psychological importance of natural light should not be overlooked.

sun and windows

6

the greenhouse effect

the overheated period

the movement of the sun

shading devices

sun and windows

The influence of windows over the entire comfort problem is far greater than that of the adjacent wall surfaces. Windows behave as holes, rapidly leaking or transmitting many more times the energy that the adjacent opaque wall surrounding it. One might immediately suggest the elimination of all glass areas to save energy. However, such a proposal, if implemented, may cause a drastic reduction in the quality of the building's internal environment, producing a tomb-like character that is sure to effect the well-being of the people occupying the building. An energy conserving building may include glass areas and still save energy without having to resort to such extremes. In fact, at certain times and in certain climates window areas can actually be used to positively supplement heating or cooling, rather than always being assumed to have a negative effect.

A look at the physical properties of glass will provide an indication of how it can be best used as a building material. Glass transfers heat in two distinctly different ways -- conduction and direct transmission. Like all materials, the ability of glass to conduct heat is measured by its characteristic "K" value and by the magnitude of the temperature difference between the air on either side. The "U" value for a single thickness of glass is 1.08 BTU/hour and will conduct heat at a rate 13½ times that of a surrounding conventional wall of "U" value .08 BTU/hour. Double-pane insulating glass rated at .56 BTU/hour will reduce heat flow considerably but the rate is still seven times as great.

Regardless of its comparatively poor resistance to heat flow, its ability to immediately transmit solar radiation has a much greater impact on the heating or cooling load in a building. When incoming radiation from the sun strikes a window, it is divided into three components.(Figure 1) One portion will be reflected, another transmitted, and the third will be absorbed into the glass itself. The relative proportions of these components depends on the sun's angle of incidence with the glass. When the sun strikes the glass, more nearly perpendicular, the transmitted component is large and the reflected component is small. At incidence angles beyond 60°, the reflected component increases greatly and the transmitted portion decreases.

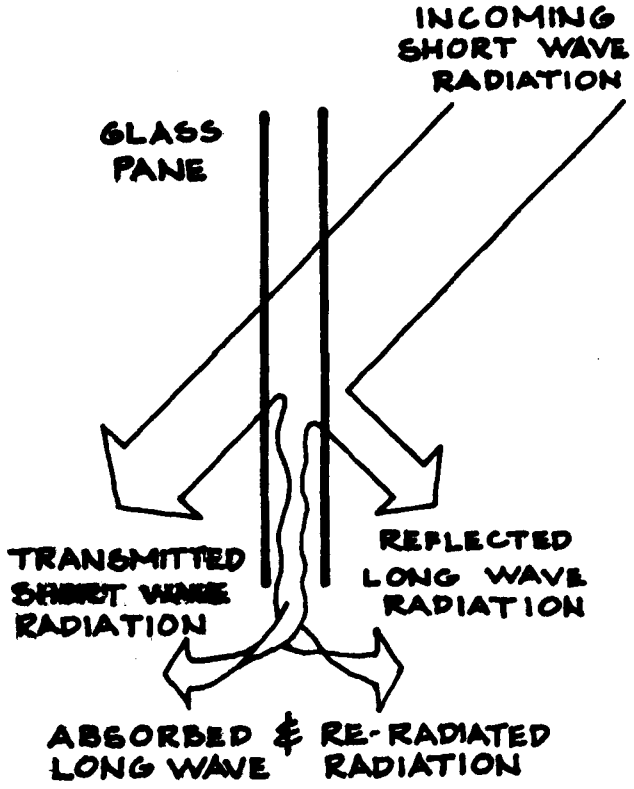


Figure 1

the greenhouse effect

The characteristic property of glass that allows it to transmit

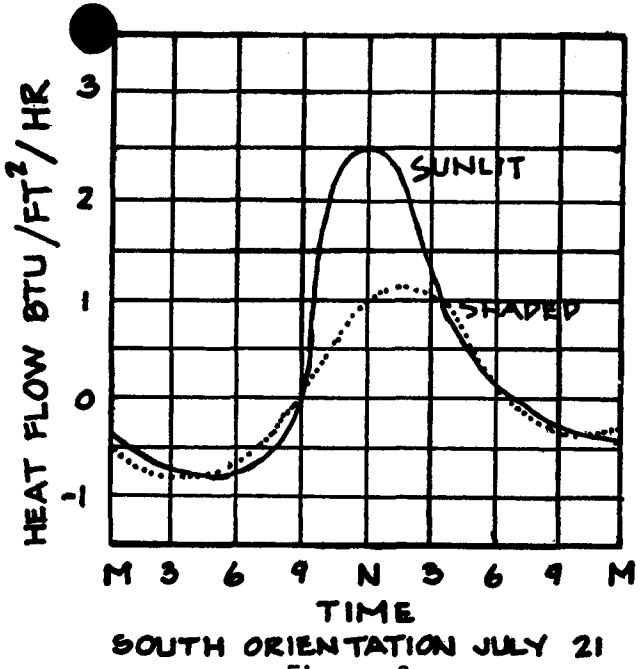


Figure 2

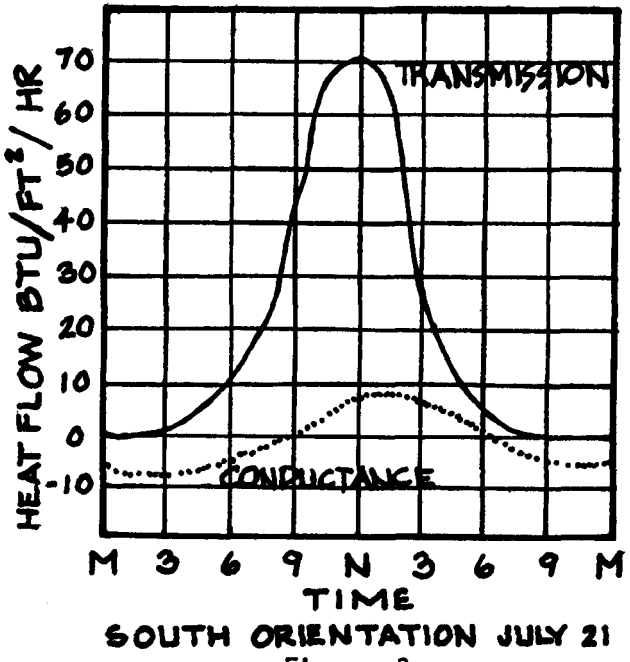


Figure 3

heat is its transparency to short waves of the spectrum and opaqueness to the long waves. The short waves pass freely through a glass thickness, to strike the air and objects within the space, which can only re-radiate the energy in long wavelength radiation. Once inside, the transformed waves cannot re-radiate out through the window. This phenomenon is known as the *greenhouse effect*. Large amounts of heat can then be trapped within a space but can only slowly escape by conduction. The difference between heat transmitted by radiation directly through a window, and that conducted through a window can be quite large and much greater than that conducted through a conventional wall. This difference widens further when the conduction value of glass is added to its transmission component, and this total is compared to an equal area of wall. The extreme difference in heat transmission that can exist between windows and walls can be seen in Figures 2 and 3, which compare transmission rates of glass and wall area on a south wall on July 21st, at 32° N latitude, Mission Viejo, California. The curves show rates for glass nearly 35 times as great as that for the wall.

When the quantity of heat transmitted through window glass becomes excessive, it must be removed by an energy consuming mechanical system if comfort in the enclosed space is to be maintained. An obvious need, then, is for shading. Throughout a sunny day, an object or surface will become shaded if any portion of the sky vault (where the sun will move during that day) is obstructed by another object. The duration of shading over a day or year depends on the amount of "area" of the sun's movement that can be obstructed. These areas of the sky vault correspond to sun time and to determine when shading is appropriate is the essential requirement of the passive technique of energy conservation. Given enough information about the movement of the sun, periods of overheating, and ways of shading, the drastic effect of transmitted radiation on the cooling load can be controlled.

the overheated period

The times during the year when shading is necessary are during periods of overheating and can be equated with certain portions or sub-areas within the sun's larger field of movement in a particular latitude. If a shading device could be designed to deflect the sun's rays only as it travels through that particular area of the sky, overheating inside the space could be reduced. Determining the exact *overheated period* then becomes an essential effort in the search for means to reduce energy needs.

A reasonable approximation of the overheated period can be easily determined by using local weather data. Daily temperatures, that are above the comfort zone when plotted on a chart showing the time of day and month in which they have occurred will graphically illustrate the overheated period throughout the year on a hourly basis. (Figure 4) Having established this information, it can be assumed that the period represented on the chart is that period for which shading is required. This simple method is relevant only in the design of residences or other small buildings where internal heat sources are minimal. The true overheated period is the period when cooling is required. In larger buildings with more lights, people and equipment creating internal heat, the overheated period is enlarged, and shading is required for a longer portion of the year. This type of in-depth analysis requires more advanced techniques.

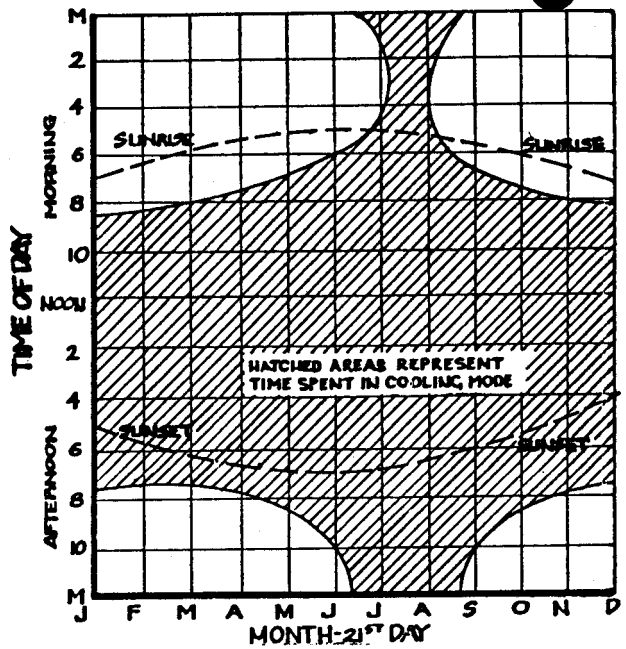


Figure 4

The MED house as an example of window shading is rather peculiar. In most areas of the country, there are times during daylight hours when it would be beneficial to allow the sunlight in, especially during the winter months. But because of the characteristics of the MED house which retains internal heat buildup, and the mild climate which prevents substantial heat loss, this house should be protected from incoming solar radiation most of the year. The method for designing shading devices is still valid for application in more balanced heating and cooling areas. After times of overheating have been determined, they must be correlated with the position of the sun so that a shading device can be designed to block the solar radiation. The method of determining the sun's position at a given time is explained in the next section.

the movement of the sun

The position of the sun in the sky is similar to a point in a field which can be defined by two coordinates. (Figure 5) The two coordinates for the sun are its *altitude* and its *azimuth*. The altitude of the sun is its vertical rise from the horizon, measured in degrees from horizontal. The azimuth measures the sun's horizontal movement across the sky vault and is called the sun's bearing. In the northern hemisphere, it is measured in degrees from true south.

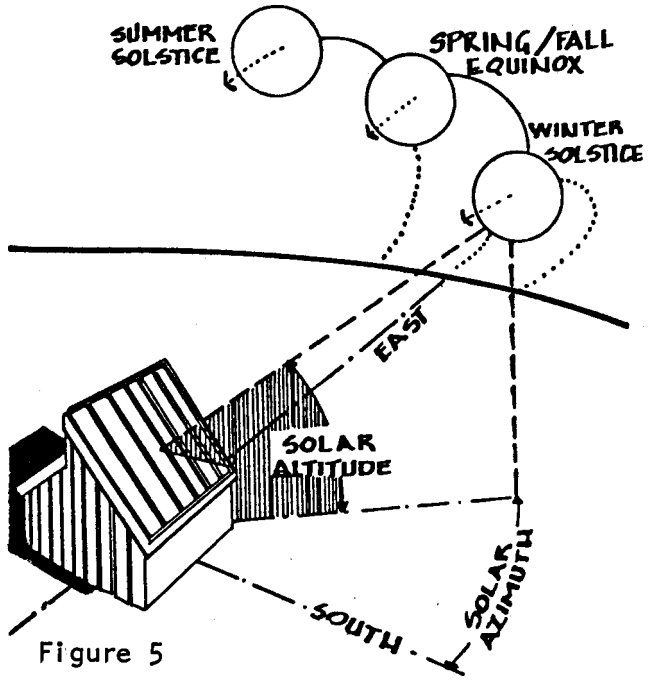


Figure 5

The altitude and azimuth of the sun, for any given time during the day and year for any spot on earth, can easily be predicted with

the use of sun charts. The calculator illustrated in Figure 6 is available from Libbey-Owens-Ford, Attention Merchandising, 811 Madison Avenue, Toledo, Ohio 43695. Depending on latitude, the field of movement year after year of the sun across the sky vault is an unchanging, well defined area. After the first day of winter when the sun is at its lowest point in the sky at noon, it begins increasing its altitude each day thereafter throughout the winter and spring. With the approach of summer, it has gained considerable height and range of movement from horizon

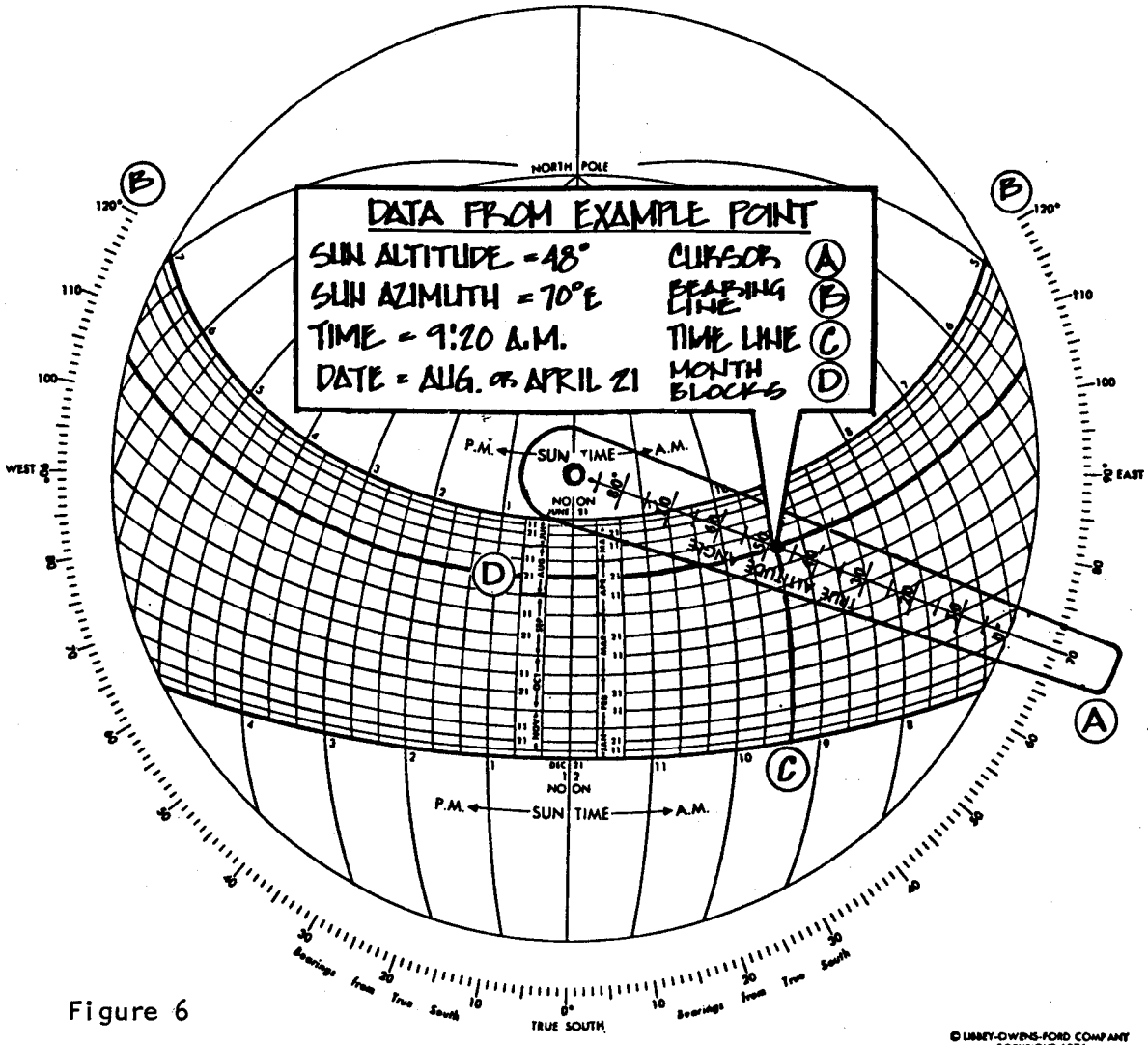


Figure 6

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to horizon. After its highest point on the first day of summer, it begins falling again. Upon the second day of summer and throughout summer and fall, the sun will retrace, in reverse order the same paths of movement during each day of winter and spring. A fixed shading device, therefore, would provide the exact same patterns of shading for two days of different times during the year. This can present problems because the hottest period of summer is not at the beginning when the sun is at its highest point, but occurs later, delayed by a lag time as the earth gradually increases its average temperature. Sun that streams through a window in the cool spring to pleasantly light and warm a space, would penetrate similarly in late summer to heat it to an uncomfortable temperature. In these cases a compromise in shading must be reached.

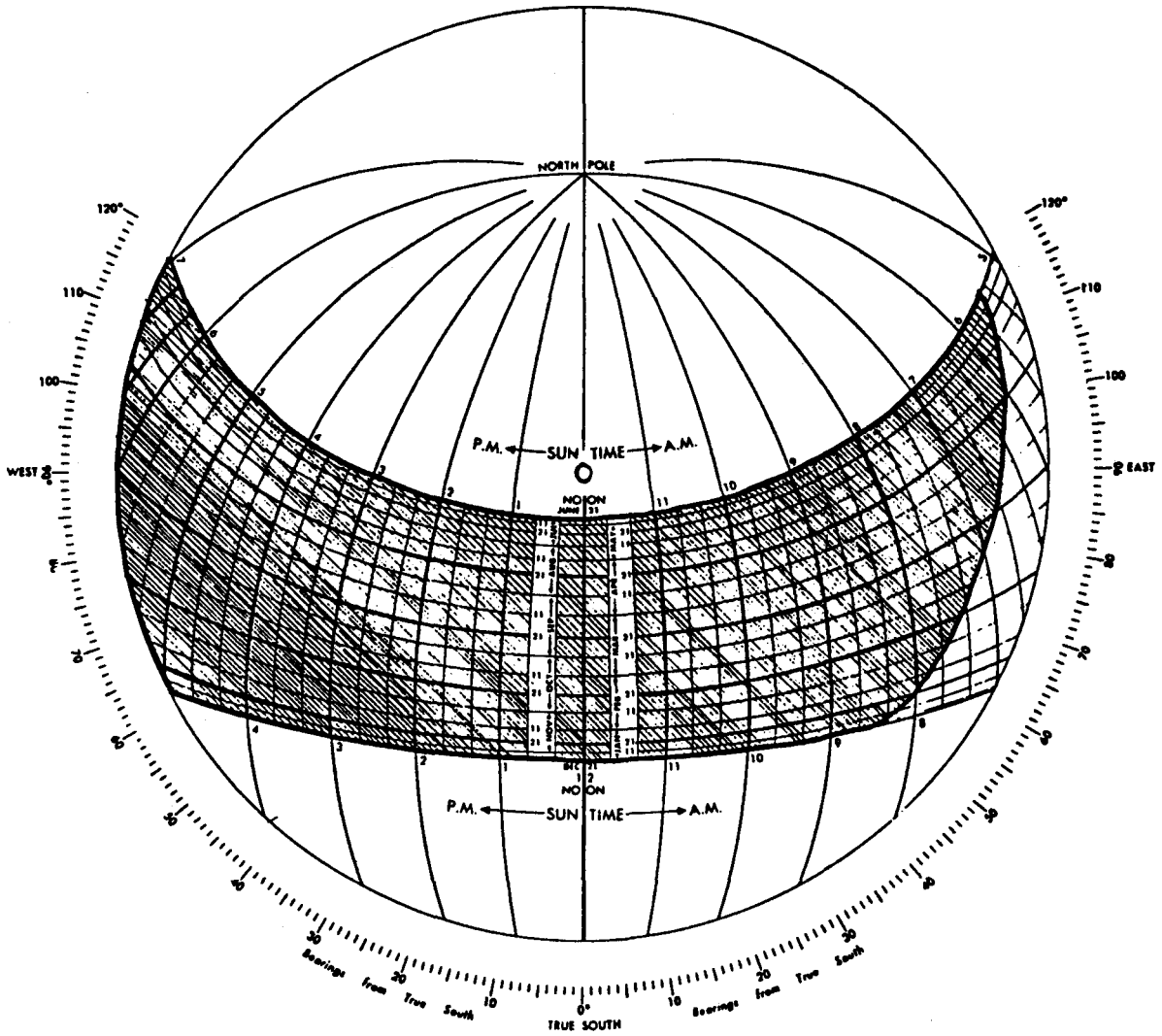
The nature of the sun's movement across the sky can be plotted on a sun path diagram. A circular disk with lines representing the pairs of dates when the sun's track is identical. Figure 6 shows the area of the sun's movement across the sky vault at 32°N latitude, plotted as a sun path diagram. Along the outer circumference of the disk, the bearing points are calibrated and labeled "B". The movement of the sun during the day in a particular month is identified by the curving horizontal lines. The line labeled "D" depicts the sun's movement during August or April 21st. The curving vertical lines represent the hours during the day. In this particular example, line "C" plots the hour of 9:20 A.M. With a given month and hour, the position of the sun can be determined.

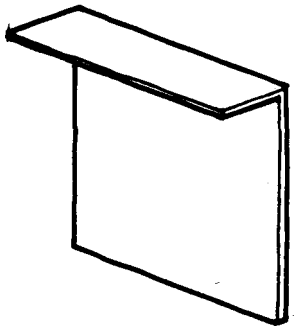
shading devices

Shading devices can be separated into three categories:

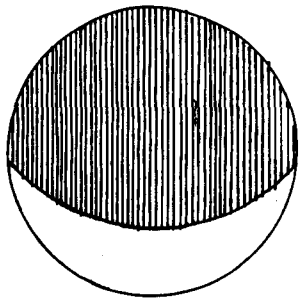
- Fixed devices, such as overhangs and vertical fins that are physically integrated with the building's enclosure system.
- Manufactured devices which can be purchased according to their effectiveness and attached to the house to shade the windows. A number of these are adjustable and offer other benefits besides shading.
- Organic means available for shading -- the various trees, shrubs, and vines that can be strategically planted to offer shade at the appropriate time.

Shaping a device by design for shading can be a fairly orderly process if enough information is known. A method for relating the proper times for shading to the proper shape of the device has been developed.[1] The information needed is the period of the year during which the building is overheated; the graphic format is the sun path diagram. With these tools, the design can proceed in a straightforward manner. A graph showing the overheated period is transferred to the sun path diagram as shown in Figure 7. Since the sun chart is a two dimentional *sky vault* and can be projected as a dome, the



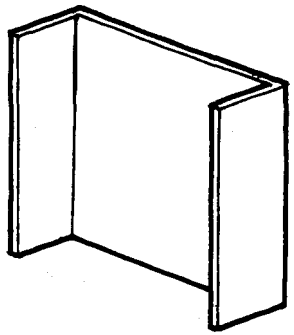


HORIZONTAL

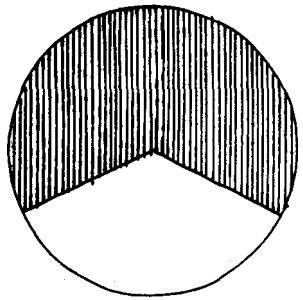


SEGMENTAL MASK

Figure 8



VERTICAL



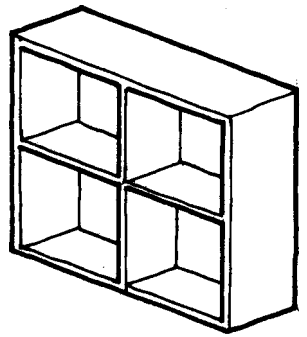
RADIAL MASK

Figure 9

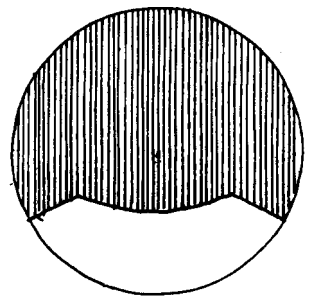
plotted overheated period can also be thought of as a three-dimensional sky vault and can be projected as a dome. The plotted overheated period can also be thought of as a three-dimensional curved area projected on that dome. Next, the center of the chart can be imagined as the object to be shaded. Straight lines projecting from this center to the boundaries of the curved overheated area of the sky vault would represent the instreaming rays from the sun's position in the sky. A three-dimentional object that would intersect those lines would be the properly shaped device.

The three essential geometrical configurations for shading are a horizontal plane (overhang), a vertical plane (fin), and their combination (egg crate). The technique that relates shape to overheated sun time transforms the basic geometrics from three dimensional projections to two dimensional shading masks.

Figures 8, 9, and 10. All shading devices are either horizontal or vertical in nature, or a combination of both. Each generic type of shading device will cast a shading mask on the sun path diagram. A horizontal shading device masks the high angles or high altitude sun positions. The vertical shading device masks the azimuth angles. The degree to which the shading device restricts the sky vault is a function of the dimensions of the opening and the shading devices.



EGGCRATE



COMPINATIVE MASK

Figure 10

1. Olgyay, Victor, Design With Climate: Bioclimatic Approach To Architectural Regionalism, Princeton Univ. Press, N.J., 1965.

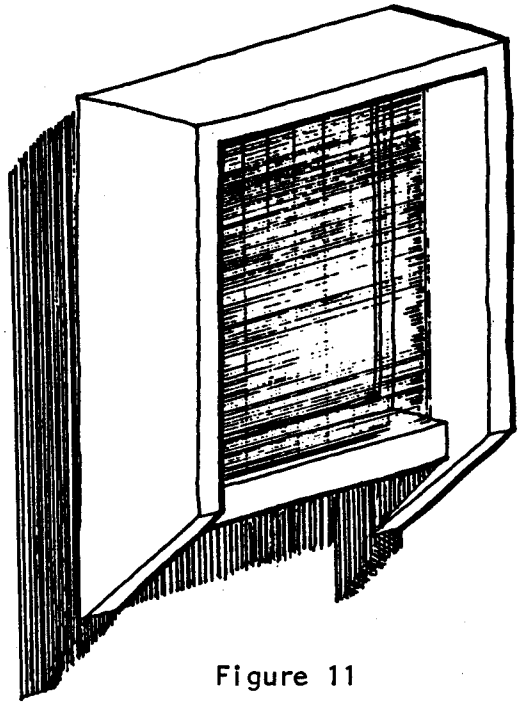


Figure 11

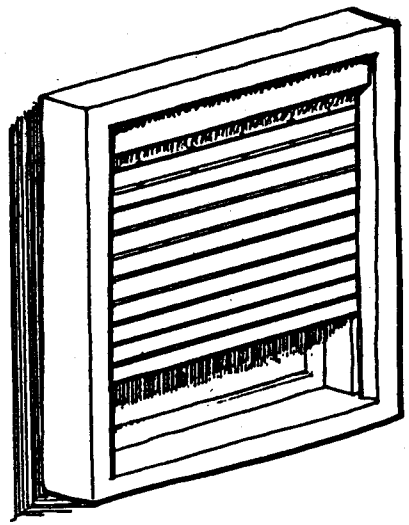


Figure 12

The calculation of the effective shading angle is relatively simple, given the length to be shaded and the protruding horizontal distance of the shading device. For instance, suppose a south-facing 4' high and 3' wide window had a shading device with a 3' horizontal overhang and a 1.5' vertical fin, and the problem consisted of drawing the sun mask on the sun path diagram. The effective altitude and azimuth can be calculated using the following formula:

$$\text{effective profile angle} = \arctan \frac{(\text{Length to be shaded})}{(\text{Length of projection})}$$

Using the formula for the overhang, the effective profile angle can be calculated.

$$\text{effective profile angle} = \arctan \frac{(4 \text{ feet})}{(3 \text{ feet})}$$

$$= \arctan (1.333)$$

$$= 53^{\circ}$$

Using the same formula for the side fin, the effective profile angle can be calculated:

$$\text{effective azimuth} = \arctan \frac{(3 \text{ feet})}{(1.5 \text{ feet})}$$

$$= \arctan (2.0)$$

$$= 63^{\circ}$$

These angles can be superimposed on the sun path diagram, as shown in Figure 11. The curving horizontal line is plotted using the cursor and 53° effective altitude angle. The vertical fins are represented on the sun path diagram as the lines perpendicular to the tangent of the circle and are located by subtracting 63° from 90 and plotting the 27° line.

Koolshade Solar Screen -- These exterior screens are manufactured by the Koolshade Corporation located at 722 Genevieve Street, Solana Beach, California 92075. (Figure 11) The Koolshade is a miniature venetian blind made from fine wire and tiny flat bands of metal. These bands, available in bronze or aluminum, stretch horizontally and are vertically tied together with a wrap wire of

special alloy. This makes for a very stiff assembly that is durable and can add security and protection from vandalism. Koolshade is manufactured in widths up to 72½" and unlimited length. It comes in two types -- Standard Koolshade with 17 louvers per inch, and Low Sun Angle Koolshade with 23 louvers per inch. Standard Koolshade is 100% effective at solar altitudes above 30°, while Low Sun Angle Koolshade is 100% effective at solar altitudes above 26°.

Swiss Blinds. Richard Goder Associates, Inc. distributes the Swiss Blind. The company's location is 7064 Lyndon, Rosemont, Illinois 60018. Swiss blinds are the most versitile of the shading devices on the market. They are manufactured in Europe and have been used there for a number of years. (Figure 12) These devices are rolling shutters that can be lowered to fully protect the window or be completely raised for full exposure. Normally, Swiss Blinds are operated manually, but if desired, their operation can be motorized. Motorized operation may be desirable in certain large-scale situations where uniformity of shading protection is desired.

Pella Window With Slimshade The Pella window combines the functions of window and shade. (Figure 13) The slimshade option offered by the Pella Window Company is a narrow venetian blind installed between the double insulating glass panes of their window. In this position, the delicate shade is protected from both outside and inside. The weatherstripped inner pane of glass can be removed for access to the slimshade for cleaning and repair. The angle of the horizontal slats can be adjusted by means of a knob mounted on the window frame.

Interior Insulating Shutter. Figure 14 illustrates the construction and operation of a lightweight insulating shutter that was designed during the MED project. The device was not used because the expected benefit would not justify the increased cost of such an insulating device in the mild coastal Southern California climate. This type of shading and insulating device would be justified in a more temperate climate. The device is made by joining two pieces of fabric in a manner to accept 12" wide lengths of 2" thick styrofoam board into "pockets" sewn into the material. The "pockets" in the fabric are sewn in order to allow the entire array of insulated pocketed panels to fold up into a neat stack. The continuous fabric acts as soft hinges between the panels. The shutter develops a tight fit around a window or

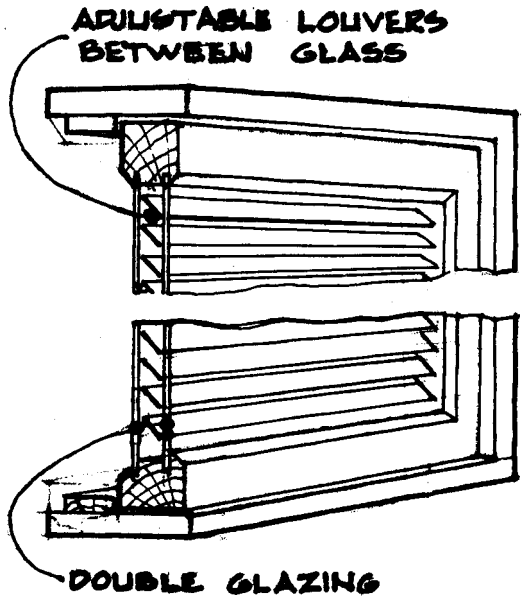


Figure 13

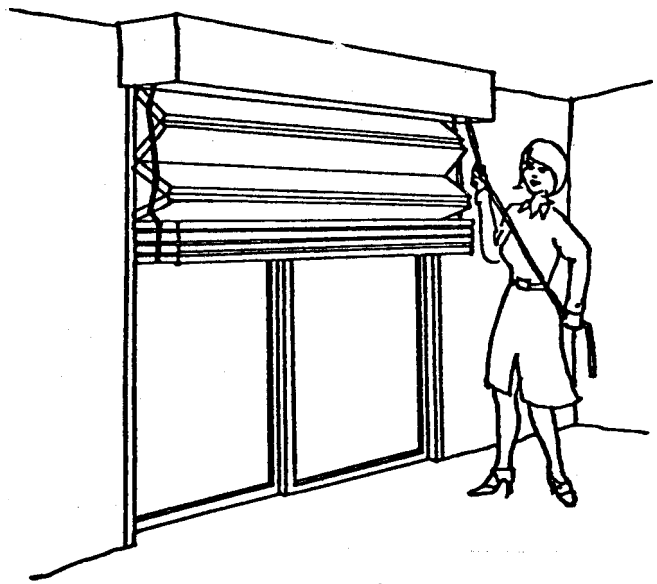


Figure 14

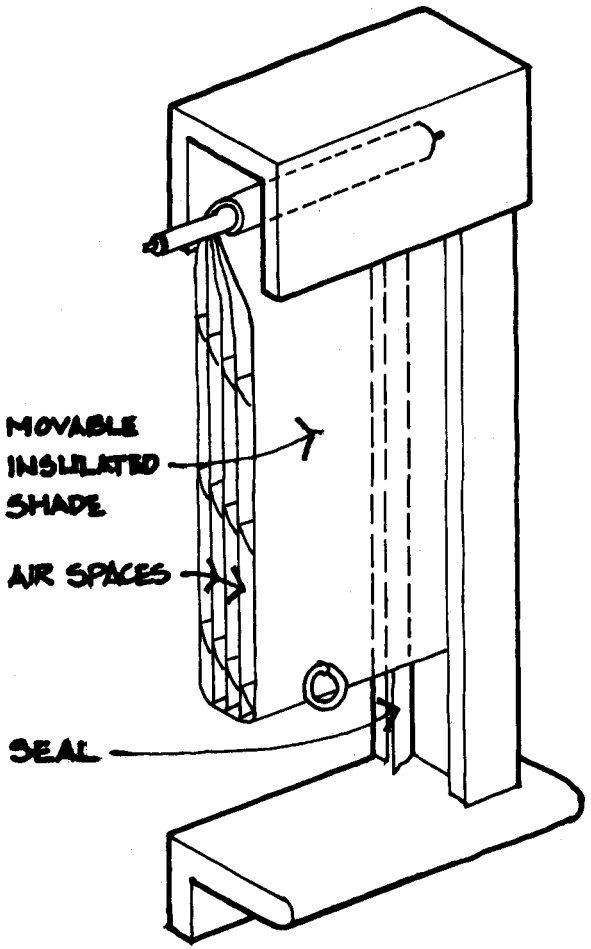


Figure 15

sliding glass door by using strips of *Velcro* on both panels and frame of the opening. Pressing those surfaces together will develop a tight fit against infiltration and convection.

The IS High "R" tm Shade. This new shading device is similar in function to the Interior Insulating Shutter in that it combines movable shading with very efficient insulating qualities. (Figure 15) The shade is placed on the interior side of the windows and is made up of multiple layers of plastic film. The shade is very compact when rolled up. When the shade is pulled down, these layers separate to form multiple dead air spaces. Special seals are used at the perimeter of the shade to prevent infiltration of unconditioned air. Available from: IS Company, 17 Water Street, Guilford, Connecticut 06437.

ventilation and infiltration 7

wind and buildings

the stack effect

infiltration

ventilation

ventilation and infiltration

The introduction of unconditioned outside air into a conditioned space by ventilation or infiltration will most often place an added burden on the mechanical system. Large amounts of outside air are introduced intentionally through ventilation or unintentionally by infiltration. In either case, the difference between uncomfortable outside air and interior air conditions within the comfort zone is maintained by the use of energy. The conditioned interior air is constantly being diluted with unacceptable outside air. The design objectives in this are to maintain the fresh air requirements for the occupants while simultaneously reducing the energy impact of unneeded outdoor air.

infiltration

Infiltration is caused primarily by wind flow around a building creating regions of positive and negative pressure forcing air through cracks in the windward side and drawing air out through cracks in the low pressure zone on the leeward side. The "chimney" or stack effect caused by indoor-outdoor temperature differences rather than wind forces, contributes substantially to air leakage. For example, in winter or summer, heated air rising through a building to pass through openings or cracks high in the structure will draw in unconditioned air at openings or cracks low in the structure.

wind and buildings

Buildings in the wind are like rocks in a stream which disrupt the uniform, even pattern of water flow. (Figure 1) A house, in the path of the wind, creates pressures that are both above and below the static pressure of the air stream. Wind that flows directly into a wall will build up and form a high pressure zone. As the wind slips over and around to draw away from the structure, it creates a low pressure area on the leeward side resulting in the outward flow of internal air from the structure. Walls parallel or angled slightly toward the wind will also be subjected to negative air pressures. Flat or low roofs are usually in areas of negative pressure, while the windward side and leeward side of steep roofs respectively form positive and negative zones. The wind speed responsible for these zones will determine the magnitude of the pressure difference between inside and outside, and thus the magnitude of new air volume penetrating and structure.

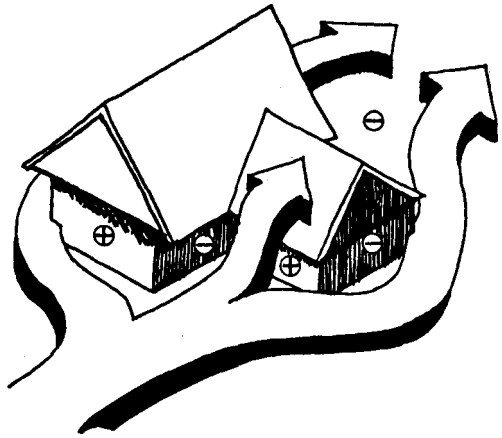


Figure 1

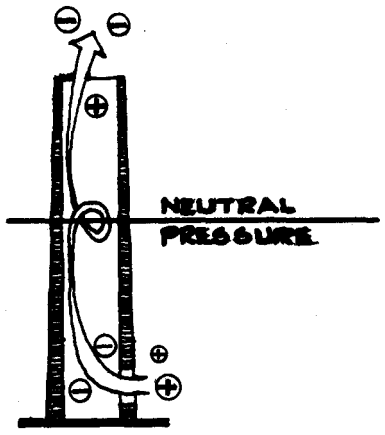


Figure 2

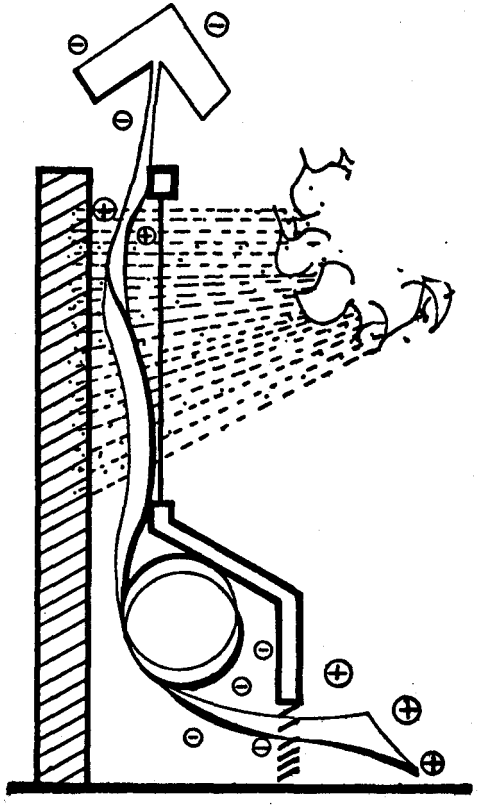


Figure 3

the stack effect

The *stack effect* is caused primarily by temperature differences within a building. A temperature difference varies air density which promotes a pressure difference giving rise to air movement. (Figure 2) A chimney is the simplest example of this. Hot gases on the inside of a chimney produce a negative pressure and an inward draft of air through openings at low levels. This stack effect also creates a positive pressure and an outward flow at the top of the chimney. The higher the stack, the greater the flow of air. At some point between these extremes lies a point of neutral pressure. From this neutral point, the magnitude of pressure difference varies with the distance from the neutral zone. Buildings are roughly analagous to chimneys but differ because of the walls and floors within the space. These "obstructions" cause resistance to air flow within the building and result in pressure losses. The resistance depends on the size and distribution of openings between floors and exterior walls. If the resistance is low, which is usual, the building will act like a chimney whose rising air stream has the same static pressure along its length or height.

The stack effect can be used to an advantage in some cases. An interesting application is to induce a stack action for summer cooling. The method employs the heating of a large quantity of a dense material to an elevated temperature with the use of solar energy. The material would have to be placed in an unconditioned space to avoid an increase in the cooling load. (Figure 3) At night, after a day of solar energy collection, a "solar chimney effect" will occur when the massive material will heat air and cause it to rise and pull cooler outside air into the living space through openings low in the building.

infiltration

With modern residential building techniques, the building shell of today is a much more airtight assembly than it has been traditionally. It has become common practice to install a continuous pastic *vapor barrier* between inside finished wall panels and the wood frame. Were it not for penetrations such as windows, doors, electrical outlets, etc., and the vulnerable joint at the sill connection, infiltration would be minimal. Therefore, any effort to reduce infiltration should be directed toward these problem areas.

Weatherstripping on doors and windows is becoming increasingly important as infiltration becomes a dominant component in the energy consumption of a house. The use of weatherstripping can be classified into three main groups:

- Jambs
- *Astragals*
- Sills

Each poses a different type of weatherstripping problem. The jamb, the vertical edge of a door or window, is one of the easiest areas to solve. The primary concern is a seal which is unobtrusive while maintaining low cost and ease of installation. The astragal, the vertical joint where two movable doors or windows come together, require a similar solution. The sill of a door demands a device which can withstand the constant foot traffic on top of it without deteriorating.

The type of weatherstripping can be broken down into the following:

- Interlock--Consists of interlocking strips of metal connected to both the jamb and door. It is one of the best seals available if properly installed.

- Spring Metal--If metal strips are correctly installed, they can be highly efficient. They come as flat "tension strips" sold in rolls. One edge of the strip is nailed to a door or window frame. Then the free edge is lifted away from the frame. The spring developed holds the strip of metal against the door when closed.

- Gasket--A gasket consists of compressible tubing manufactured out of rubber or vinyl plastic tube with a flange for nailing to the door stops. The tubing is slightly compressed upon the door closing to create a seal. The gasket can be non-reinforced or reinforced at the flange by an aluminum strip.

- Felts--Felts are not quite as compressible as gaskets and come in a variety of materials. All-wool felt is preferable. It, too, can be obtained in reinforced and non-reinforced types.

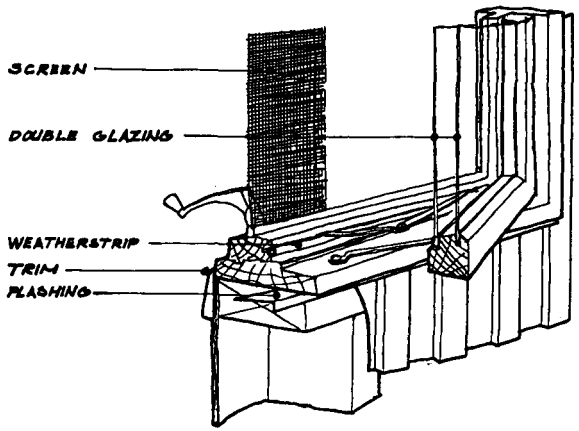


Figure 4

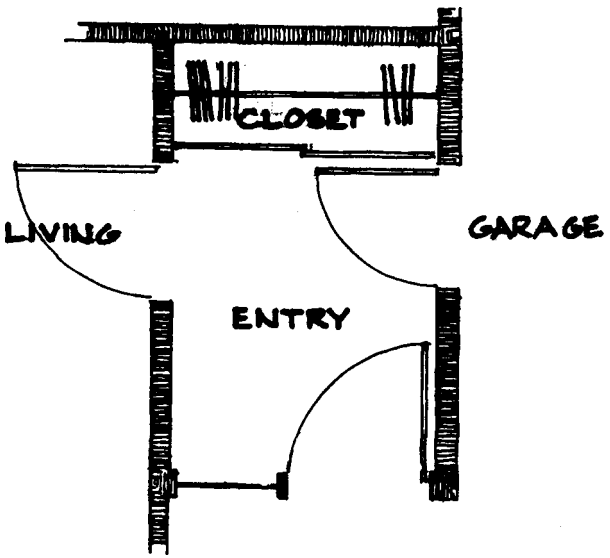


Figure 5

Foam Strips--Usually made of a synthetic material, foam strips come in rolls of various widths and thicknesses. They can be applied in a variety of methods. Some are glued on, usually by means of pre-applied adhesive protected by a peel-away paper covering.

Sill Seal-This joint between the wood frame and the foundation wall can be sealed by the use of commercially available products. These sales are in the form of a fiberglass pad or a special putty. Both types are manufactured in coils that are simply rolled out on cleaned concrete and the wall frame is placed in top. When the final connections are made these materials are compressed between the wood sill and the foundation to form a good seal.

Windows--When selecting windows, care should be taken to insure that the manufacturer has provided weatherstripping as an integral part of the window design. The window selected for the MED houses is a Pella *casement window*. (Figure 4) In this window, the sash closes against a compressible vinyl gasket tubing. This integral weatherstripping is factory installed around the entire perimeter of the window. After the window is closed with the crank mechanism, a lever operated lock can be engaged to tighten the seal around the window.

Another problem area that requires some attention is the gap that occurs between the rough wood frame and the finished window frame. This is a potential area of air infiltration that can be very simply eliminated. Prior to the installation of the interior wall panels, this opening should be stuffed with fiberglass insulation.

Air Lock Entry--The MED houses have an entry arrangement that prevents direct infiltration or loss of conditioned air to the outside. The entryway has three doors connected to it. One opens to the garage, one to the living room, and one to the outside. Thus, when entering the house, one must use two doors. (Figure 5) As designed, the entryway has become an additional storage room for the family and therefore a saleable feature. The front door and garage doors are metal with a magnetic weatherstripping around the edges of the doorway.

Electrical Boxes located in exterior walls present a problem in that they are penetrations through the vapor barrier and the interior wall finish. The boxes themselves have many holes to facilitate a variety of electrical connections. Infiltration then occurs through and around the electrical box. In the MED houses, all electrical boxes were wrapped with a sheet putty material to prevent infiltration. Care was also taken in installing wiring. Under normal conditions, a hole is drilled through the center of the stud construction and the wiring is fed through the hole. In this situation the insulation must be compressed over the wires, reducing the thermal resistance of the insulation. In the Minimum Energy Dwelling, a notch is placed in the interior stud face and the wiring stapled to the notch. This prevents the compression of the insulation.

The MED houses were constructed using quality materials and all of these techniques to prevent infiltration. Controlled testing of both MED houses and a third standard house indicate that these techniques were successful in reducing infiltration in the MED houses to about one quarter of the values measured for the standard house. There was, however, one problem area that if left uncorrected would negate all of the other efforts. This problem occurred in the ventilation system ductwork through the unconditioned attic space. Due to poorly fitting duct connections, the infiltration rate when the system was operating in a recirculation mode exceeded the rate of the standard house. In the past, ductwork losses were not considered a significant problem. But with tighter construction, the need for better installation techniques for residential ductwork becomes necessary. It is also critical that these connections be carefully inspected during construction, as it is often very difficult or impossible to reach these connections in a finished structure.

ventilation

Ventilation, as mentioned earier, is an intentional introduction of outside air into a building. This can be accomplished by mechanical or natural means and has three[1] primary functions:

1. Givoni, B., Man, Climate and Architecture, Elsevier Publishing Company, Ltd., New York, 1969.

Application	Smoking	Cfm per Person[b] Recommended	Minimum[c]	Cfm per Sq.Ft. of Floor[b] Minimum[c]
Apartment				
Average	Some	20	10	---
DeLuxe	Some	20	10	---
Banking space	Occasional	10	7½	---
Barber shops	Considerable	15	10	---
Beauty Parlors	Occasional	10	7½	---
Broken' board rooms	Very heavy	50	20	---
Cocktail bars		40	25	---
Corridors (supply or exhaust)		--	--	0.25
Department stores	None	7½	5	0.05
Directors' rooms	Extreme	50	30	---
Drug stores[e]	Considerable	10	7½	---
Factories[d,f]	None	10	7½	0.10
Five and Ten Cent stores	None	7½	5	---
Funeral parlors	None	10	7½	---
Garages[g]		--	--	1.0
Hospitals				
Operating rooms[f,g]	None	--	--	2.0
Private rooms	None	30	25	0.33
Wards	None	20	10	---
Hotel rooms	Heavy	30	25	0.33
Kitchens				
Restaurant		--	--	4.0
Residence		--	--	2.0
Laboratories[e]	Some	20	15	---
Meeting rooms	Very heavy	50	30	1.25
Offices				
General	Some	15	10	0.25
Private	None	25	15	0.25
Private	Considerable	30	25	0.25
Restaurants				
Cafeteria[e]	Considerable	12	10	---
Dining room[e]	Considerable	15	12	---
Schoolrooms[d]	None	--	--	---
Shop, retail	None	10	7½	---
Theater[d]	None	7½	5	---
Theater	Some	15	10	---
Toilets[d] (exhaust)		--	--	2.0

a - taken from present-day practice; b - this is contaminant-free air; c - When minimum is used, take the larger of the two; d - See local codes which may governs e - May be governed by exhaust; f - May be governed by special sources of contamination or local codes; g - All outside air recommended to overcome exhaustion hazard

Figure 6

- Health Ventilation
- Comfort Ventilation
- Structural Cooling

Health ventilation maintains the quality of indoor air by replacing indoor air, stale from oxygen depletion and odor contamination, with outdoor air. Ventilating standards for required ventilating air in cubic feet per minute per person are listed in Figure 6, for certain residential functions and various commercial and industrial establishments. Health ventilation has not been of great concern to residential builders in the past because of the great amounts of natural ventilating occuring in older, less airtight structures. However, with the trend for airtight construction methods, natural infiltration may not meet health ventilation requirements. Such features as the pilotless ignition which eliminates unwanted carbon monoxide production and air cleanining equipment in the air handling system may become mandatory. The use of recirculating fans and bathrooms and kitchens contaning activated charcoal for odor control eliminates the need for exhaust to the exterior. Fresh air requirements then would be met by controlled means in the air handling system.

Thermal comfort ventilation is the maintenance or improvement of indoor comfort by the use of moving air. It involves preventing uncomfortable feelings of warmth or skin wetness by the introduction of moving air. When such feelings overcome a person, he is likely to unconsciously adjust his clothing or open a window. The actual relationships of the building that govern the heat exchange between man and the thermal environment are numerous and complex. The shape of the space and location of openings affect the air movement. Laboratory experiments demonstrate that thermal comfort ventilation actually relates more closely to the velocity of the ventilating air. A small stream of air directed at desk top level will cool a person sitting at work, but a slow movement of a large volume of air overhead near the ceiling will have less effect. For this reason, requirements for thermal comfort ventilation should always be rated in velocity rather than air changes.

The third function of ventilation is to cool the structure of the building when inside temperature is higher than outdoors. During hours when the indoor temperatures are above the outdoor level ventilation always has a cooling effect. In residences the most

common type of structural cooling is attic ventilation. Attic spaces, a characteristic of most single family dwellings, are the result of a number of factors. The rise of a sloping roof necessary to shed water adds oddly shaped volume to a house which is difficult and expensive to finish. Ordinarily, this volume is closed off with a flat ceiling -- a procedure often expedited by the convenient presence of the horizontal bottom cords of the roof trusses. Three things are accomplished:

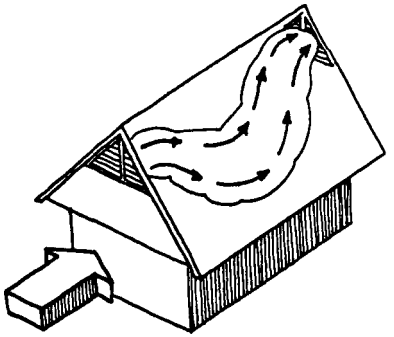
- Less material and time are needed to finish the simplified, smaller space below the attic
- The volume of the space to heat and/or cool is reduced (if the insulation is laid on top of the ceiling
- An out-of-the-way storage place for cast-off or seldom used articles is created.

During the summer, if not properly ventilated, the heat of the sun can build up within the attic and be transferred to the space below, causing discomfort to the occupants.

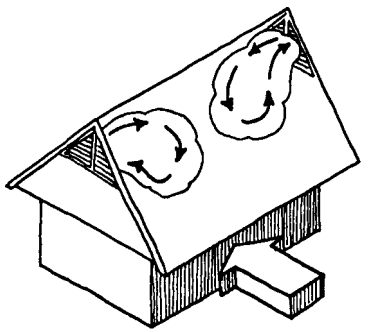
Low humidity winter-time conditions present a second different problem. The heated, moist air of the interior space unbalances the vapor pressures between indoors and out, sending water vapor through the insulated ceiling into the cold space of the attic. It is certain that this vapor will condense repeatedly throughout the winter on the cold surfaces of the roof structure, causing considerable damage if it is not allowed relief by escaping to the low vapor pressure exterior. Both problems of heat buildup and condensation are solved by ventilation.

Providing openings to allow sufficient air movement in and out of the attic will prevent both heat buildup and condensation problems. The effectiveness of this ventilation in solving these problems depends upon the quantity of air introduced and the uniformity of its movement through the attic. Satisfying these two requirements demands the proper location of vents which have adequate open area.

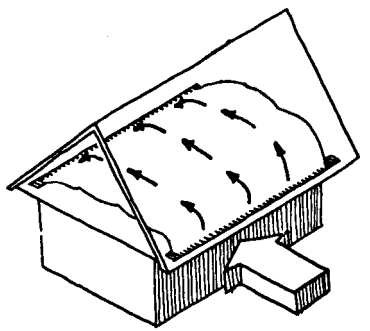
A number of different devices are available on the market, but all do not have the same effectiveness. Roof louvers are small domes



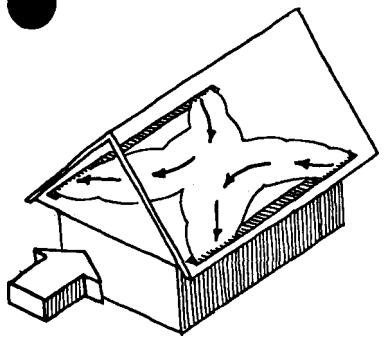
(7) Gable End Louvers - Parallel To Wind



(8) Gable End Louvers - Perpendicular To Wind



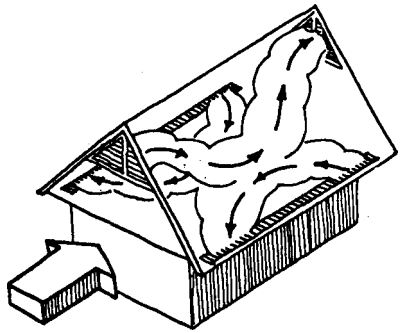
(9) Soffit Vents - Parallel To Wind



(10) Soffit Vents - Perpendicular to Wind

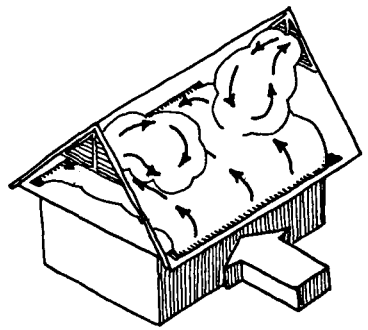
which are mounted near the roof ridge. Some in this class have a type of baffle designed to reduce weather infiltration and improve air flow. Others have turbines which spin in the wind and draw air from the attic, but these are only effective at higher wind velocities when attic ventilation is less needed. Most of these louvers have only a small net-free area, so it is difficult to induce adequate flow unless a great number of vents is used. Even then, air movement is restricted to flow between the vents near the ridge point.

Gable end louvers are triangular vents set in the points of the attic's two gable ends. They are inconspicuous and inexpensive, thus making them the most popular devices in use. If a house fitted with gable end louvers is aligned parallel with the direction of the wind, air will move through the attic from end to end in the narrow path shown in Figure 7. Wind blowing roughly perpendicular has a reduced effect, causing only local air movement near each vent without the benefit of cross ventilation. (Figure 8) Soffit vents will move air only along the attic floor or (Figures 9 & 10) Soffit vents will move air only along the length of each vent. (Figures 11, 12) Combinations of both gable ends and soffit vents still are not totally effective; both tend to act independently of each other.

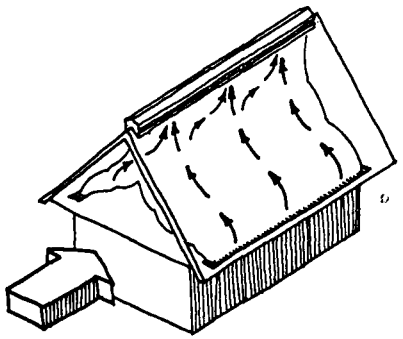


(11) Combination - Parallel To Wind

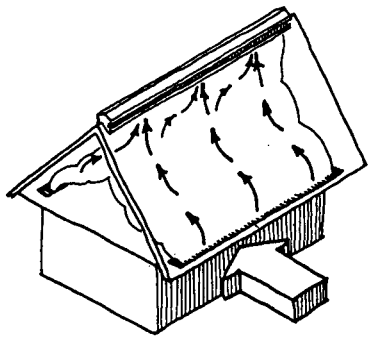
The only venting arrangement which secures adequate quantity and uniformity of flow is the balanced system using a continuous ridge vent at the highest point in the attic and soffit vents at the lowest point along the extreme edge of the attic near the eaves. (Figures 13, 14) This arrangement allows the air moving



(12) Combination - Perpendicular To Wind



(13) Ridge and Soffit - Parallel To Wind



(14) Ridge and Soffit - Perpendicular To Wind

through to uniformly contact all surfaces where condensation may occur in the winter, and in the summer will exhaust heated air from all points in the attic volume. The net-free area of the continuous ridge vent should equal the total net-free area split between both continuous soffit vents. This permits free entry and departure of air without any pressure losses. The effectiveness of attic ventilation will be shown by reduced attic floor temperatures in the summer. Figures 15 and 16 illustrate, first of all, the relationship between wind velocity and roof temperature. Note that a radical drop in roof temperatures occurs only after wind velocities reach 10 miles per hour and beyond. Figure 15 shows the effect attic venting has in reducing attic floor temperatures. Even without wind movement, the continuous ridge and soffit arrangement induces a convective flow of air--hot air near the ridge vent moves up and out and pulls cooler air in through the soffit vents preventing floor temperatures from reaching 120°F. The temperature reduces further when increased wind velocity pulls air quantities through the attic.

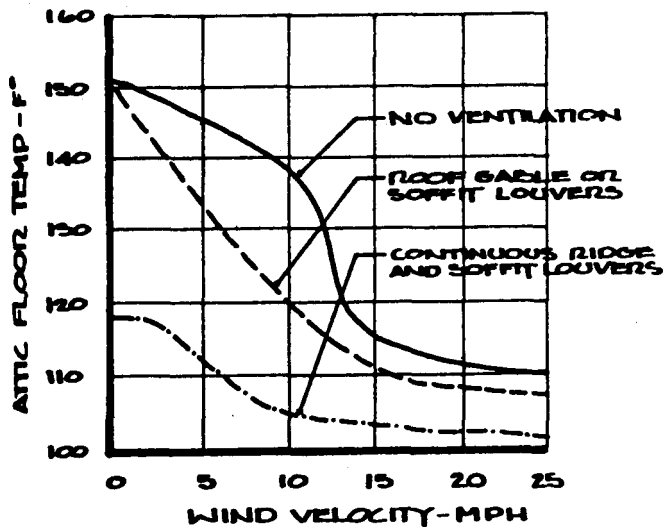


Figure 15

SOURCE: Fundamentals of Residential Attic Ventilation

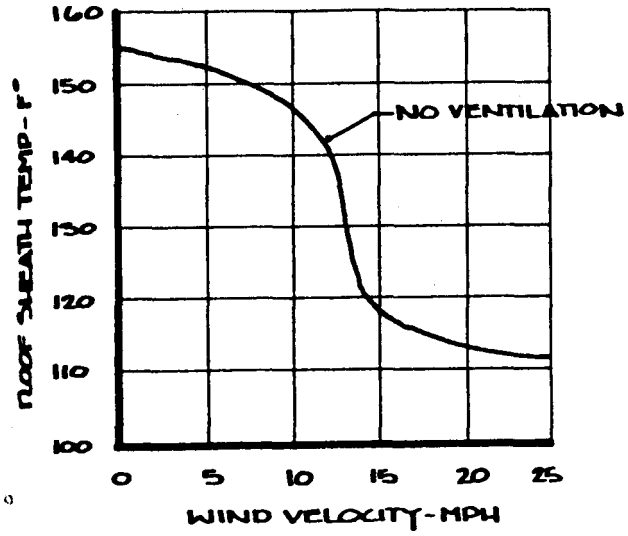


Figure 16

SOURCE: Fundamentals of Residential Attic Ventilation

internal loads

people

lighting

appliances

internal loads

Heat produced by people or appliances and other mechanical equipment inside a building, excluding that supplied by design through the mechanical system, is considered to be an *internal load*. The effect of an internal heat source on a building's energy consumption is dependent on three factors:

- Climate
- Building Composition
- Heating or Cooling Mode of Operation

Depending upon these factors, an internal heat load may be either a detriment or a benefit. For example, in a climate where heating is a primary concern, internal heat produced outside of the mechanical system is a benefit. If cooling is necessary, internal heat sources become detrimental. Composition of a building is also very important. As pointed out previously in the Mass discussion, the composition of a building's shell can greatly affect its thermal performance, total energy consumption and even equipment size. For example, in a climate where mechanical cooling is required, interior walls that receive direct sunlight have the ability to absorb and re-radiate heat, resulting in an increased cooling load. Internally produced heat can be so great in commercial buildings that it is not uncommon to find a building that requires cooling during a season that normally requires heating. Similarly, during summer months, air conditioning failures often occur due to overloads caused by internal heat.

On a residential scale, the sources of internal heat are of a much smaller magnitude and are not as varied. However, the building is much smaller and with today's trend toward heavily insulated building shells, internal heat is retained within the residence. In climates where mechanical cooling is necessary, this retention of internal heat represents an added cooling load. Since there are many different sources of internal heat, it is necessary to consider each one separately and eliminate or reduce its impact. This process was carried out in detail for the MED house.

To examine the amount of internal heat produced in the MED, the individual heat sources must first be identified. The following categories were considered in analyzing the internally produced heat loads in the MED:

RATES OF HEAT GAIN FROM OCCUPANTS OF CONDITIONED SPACES

Degree of Activity	Total Heat Male Btu/Hr.	Total Heat Female Btu/Hr.	Total Heat Child Btu/Hr.	%* Sensible
seated at rest	390	310	295	70
seated, very light work	450	360	340	60
moderately active office work	475	380	355	55
standing, light work; or walking slowly	550	440	415	55
light bench work	800	640	600	35
moderate dancing	900	720	675	35
walking, 3 mph	1000	800	750	35
moderately heavy work	1000	800	750	35
heavy work	1500	1200	1125	40

*Tabulated values are based on 75°F. room dry-bulb. For 80°F. room dry-bulb, the value calculated should be reduced by 20% and the latent heat values increased accordingly.

Figure 1

- People
- Lighting
- Appliances
- Bathroom Activities

All four categories were studied on a twenty-four hour basis for three different days: Weekdays, Saturdays, Sundays and holidays. The information provided by this very detailed study provides us with an indication of how much internal heat is produced in the home as a result of daily appliance use and also occupancy patterns in the home. The daily use patterns will be discussed later. First, let's look at the heat generated on an hourly basis in each of the four categories.

people

Depending on the type of activity one is engaged in as well as age and sex, the amount of heat produced by building occupants varies greatly. (See Figure 1) As one might expect, the more strenuous the activity, the greater the amount of heat introduced to the interior space. In developing the daily heat gain for the MED house two values for heat only from occupants were developed: An average "sedentary" value of 350 BTU/hour and an "active" value of 450 BTU/hour. This results in slightly lower values during working hours. However, increasing the sedentary value takes into account periods during late evening or early morning when personal activity generates more heat than the 450 BTU/hour and above values which are normally associated with various daily activities. The totals compare favorably with similar studies done by Westinghouse for the MED project, and coincide with the average values given in the ASHRAE Handbook of Fundamentals.

lighting

Twenty-eight percent of the total daily internal heat produced in the MED home is attributed to lighting. A standard 100 watt light bulb produces 340 BTU/hour of heat or nearly the same as the heat given off by one sedentary occupant. Residential lighting is one area in which the designer can improve the environment while reducing internal loads. The substitution of flourescent lighting for incandescent lamps will result in a savings in electrical energy and in internal heat production. Regardless of incandescent

1. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineering, Inc., New York, 1972, Chapter 22, P. 416.

or flourescent lamp type, one watt of electricity producing light makes 3.4 BTU/hour of internal heat. However, a standard 40 watt flourescent fixture produces nearly 2 times more light than a 100 watt incandescent lamp, and therefore fewer flourescent fixtures are required to achieve the same lighting level. Another method called "task lighting" is very effective. (Figure 2) This consists of lighting the specific work surface where lighting is required rather than intense general illumination of the entire occupied space. The savings with either of these two methods result in not only reduced internal heat but also reduced consumption of electricity.

The benefits of natural light should not be overlooked. If care is taken to minimize undesirable heat gain and heat loss through the use of shading techniques and moveable insulation as discussed previously, daytime lighting needs can be handled through careful layout of the home. Good quality thermal insulated windows and skylights in strategic locations and well oriented clerestories can provide energy free daytime illumination. The most tangible benefits of good lighting design using both artificial and natural light are in energy savings. However, other benefits may result in the form of a more interesting and aesthetically pleasing design that makes for a better environment.

Figure 2

appliances

The selection of home appliances can have a great effect on internal heat as well as energy and water consumption. We, as consumers must consider the entire cost of an appliance throughout its functional lifetime. With rising energy costs, appliance manufacturers are responding with new features designed to save energy and effectively offset any additional first cost that is passed on to the consumer. The following is a brief discussion of decisions made when selecting appliances for the MED houses.

The major appliances used in the internal heat studies for the MED home are those which will actually be supplied. They differ from those normally found in a conventional home in that they are energy and water conserving.

Clothes Washer - The Maytag Model A608 was selected for use in the MED home. It draws approximately .2 KWH of electricity resulting in a 683 BTUH heat output. A water supply of 140°F. is recommended for the hot wash cycles of this machine. However, according to manufacturer's test data and consumer surveys, most wash loads are

done with warm settings using 100°F. water. Although the wash water experiences a 15°F. temperature drop, most of the heat introduced into the unit via the water leaves at the end of each cycle through the drain. Because the 683 BTUH output from washer operation is relatively low, it may be safely assumed that the clothes washer is responsible for a negligible part of the internal loads. Washing the average four loads per week results in only 2732 total BTUH, or an average of 390 BTU a day--roughly the equivalent of an adult male in a sedentary state for one hour.

Clothes Dryer - Clothes drying is accomplished through the inclusion of a DC608 Maytag clothes dryer with a pilotless electronic ignition. The Maytag company rates the unit at 22,000 BTUH input. The product testing division estimates that at least 95% or 20,900 BTUH are effectively exhausted and do not contribute to conditioned space heat up. Research does reveal that heat reclaimation from the dryer in heating modes can be accomplished but is not desirable except under the most severe heating demands. In order to collect exhaust heat from the dryer, an additional lint filter would have to be supplied on the discharger side of the dryer's fan. Also increased static pressure from additional ductwork would necessitate the addition of a larger fan. Some question exists as to whether the high humidity heat would be desirable.

Of particular interest is the *pilotless electronic ignition.* According to an article in the June, 1976 issue of ASHRAE Journal entitled, "Standing Pilot Gas Consumption", a standing pilot will consume 350 BTU an hour. Fueling the pilot twenty-four hours a day for 365 days a year results in a total consumption of 3,066,000 BTU a year. Eliminating the pilot eliminates this amount of internally generated heat from the total cooling load and enables a savings of 3,066 cubic ft. of gas. A conventional gas dryer with a pilot light will consume twice the amount of gas as one with a pilotless ignition.

Dishwasher - Water consumption as well as energy considerations dictated the selection of a Whirlpool SUD 9000 dishwasher for the MED. The SUD 9000 enables the user to choose one of six different wash cycles for various loads and dishwashing chores. These range from the Super Wash and Super Scour cycles, each of which use 13.9 gallons of 140°F water, to a Rinse-Hold cycle using only 4.6

gallons of warm water. The unit includes an 800 watt heating element which may be used or omitted to control the addition of heat with "Add Wash Heat". "Add Dry Heat", and "Add No Heat" options. This permits the user to control heat input to each cycle. Allowing the contents of the dishwasher to dry naturally saves the energy that would normally be automatically used to accomplish the same result in a shorter period.

The major portion of the heat generated by the dishwasher is a product of the 800 watt heating element. Supply water for the unit, introduced at 140°F. undergoes only a 50°F. temperature drop before being discharged down the drain. Because no water is retained in the unit, the heat generated from the wash water is minimal. Discussion with the manufacturer revealed that on the average, 1944 BTUH are generated by the dishwasher during the operation of the "Super Wash Cycle". This heat is attributed almost entirely to the heating element which works only a fractional part of a typical one-half to one hour cycle.

Range - The MED features Tappan Model 30-3866 Gas Convection-aire Ranges with self-cleaning ovens. A medium consumption rate of 9250 BTUH was determined for the oven/broiler burner. By averaging available information, a conservative heat output by the range was guaranteed for examination purposes. Like the clothes dryer described earlier, the range has a *pilotless electronic ignition* system for both the range-top and oven/broiler burners. Table 1 in the June, 1976 ASHRAE Journal article "Standing Pilot Gas Consumption" lists range pilot consumption rates at 400 BTUH. This is equal to 9600 BTU per day or 3,504,000 BTU a year. A separate pilot for the oven/broiler burner would double this number. Substitution of an electronic ignition system is a definite benefit in the MED as it will be in a cooling mode most of the year. Assuming the given 400 BTUH consumption rate stated in the article, 3504 cubic feet of natural gas could be saved by one pilot light. Separate pilots would, of course, conserve twice that amount.

The problem of range-generated heat was studied a number of various ways in the early stages of the MED development. One particularly interesting technique of heat removal was proximity range venting. Proximity venting is a system by which cooling heat and vapor are collected at stove-top level and discharged

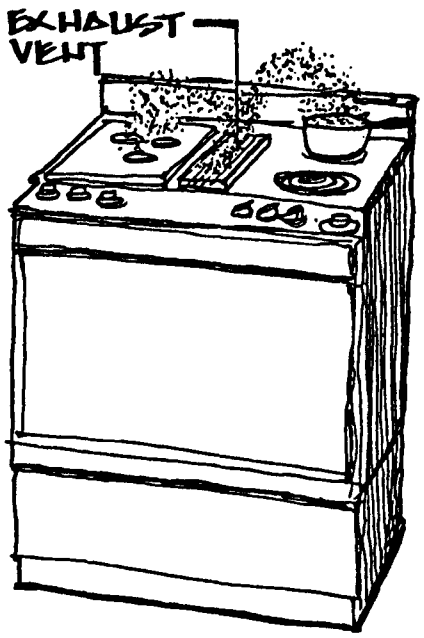


Figure 3

through a ductwork and fan integral with the range appliance. In such an arrangement, the heat and moisture are not allowed to saturate the air above the range top, even enroute to discharge.(Figure 3) However, conditioned air in the vicinity of the range is drawn through the appliance and discharged to the outside. Outside air must eventually be supplied to make up this discharged air. During periods when high humidity outside air conditions make it highly undesirable for intake, the mechanical system will be asked to condition air which is being simultaneously discharged back to the exterior. The energy used to power the range's ventilating fan would also have to be taken into account under such circumstances.

Refrigerator--The efficiency of the refrigerator has greatly improved in recent years. The development of high quality foam insulation and also improved door seals are the primary advances. Some manufacturers claim a 45% reduced electrical consumption with these latest improvements. When selecting a refrigerator, the homeowner should look for a high quality in these two components. Also care should be taken to select a unit that is sized according to need. Regardless of quality, an oversized refrigerator will consume more energy than is necessary.

The internal heat problem caused by the refrigerator is due to the passage of air over the condensor coil. This heat amounts to 400 BTU/hour. Figure 4 illustrates a condenser venting arrangement that was used in the MED house. The lower portion of the kitchen corner cabinet is converted to an insulated compartment for the refrigerator's condensing unit. Two pairs of dampers are used to reject the heat into the Living Area (during heating season) or to the outside (during cooling season). When rejecting heat to the outside, the refrigerator operates as an inefficient air conditioner rejecting 1200 BTU/hour to the outside.

The Fireplace is often considered a supplemental heat source. However, to the contrary, the typical residential fireplace is often a net heat loss. This is due primarily to conditioned room air being drawn into the hearth to provide combustion air for the fire. Any heat conducted into the air is quickly drawn up the flue and outside-pulling more room air with it. The only heat felt by the occupants is that heat radiated in the immediate area of the fireplace. Meanwhile, areas of the residence remote from the fireplace are becoming

cooler as outside air infiltrates to make up the air lost up the flue. Eventually the furnace will come on to make up the heat lost through the fireplace. At this point, more energy is being consumed than if the fireplace were not in operation.

The solution to this problem is simply to introduce outside air at hearth level to make up combustion air. (Figure 4) This can be further improved by installing tempered glass doors over the firebox to effectively separate the combustion air from room air. In new fireplaces, serious consideration should be given to the installation of ducts to extract heat absorbed by the fire chamber enclosure and distribute it to adjacent interior spaces. Many other suggestions are available from fireplace distributors and manufacturers. The major concern is to provide a fireplace that is more than decorative -- an installation that will not sacrifice the rest of the home to heat a small area.

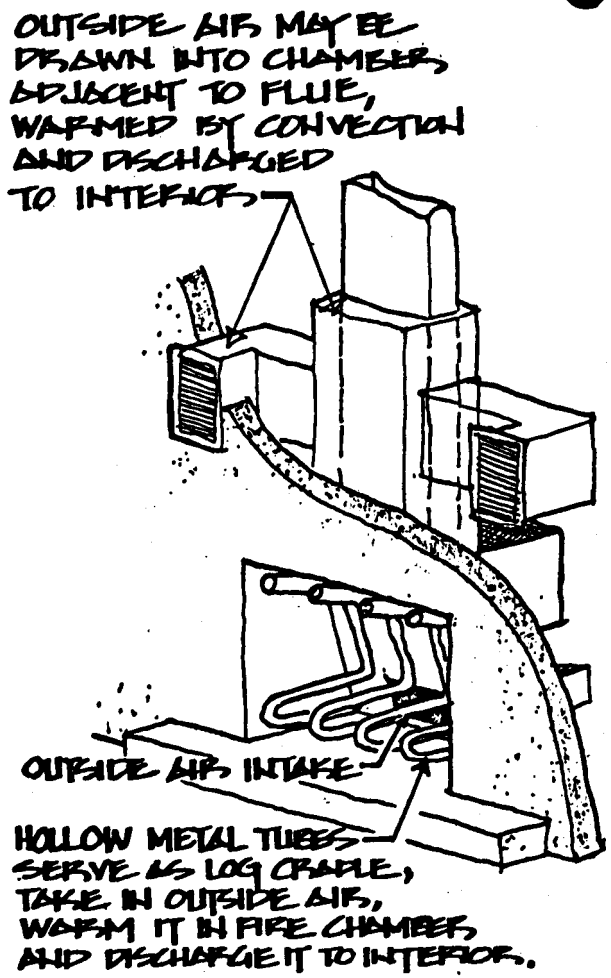


Figure 4

saving water to save energy

In Southern California, water conservation is an area of real concern. There is a lack of both surface waters and significant underground basins. The Mission Viejo development is supplied by a blend of water from Northern California and the Colorado River. Both sources are quite remote and the construction of large scale supply lines was required to meet water demands. The consequences of the arrangement are twofold for any large scale development in Southern California:

- Developments in Southern California have a noticeable impact on the available water supply.

- Developments in Southern California will present significant sewage disposal problems.

The Mission Viejo development is directly affected by this situation. The developers have expressed an awareness of the problem and a willingness to investigate alternatives.

The environmental impact statement written for the Mission Viejo Tract states that a total of 282,500 gallons of water a day are required to supply the residents of Mission Viejo. This estimate is based on 178 gallons a day for 1587 persons and includes all water uses public and private. The 178 gallons per day is equivalent to 100 cubic feet of water required for a family of four. This is roughly equivalent to the amount of water passed by flushing an average toilet 140 times. Although the Santa Margarita Water District reported that their water supply is adequate to serve the Project, it will unavoidably reduce the amount of water available to existing and future developments unless other water sources are developed.

The Mission Viejo Development will also generate approximately 175,000 gallons of sewage per day, all of which is treated at the San Juan Capistrano Treatment Plant and discharged into the Pacific Ocean. The 107,500 gallons difference between the figure stated in the previous paragraph represents water which is not dischaged into the sewage system. This includes water in public and private pools, fire prevention systems, lawn and garden watering. It is the judgement of this report that the waste of potable water in the conventional sewage removal and treatment process is most unfortunate and certainly deserving further study.

saving water to save energy 9

residential water use

five waste disposal processes

grey water re-use

magic flush

reducing water consumption

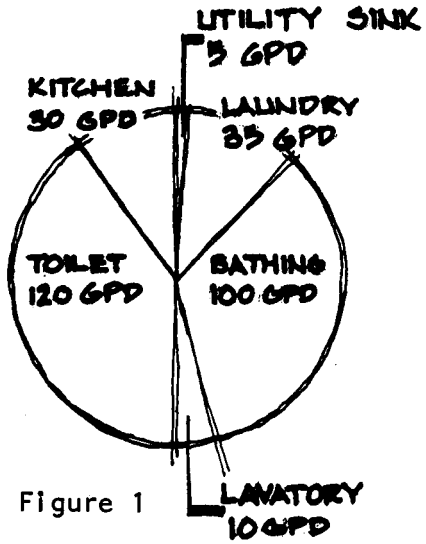


Figure 1

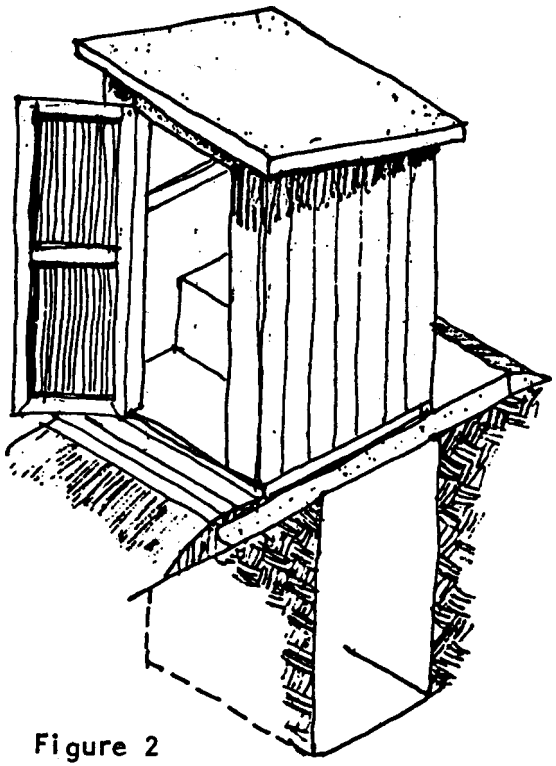


Figure 2

residential water use

If we consider only the potable water used privately in the residence, the per person consumption rate is between 60 and 75 gallons a day per person, or about 240 gallons a day for a family of four, as opposed to the previously stated 178 gallons a day per person for public and private usage combined. This results in the family of four using between 88,000 and 110,000 gallons a year for indoor use. (Figure 1) The breakdown for an average residence is as follows:

Toilets	40%
Bathing	33%
Laundry	12%
Kitchen	10%
Lavatories	3%
Utility Sinks	2%
Total	100%

It is apparent from this breakdown that most of our potable water is not used for drinking but for hygiene. In fact, nearly 100% of the total potable water is used for waste removal and cleaning. In most instances this water, some of which is only partially soiled is discharged into public sewage or septic systems and lost. This constitutes a potable water that could be drastically reduced by more efficient fixtures and re-examination of our western attitudes and habits concerning water usage. The following is an examination of possible waste removal systems by generic types and techniques. The approach chosen for this discussion is to group disposal methods by the processes as found in Stop The Five-Gallon Flush![2]

five waste disposal types

Infiltration--The oldest and most widespread method for waste treatment is infiltration. (Figure 2) In this process, waste material is contained in a pit or enclosure and allowed to gradually infiltrate the soil. Although infiltration may take place with or without water, the digestion process slows down with the introduction of water, impeding the sterilization or neutralization rates. The capacity of the soil to absorb the waste material is critical. Sufficient land area must be available for the underground dispersal of the effluent. The proper soil type must be present to

2. The Minimum Cost Housing Group, Stop The Five-Gallon Flush, Minimum Cost Housing Studies of McGill University, Montreal, Canada, 1975.

accept the sewage at a rate equal to or greater than the rate of discharge.

Typical examples of fixtures dependent upon the infiltration system are the family of pit-latrines and aqua privys. Some pit latrines use no water at all, depending on configuration and location in the home. The aqua privys use various amounts of water, but all use considerably less than the five to seven gallons required by the typical water closet.

Manual Removal--In situations where extreme cold, low porosity soil or excessive population densities exist, (Figure 3) waste is manually picked up and carried away from residential or commercial areas and delivered to leaching pits or sewage lagoons for disposal. Chemicals which help neutralize the waste are necessary with this process to reduce the odor and minimize the risk of contamination at either site. The primitive bucket, used for centuries, is the simplest tool for removal. However, large temporary gatherings or people-assembled events that last several days may depend on waste removal by special trucks and equipment.

Figure 3

The modern chemical toilet, like the primitive bucket, uses no water, but is slightly more sophisticated. Its large storage capacity, the addition of chemicals which break down the waste, and the addition of perfumes to mask odors make its use considerably more pleasant. Included in this family of chemical toilets is a series of recirculating systems in which the circulating fluid is reused.

Destruction--Human and animal feces have been used for ages as fuel. The burning of human waste is the basis for the development of the incinerating toilet.

(Figure 4) In the incinerating toilet, destruction is accomplished by burning the waste material with either gas or electricity. Special problems are encountered when introducing these systems in the toilet apparatus. Consequently, destruction units are used only under the most severe or unusual circumstances. Odors from the resultant smoke may offend settlements or businesses nearby and are the basis for code restrictions in some areas. The inherent complexities of these fixtures and the use of gas or electricity are the other factors limiting their application.

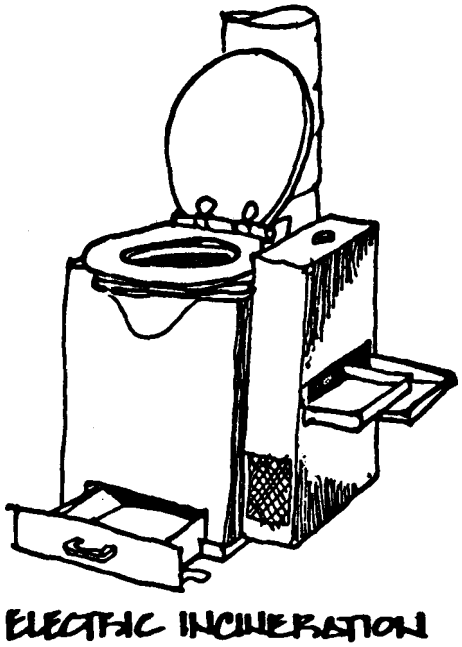


Figure 4

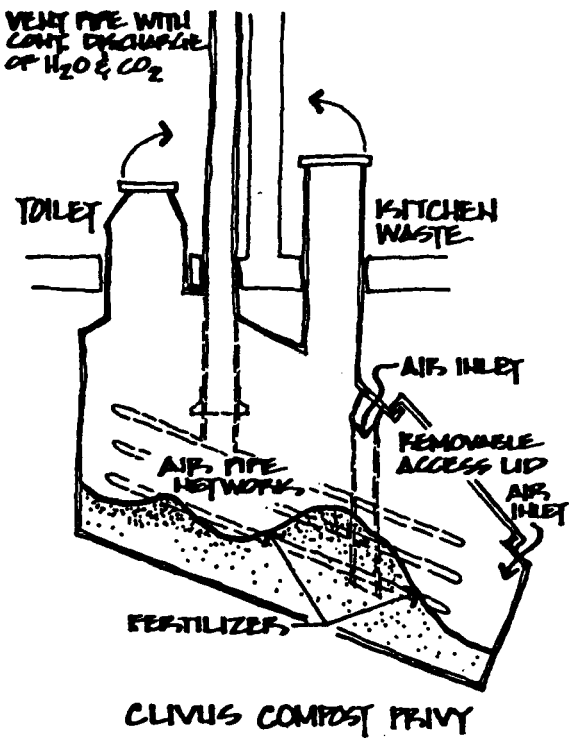


Figure 5

Decomposition--The decomposition process is very similar to that which takes place in a common septic system. Decomposition may be achieved by aerobic or anaerobic means.

In *aerobic* decomposition, oxygen is present which aids bacteria in digesting or burning the waste material. This burning process actually warms the soil, creating an environment conducive to beneficial bacteria growth. (Figure 5) The bacteria transforms the waste completely into stable chemical compounds which, like ashes in a fireplace, need no further oxygen to render them harmless.

Aerobic decomposition works in harmony with higher plant chains. The excrement of aerobic bacteria is very soluable in water. It is also a natural plant nutrient. In addition, the warm, moist, well-aerated soil conditions created by the aerobic process promotes root growth and aids the plants consuming the available food and water. Returning water to the atmosphere through plants, or evapo-transpiration, is one of the primary ways water is returned to the biosphere water cycle and wet soils are drained.

Anaerobic means "without the presence of oxygen". Under anearobic conditions, the bacteria that need oxygen to function go dormant or die off. In their place a community of fungi and other lower order organisms take over. Unlike the aerobic process, anaerobic decomposition is not complete and results in compounds which need more oxygen to stabilize. The compounds seek the additional oxygen from other natural soil communities. In anearobic soils, carbohydrates change to acids instead of nutritious sugar. Under extreme conditions, these may become toxic to plants. Without dissolved oxygen, iron combines with sulphur (instead of oxygen) creating Ferrous Sulfide, a black insoluable sludge that spreads throughout the soil, ruining the drainage capability. Together, these conditions result in decomposition ten to twenty times slower than, and not as efficient as, the aerobic process.

One important advantage of the decomposition process is that it is energy efficient. Most aerobic decomposition fixtures produce excellent fertilizers which in turn may be recycled naturally back into the earth. Although most require periodic addition of chemicals, no water is involved.

The compost privy, continuous aerobic units and algae digester

are all based on the decomposition process. In spite of the benefits, users may enjoy through installation of decomposition fixtures, social preference to waterborne networks, state and local codes, and in some instances excessive costs have limited their use in this country.

Mechanical Removal--The majority of waste disposal systems familiar to Americans are dependent upon mechanical removal for eliminating waste materials. The population density of cities and towns prohibits the use of infiltration due to the scarcity of space. Manual removal is also difficult. Continually removing thousands of tons of sewage away from an urban center would require a continuous massive effort.

The major disadvantage of mechanically removing waste, via municipal sewage networks or private septic systems, is the consumption of large quantities of potable water. If we refer to our previous figures, we find that a typical family of four uses between 88,000 and 110,000 gallons of water in a year. If we assume a standard toilet fixture, 40% of that quantity results in a consumption rate of between 35,000 to 44,000 gallons a year of pure, potable water.

The unfortunate aspect of this situation is that 99.9% of the sewage in a system of this type is water. Only one-tenth of 1% is solid matter, i.e., feces, urine, detergents, etc. Of this one-tenth of 1%, 80% to 85% is organic. A very small 15% to 20% of this one-tenth is inorganic If we were to include showers, lavatories, dishwashers and clothes washers in with sewage waste, 60% of the total effluent we produce would be *grey water* or lightly polluted. Only 40% of the total sewage would be heavily polluted, or *black water*. This is a serious consideration when we realize that water-borne systems demand large expenditures of water, capital, and energy to treat the transportation medium and not the waste material.

Water-borne systems have other far reaching ecological consequences. Centralized sewers and massive treatment plants waste an estimated minimum 1.1 million tons of usable fixed nitrogen because the sewage is treated in surface water pools. This is equivalent to 10 million tons of petroleum based fertilizer.

On-site sewage treatment techniques present different problems. If all of North America's 22 million on-site (i.e., non-remote) systems were functioning properly, one million tons of nitrogen and one-quarter of a million tons of phosphorous would recycle back into the earth quickly and efficienctly each year. This would induce far better plant growth and better vapo-transpiration--two facets of ecological balance. Recycling sewage directly back into the earth also saves between eight and nine million tons of petroleum based fertilizer each year. However, the home septic system still consumes a large amount of potable water for the amount of waste material that is effectively treated. This would suggest one of two obvious solutions:

- To recycle treated grey water in such a way as to supply the discharge quantities required by toilet fixtures, using the remainder, if any, for outside or other nonconsumptive purposes; or

- Incorporate a sewage removal system which uses no water at all. Of added beenfit would be an alternative system that is non-energy intensive and ecologically sound.

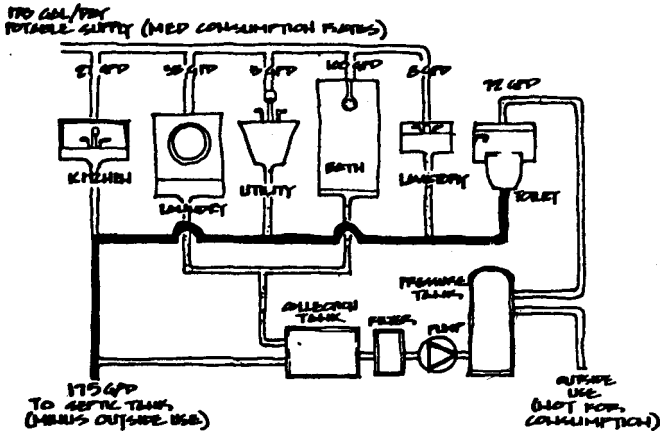


Figure 6

An example of the first solution would be a design like that illustrated in Figure 6. The figures shown in MED consumption rates with the 175 gallons a day for a four-member family resulting in a total of 63,865 gallons a year. This is below the previously discussed limits of between 88,000 and 110,000 gallons a year. By using such a system, potable water is used only for cleansing or consumption and not as a transportation medium for sewage. Filtered grey water is used in its place in the toilet fixtures and disposed of conventionally as black water sewage. The pressure tank may be tapped and grey water diverted for outside use also. Water used to irrigate the lawn, or to wash windows, the car, etc. could possibly reduce the 175 gallon a day load on the septic system to almost nothing. On a day of heavy "outside" water use, this would constitute a complete reuse and recycling of that given day's potable water supply, none of which was used directly for sewage disposal.

The singular advantage of this design lies in the additional assortment of tanks, filters, and pumps to provide what is essentially a

separate supply system for the water closet. In spite of the increased cost and maintenance, this particular design proposes a good solution to the problem of potable water consumption.

During the course of the project, the Magic Flush Toilet System was also investigated for the Minimum Energy Dwelling. (Figure 7) The Magic Flush System, a recirculating fluid toilet, eliminates the use of potable water entirely by incorporating an inert water-white fluid as the transportation medium. The fluid is completely immiscible to human waste, enabling it to be readily separated and reused. The separated wastes are stored in a small tank for collection by a vacuum truck. A typical single toilet system employs 20 to 30 gallons of fluid with 8 additional gallons per toilet required for additional fixtures. A 320 gallon storage tank will contain the waste of a family of four with semi-annual service.

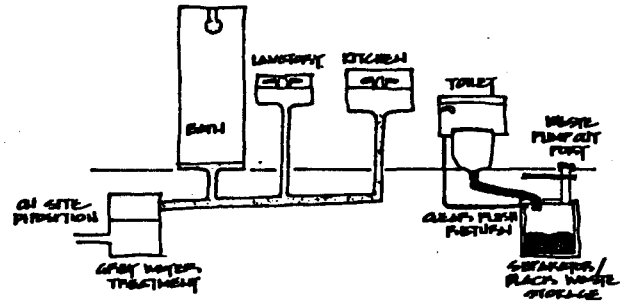


Figure 7

The Magic Flush toilet fixture itself is indistinguishable from any other conventional toilet except for the teflon coating on the inside of the bowl. Waste sinks to the bottom of the bowl, sealing off the odors usually associated with typical fixtures. The owner has no daily operating responsibilities with the Magic Flush fixtures. Fecal and mineral buildup is eliminated by design, and the distributors maintain the system as required. Consequently, the Magic Flush system is cleaner and much more pleasant to use than the conventional system. Peace of mind is afforded by the fact that the system is failsafe--it is a closed looped system. If the tank becomes full and separation cannot occur, the system stops operating until attended. The contaminated wastes are concentrated and hygienically contained until removed. This facilitates the ultimate disposal of waste and eliminates on-site pollution problems. The disadvantages of the Magic Flush system are that it requires electric power to circulate the transportation fluid and also the use of a collection truck to periodically remove waste.

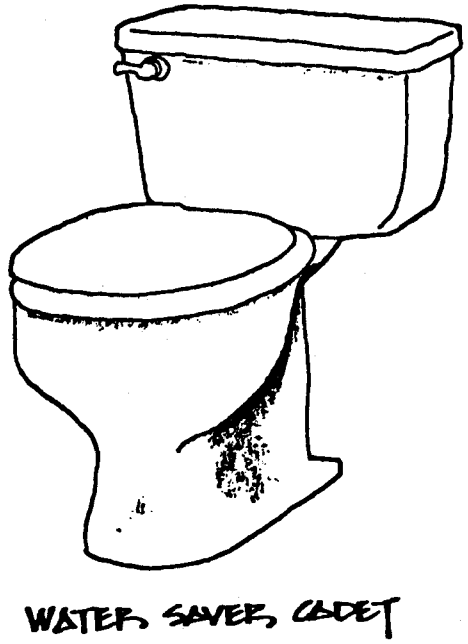


Figure 8

The problem of water consumption versus cost per installation is solved in the MED home through the use of the Water-Saver Cadet. (Figure 8) This particular fixture uses three gallons of water per flush, resulting in water savings of between 40% and 60% when compared to conventional fixtures using between five and seven gallons per flush. Based on three uses per day by each of four family members, this would result in a potable water savings of between 24

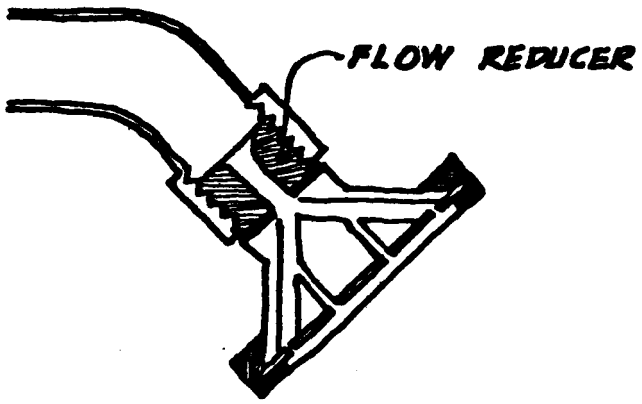


Figure 9

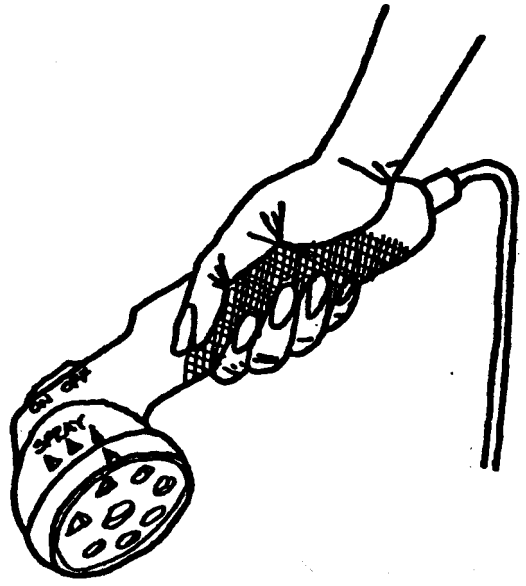


Figure 10

and 50 gallons a day for the typical residence. In addition, the Water Saver Cadet needs no power source or special components for operation. It is indistinguishable from any other conventional toilet and therefore satisfies western preferences. Also, it is less expensive than comparable units lending itself to widespread development applications like the Mission Viejo Project.

It may be seen from the previous figures that bathing and the use of lavatory fixtures constitute the second largest demand on a resident's potable water supply. Bathing is responsible for approximately 33% of the total consumption. Lavatory usage determines an additional 3%. Unlike the toilet fixture which functions repetitively without variation, the user has a much greater control over the lavatory, bath and shower. It is the user, therefore, who is critical to water conservation. No matter how water conserving or energy efficient a particular fixture may be, careless use and thoughtless habits will still waste large amounts of water and energy.

Flow Reducing Shower Heads--(Figure 9) The best designed shower heads have integrated flow reducers. These devices can reduce the flow rate to as little as 1/2 gallon per minute. This reduced flow rate, in combination with a wide spray pattern, will provide an enjoyable shower while saving water. Simple arithmetic shows a water savings of between 15 and 25 gallons for a ten minute shower when compared to a typical water use of 20-30 gallons for the same period with fixtures permitting a 2-3 gallon per minute rate. This savings could be even more substantial if flow reduction devices were to be retrofitted into some shower heads marketed today which allow six gallon per minute flow rates.

Hand Held Shower Fixtures--(Figure 10) Another excellent water saving device is the hand held shower fixture with integral on-off control. This device takes the flow reducing shower head one step further, by giving the user complete control over the shower spray. The on-off control feature allows the water flow to be conveniently turned off while lathering and on to rinse. Also typical of this type of device is an adjustable spray pattern feature permitting selection of spray according to individual preference. Water savings from this type of device should be even greater than savings of a 1/2 gallon per minute fixture.

Lavatory Use Habits--Lavatory use contributes a somewhat insignifi-

cant to household water consumption. However, the simple habit of turning off the faucet while brushing one's teeth may mean the difference between using two or three gallons of water at three gallons per minute, and as little as a pint or a quart of water. If we consider all four members of the family brushing their teeth twice a day, the savings may be as much as seven or eight gallons per day.

Ultra Flo Water Distribution System--The MED houses deal with the problems of water consumption through the use of a central water distribution system. (Figure 11) This system, the Ultra Flo, is comprised of two major components:

- Valve Unit--The valve unit contains the initial electrical supply and water control system. Hot and cold water supplies are connected to a series of electrically operated mixing valves. These valves are remotely operated with push button panels at each fixture. When, for example, the "warm" button is pressed at the kitchen sink, a pair of mixing valves are activated by low voltage current to mix hot and cold water to a pre-set temperature. The water then leaves the control unit at a low flow rate (2.0 to 2.5 gpm for kitchen sink, tub and shower, 1.5 gpm to lavatory basins) through a single small diameter tube. A typical small diameter Ultra Flo tubing 50 feet long holds only .75 quarters of water as compared to 2.4 quarters in the same length of standard 1/2" copper line. This substantially reduces losses due to hot water standing in supply lines.

- Push Button Control Panel--The second main component of the Ultra Flo system is the control point. The three control panels illustrated in Figures 12, 13 and 14 are typically used in residence. These panels require only a 12 volt power supply, an extremely small load for the energy and water savings realized by the Ultra Flo system. The manufacturer claims a 33% hot water reduction for a family of four. Using 20,800 gallons of hot water a year, this would resilt in a potable water savings of 8,500 gallons, and an energy reduction of 5.6 million BTU.

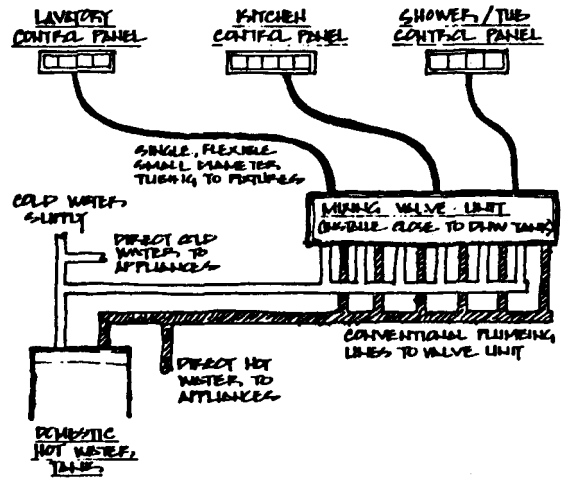


Figure 11

KITCHEN CONTROL PANEL

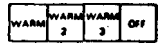
SELECT BUTTON	RESULT PROVIDED
HOT	Water directly from the hot water supply.
WARM	Hot and cold water blended to the pre-set temperature desired by the user.
COLD	Water directly from the cold water supply.
DRINK	Water directly from the cold water supply by bypassing the water softener (when applicable) to provide more palatable drinking water.
DISP	Simultaneous operation of disposal unit and cold water flow.
HIGH FLOW	Maximum pre-set water flow desired by user.
LOW FLOW	Provides reduced water flow when desired.
OFF	Halts all activity generated by the switch.

Figure 12

LAVATORY CONTROL PANEL

SELECT BUTTON	RESULT PROVIDED
HOT	Water directly from the hot water supply.
WARM	Water blended to the pre-set temperature desired by the user.
COLD	Water directly from the cold water supply.
OFF	Stops all flow of water to fixture.

Figure 13



SHOWER/TUB CONTROL PANEL

SELECT BUTTON	RESULT PROVIDED
WARM	Water blended to the pre-set temperature desired by the user.
WARM 2	Water blended to a greater temperature than the WARM setting.
WARM 3	Water blended to a higher temperature than the WARM 2 setting.
OFF	Stops all flow of water to fixture.

Figure 14

In order to examine the combined impact of water conserving fixtures and water conserving habits, the Minimum Energy Dwelling designers made a detailed study of two "typical" families. Both families consisted of four members. One family lived in a home equipped with conventional fixtures and did not practice water conservation. The second family is assumed to live in a MED home and also to practice conservation at every opportunity. According to the study, a total water savings of 70% and 75% total hot water savings were realized by the MED household. These savings were due to conscientious user habits and water conserving fixtures. It should also be noted that no real sacrifice was made on the part of the conserving family. Identical routines were followed and each chore was accomplished in a satisfactory manner. Savings such as realized by the model MED household are possible anywhere by anyone who is willing to retrofit or install water saving equipment and formulate conscientious habits.

mechanical systems 10

economizer cycle

solar collectors

collector tilt

solar and mechanical system

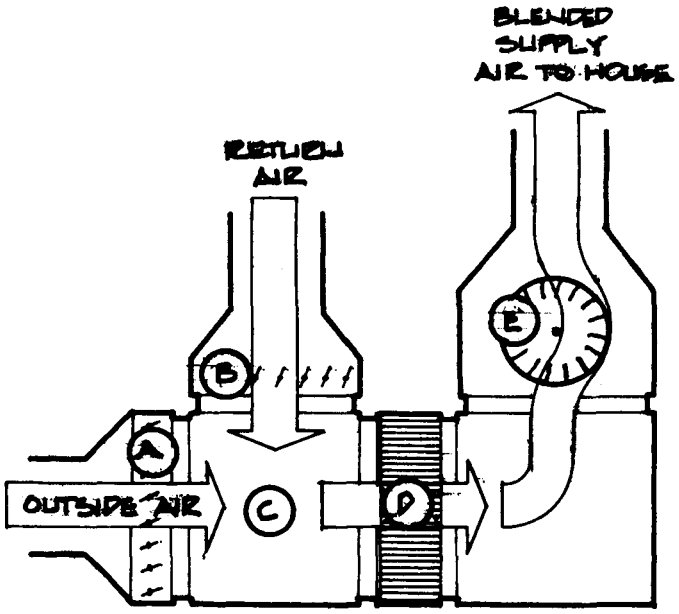
With energy costs increasing, the types and sizes of mechanical systems selected for buildings are now being more carefully considered. Manufacturers are responding with more sophisticated equipment that may cost more initially but when compared to less efficient conventional equipment will pay for itself over time through energy savings. Building techniques, materials and design methods that reduce heating and cooling loads are being more widely accepted. These techniques are often an integral part of the building structure and can have a great effect on equipment size. Without the availability of inexpensive fuels, the use of on-site renewable energy resources like solar energy are now economically feasible.

All of these approaches were used in the Minimum Energy Dwelling. As described previously in the discussions of insulation, mass, shading, infiltration and internal loads, many cost effective ways to reduce energy requirements may be included in the construction of the building shell. This effort in the MED houses resulted in a greatly reduced cooling load.

One of the original goals of the Minimum Energy Dwelling was to provide solar cooling at a reasonable cost for small single family homes. The goal was found to be very difficult to meet with present available technologies. The final solution does not meet the low cost objective, however, it does effectively cool the house with solar energy. The equipment required for this system is of a type that is used for larger commercial buildings. The smallest available commercial type equipment is too large for the 1,100 sq. ft. Minimum Energy Dwelling. Even at this writing, residential size equipment of this type is only beginning to enter the market.

the MED mechanical system

The MED houses make use of a cooling system called an *absorption chiller*. This device requires fairly low temperature heat in the neighborhood of 200°, to extract moisture from a salt solution. This 200° heat is supplied by a roof mounted array of highly efficient evacuated tube solar collectors. Also a part of the system is a cooling tower that provides heat rejection from the absorption chiller. For periods when the solar storage tank can no longer supply heat requirements a gas fired boiler has been included in the system to boost the storage temperature to the required level.



A OUTSIDE AIR INLET DAMPER
B INSIDE AIR INLET DAMPER
C MIXING BOX
D ELECTRONIC AIR FILTER
E CENTRIFUGAL FAN

Figure 1

Heating and hot water for domestic use are also supplied by the solar system. During the heating mode hot water in storage is maintained at a minimum temperature of only 90°. During periods of collector overproduction heat may be rejected through a roof mounted heat dissipator consisting of standard fin tube with fins spaced at 40 per foot. When water enroute to the collector is above 200° it is diverted through the heat dissipator. The heating operation consists of circulating hot water from storage through a coil located in the air handling unit where the heat is transferred to air moving through the coil and ducted throughout the residence.

economizer cycle

Another substitution for expensive primary energy sources is the use of cool outside air for cooling rather than expensive mechanically generated cool air. This method is the *economizer* cycle. The air distribution ducts of the Minimum Energy Dwelling are about twice the size of standard ducts. This increased size permits the movement of greater quantities of cool outside air to the interior spaces. The system is activated when an indoor thermostat senses a high indoor temperature and signals the need for cooling. At this point, an outdoor sensor known as an "enthalpy controller" reports the outside temperature and humidity. If both the temperature and the humidity are below the comfort zone, outdoor air will be used to supply cooling rather than the mechanical equipment. The probability of satisfactory outdoor air for cooling during periods of peak cooling requirements has been greatly increased by the time lag characteristics of the MED building shell.

The economizer system as installed in the MED houses is schematically illustrated in Figure 1. The primary element of the system is the mixing box where outside and inside air are mixed in varying amounts as needed to maintain interior comfort. The motor operated dampers are electronically modulated according to outside air conditions and inside comfort needs. The air then goes through an electronic air filter to remove any impurities before being distributed throughout the house.

In Southern California the average nighttime temperature, even during the hot summer months, descends to the low 60's. If enough mass was incorporated in the building shell, the interior space can remain cool during the day by pre-cooling with the use of the economizer cycle. The massive walls would then absorb the heat of day and prevent penetration until cool hight air can be used to prepare for the same cycle the following day. This concept also works during the heating season. The heat of the sun can be stored by the building's mass to heat the building at night. If the house is well insulated and weatherstripped, the appliances, lights and people could supply the required energy for heat.

solar collectors

There are many types of solar collectors both on today's market and presently under development. Many of the more elaborate types involving lenses or focusing reflectors are not economically feasible for the residential market. The photovoltaic cell, a semi conductor device that produces electric current when placed in sunlight, is now a highly developed technology. These cells when connected in series to make panels and mounted on racks in the proper solar orientation have been economically used as remote power sources for communications equipment, crop irrigation and satelites. Developments in this industry are occuring at a rapid pace in an effort to reduce costs so that solar generated electricity can ultimately become competitive with fossil fuel generated electricity. The following descriptions are of two collector types that are currently under manufacture and are in use in various parts of the country.

Flat Plate Solar Collector--Conventional *flat plate solar collectors* are composed of a metal collector plate which absorbes the sun's energy and a glass cover plate which prevents its escape. (Figures 2, 3). The sun's radiation which has short wavelengths, readily passes through the single or double glass cover and strikes the flat black collector plate and is absorbed. Heat that is re-radiated from the plate is in the form of long wavelength radiation that cannot pass through glass. (See Sun and Window, Page 37). This one way passage of radiation is known as the "Greenhouse Effect" and is one of the basic principals on which flat plate collectors depend.

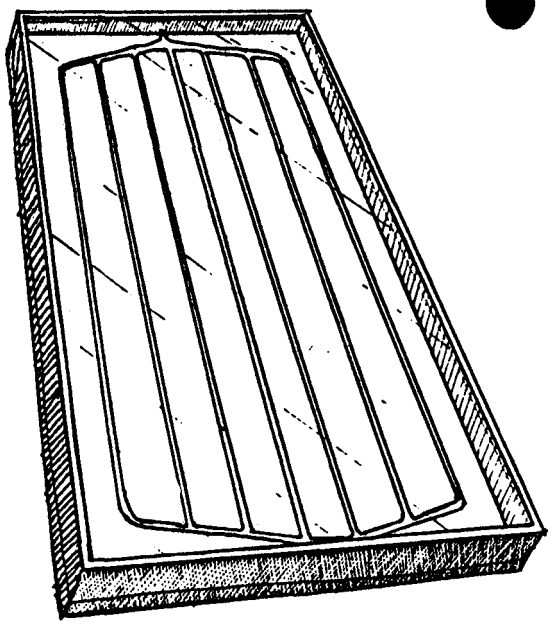


Figure 2

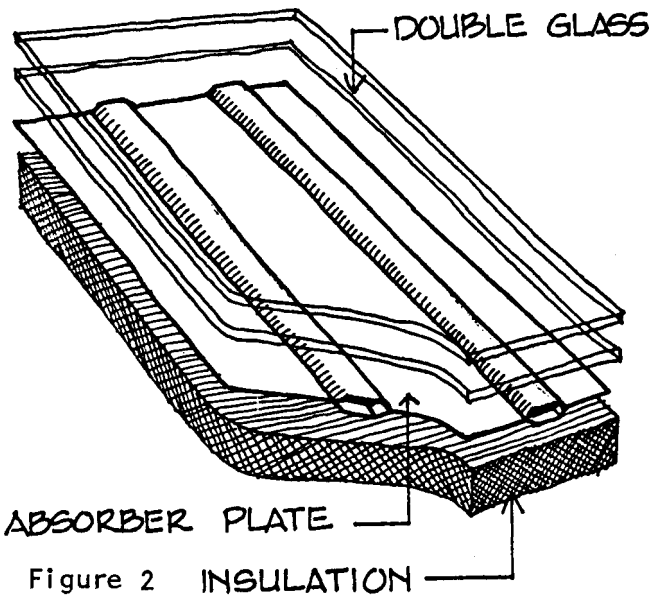


Figure 2

Figure 3

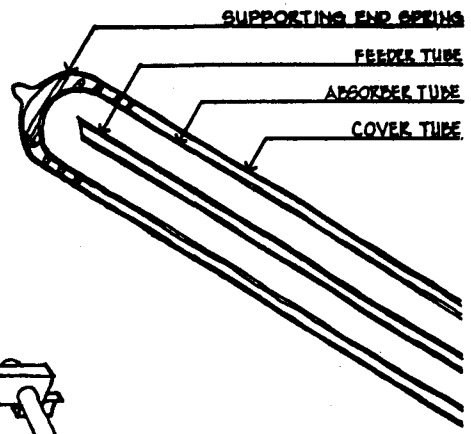


Figure 5

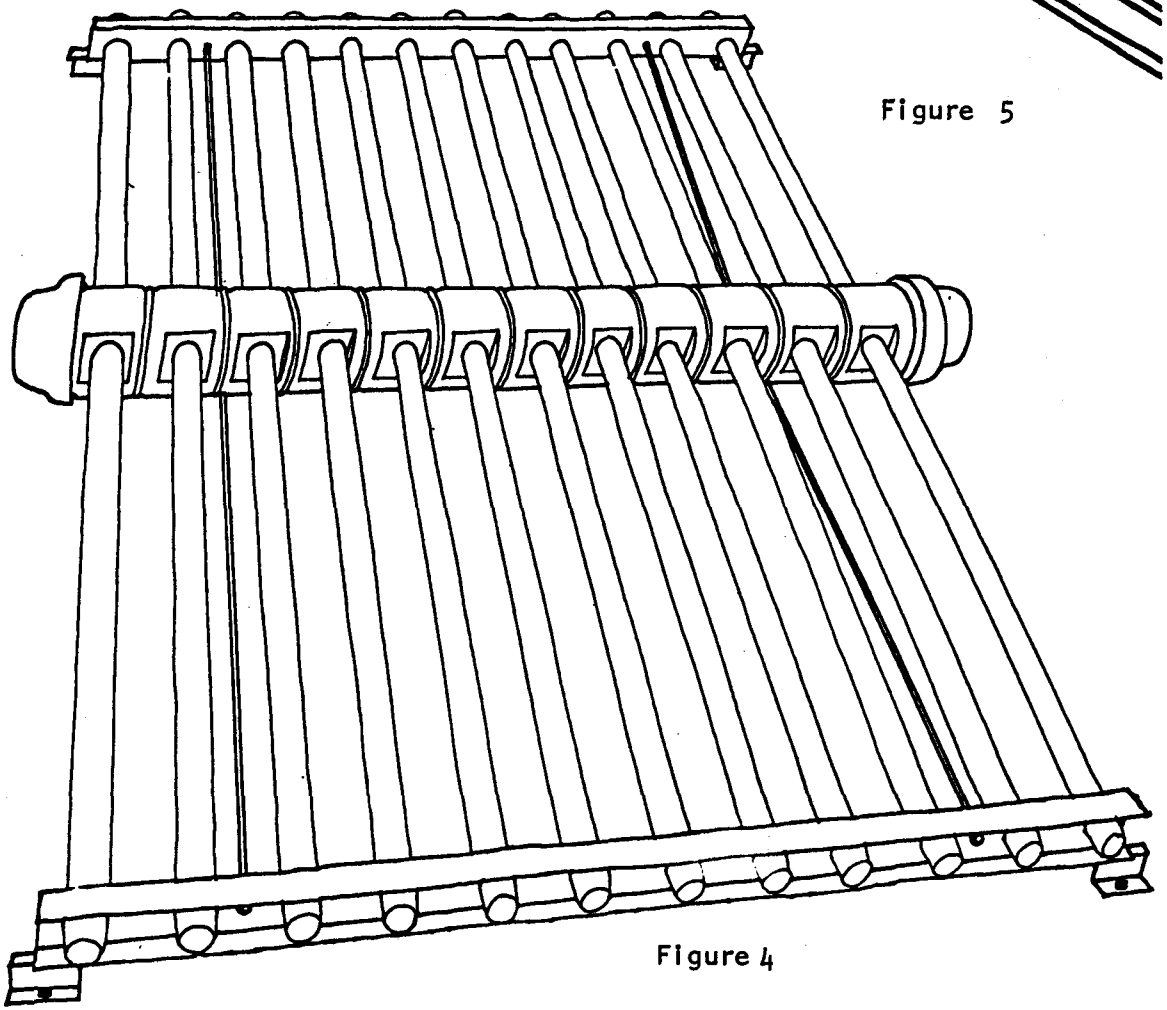


Figure 4

Once the collector surface has been heated, it is necessary to extract this heat by circulating a fluid through the collector. This fluid can be either a gas as in air collectors or a liquid. Water, with additives is the most common heat transfer fluid. It is circulated through the collector array. Then, it flows to an insulated storage tank where the heat can be retained and be used as re-required in the house.

Evacuated Tube Collector--
Figure 4 illustrates the Owens Illinois "Sunpak". This is the *evacuated tube collector* that was used to provide the 180° to 200° temperatures required for the Minimum Energy Dwelling. This collector differs greatly from the flat plate collector. More extensive manufacturing techniques are required and consequently the cost is higher. This increased cost however, is partially offset by the increased efficiency of this type of collector. Fewer collectors would be required to produce the same amount of heat.

The basic component of this unit is the glass collector tube. (Figure 5) A single glass tube collector element, approximately four feet in length and two inches in diameter,

consists of three tubes inside one another. The middle tube is the absorber tube which is covered on the outside with a coating that is highly absorptive to solar energy. (Figure 5) The smallest and innermost tube is the feeder tube which delivers the heat transfer fluid from the maifold to the inside of the absorber tube. The fluid then circulates through the absorber tube to pick up heat before returning to the manifold. The largest tube or cover tube surrounds the absorber tube and is heat sealed to it at one end. The air between the cover tube and the absorber is drawn out during manufacture. This annular space is a vacuum. This vacuum virtually eliminates heat transfer from the absorber type to the outside air and accounts for the high performance of this collector type.

As shown in Figure 5 and 6 the collector performance is further enhanced by the placement of a sheet of reflective roof material under the collector assembly Figure 6 illustrates that sunlight passing between the collector tubes is reflected back by the reflective surface to take full advantage of available sunlight. Owens Illinois also offers a parabolic shaped reflector that can be installed below the collector tubes. This reflector eliminates the need for a reflective roof surface and also improves collector performance by 25%.

collector tilt

The proper orientation of a solar collector is a function of the characteristics of the particular application. For instance, if the application is winter heating, the collector tilt should be steep so that radiation from the low winter sun strikes the collectors more directly. (Figure 7) In this situation high summer sun angles would strike the steeply tilted collector at an acute angle and a greater portion of the sunlight would be reflected. Therefore, the summer performance would be beneficially reduced at a time when energy requirements are least. The opposite is true when summertime cooling is the major need. In this case the collector tilt should be only slightly tilted to accommodate the high summer sun. If the application is only to provide domestic hot water - (a constant, year-round requirement) the collector tilt should be adjusted so that it is at an angle midway between the optimum summer and winter conditions.

The following are three rules-of-thumb for determining collector tilt in any part of the country:

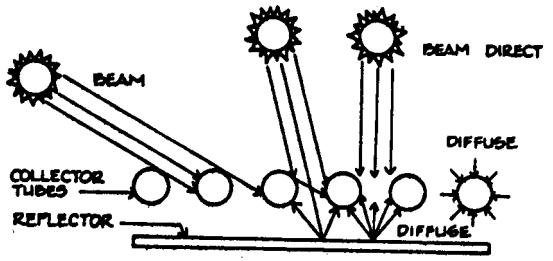


Figure 6

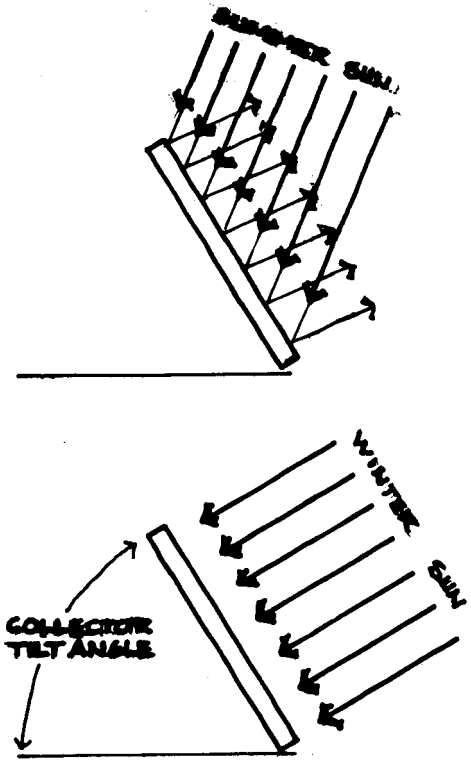


Figure 7

1. The optimum collector tilt for the winter period is an angle equal to the latitude plus 15 degrees.

2. The optimum collector tilt for the summer period is an angle equal to the latitude minus 15 degrees.

3. The optimum collector tilt for collection of solar radiation over the year is at an angle approximately equal to latitude.

The application of solar collected energy to supply residential heating needs has advanced in recent years. Manufacturers, consultants and contractors that have experience in solar system design and construction are making their services available to the homeowner. Economic feasibility of a solar system is dependent on a complex relationship of availability of solar radiation, water or space heating requirements. Availability and cost of alternating fuels and the cost of money for its construction. A method of analysis that is used to make this evaluation is the F-chart method which simplified these diverse economic variables to a cost per square foot figure. With the assistance of a trained professional, the homeowner can easily evaluate the practicality of a solar augmented mechanical system for his particular set of circumstances.

The design and construction of a solar mechanical system can be accomplished with varying amounts of professional services, depending on the owner's abilities and involvement. The following descriptions are of two systems, liquid and air, that are representative of today's solar technology. There are many variations possible including hot water baseboard heating with liquid collectors and solar augmented heat pumps using liquid or air collectors.

Liquid System With Forced Air Distribution

The typical residential liquid system is as illustrated in Figure 8. The major components consist of the solar collectors, storage tank and a heat transfer coil to transfer solar heat from storage to air being forced across the coil by the fan unit. Auxiliary heat for periods of reduced sunlight is shown as electric resistance in the illustration. However, gas, oil, or other fuels may be used. Two electric pumps are required in this system, one to circulate water from storage through the collectors and one to circulate water from storage through the coil to heat supply air.

Anti-freeze solutions are generally added to the water in this type of system. If, however, the solar heat is also to be used for domestic hot water the anti-freeze solution must be separated from the potable water by means of an additional heat exchanger in the storage tank. The alternative to the use of anti-freeze is called a drain-down system. In this system potable water is circulated through the entire system. When temperatures in the collectors approach freezing or boiling an automatically operated solenoid valve is opened and the collectors are drained.

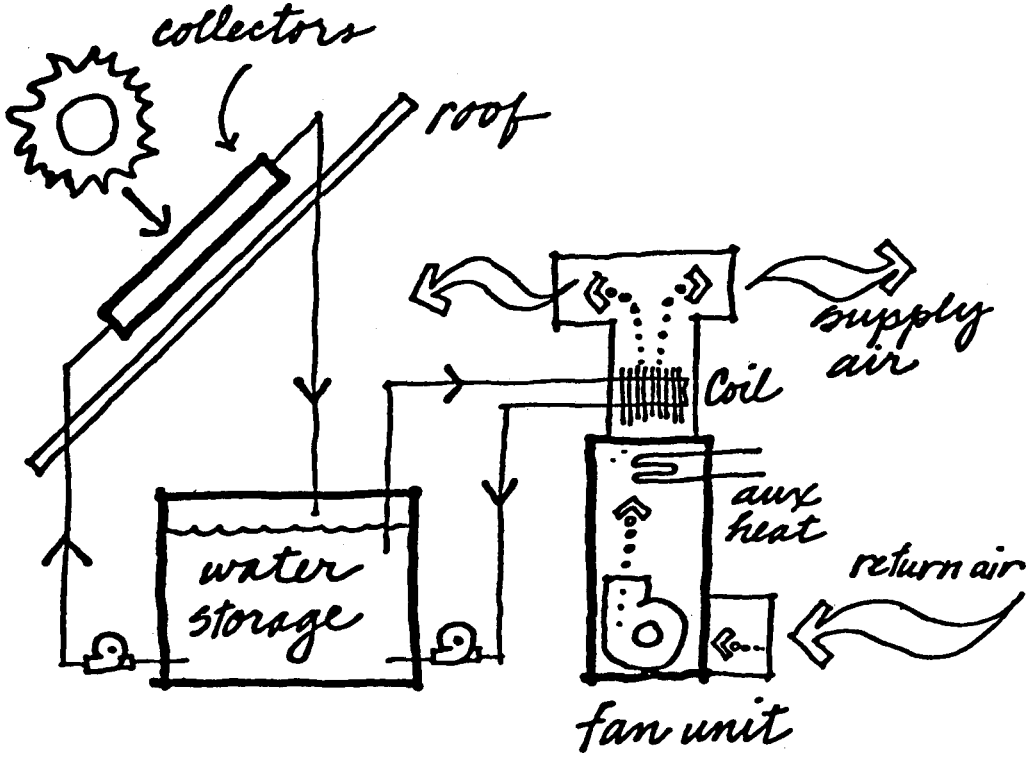


Figure 8

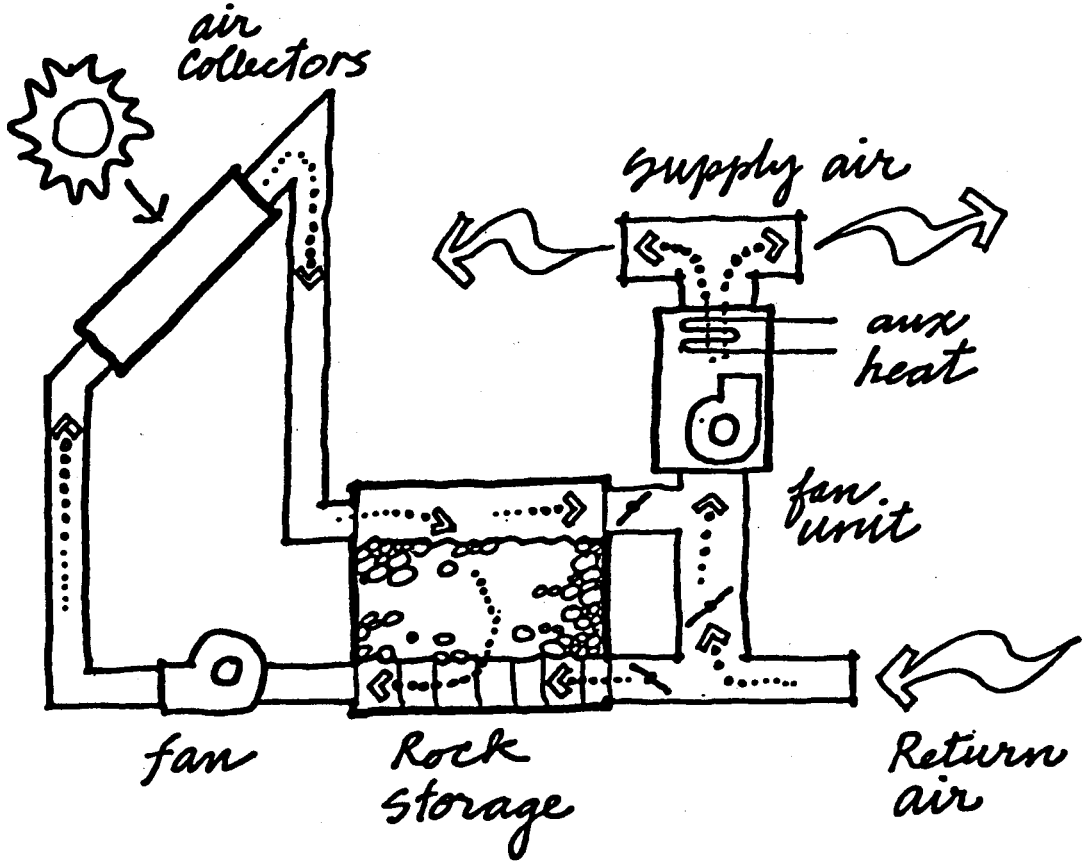


Figure 9

Air Collectors With Rock Storage

The concept of this system is identical to the liquid system. The major difference , of course, being that the fluid circulated is air. Two fan units are used in combination with a series of automatic dampers so that air can be circulated any one of three ways:

- From collectors through rock storage to store heat for use when required.
- Directly to occupied spaces from the collectors during periods when heat is required and the collectors are producing.
- Return air may be circulated directly through rock storage when storage temperature is adequate and collectors are not producing.

Like the liquid system, auxiliary heat must be provided for extended periods of reduced sunlight.

glossary

Absorption -- a process of heat transfer where one or more substances present an atmosphere or mixture of gasses or liquids; accompanied by physical change, chemical change or both of the material.

Absorption Chiller -- a refrigeration unit based on absorption refrigeration.

Absorption Refrigeration -- cooling which is effected by the expansion of liquid ammonia into gas by water. Heat is the primary source of energy.

Active -- when applied to building design, it refers to mechanical movement of energy by use of an external force of energy.

Altitude -- the measure of the vertical position of the sun in degrees above the horizontal with respect to a given position of the earth's surface.

Azimuth -- the measure the sun's position in degrees from south along the horizontal surface of the earth.

Black Water -- highly contaminated sewage.

British Thermal Unit (BTU -- the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit; a unit of heat roughly equivalent to the complete burning of a match.

Casement Window -- an operable window type that is hinged along one vertical edge and is operated by a crank type mechanism or manually. The advantage of this window type is that when open the window provides 100% free area for ventilation. Sliding or traditional type double hung windows provide at best 50% free area for ventilation. The best casement windows have a compressible vinyl weatherstrip to replice infiltration.

Comfort Zone -- the ranges of indoor air temperature, humidity and air movement under which most persons enjoy mental and physical well being.

Conduction -- a process of heat transfer whereby heat moves through a material.

Convection -- transfer of heat by the movement of a fluid or gas due to temperature differentials.

Economizer -- a cooling system that uses cool outdoor air to offset heat gains in buildings.

Evacuated Tube Collector -- a solar collector composed of air evacuated cylindrical tubes.

Flat Plate Collector -- a collector composed of sheet materials for the glazing and absorber plate.

Greenhouse Effect -- the effect of glass in trapping solar heat. When both long and short wave radiation from the sun strike glass, the short wave radiation passes through the glass and long wave radiation is reflected. Once the short wave radiation passes through the glass, it is absorbed by objects within the space. The resultant heat gain in these objects is re-radiated back into the space in the form of long waves that cannot pass back through the glass.

Grey Water -- lightly polluted bathing and washing water.

Infiltration -- the uncontrolled flow of air into and out of a building through cracks, openings, doors and other areas where air penetrates.

Internal Load --heat that is produced by people, lights, and mechanical equipment other than that supplied by mechanical conditioning equipment.

Overheated Period -- the times during the day or year, in which the interior of an enclosure is above the comfort zone and therefore requires mechanical or other means of cooling.

Pilotless Electronic Ignition -- an electronic device that eliminates the need for standing pilots in natural gas burning equipment.

Radiation -- heat energy that is transmitted to the earth from the sun.

Sky Vault -- all of the sky from the horizon in all directions, upward.

Stack Effect -- the effect of moving air up through a structure due to differences in temperature and pressure from top to bottom.

Set Back -- the distance that a building is required by code to be located from the boundary lines of the property it is on.

Thermal Lag -- the ability of materials to delay the transmission of heat.

Time Lag -- the time from the input of heat on the exterior of a wall until the heat is transmitted to the interior wall surface.

Vapor Barrier -- a component of wall construction that is impervious to the flow of moisture and air.

Velcro -- trade name denoting a fabric composed of two pieces that join together or adhere by means interlocking synthetic fibers.

Ventilation -- the intentional introduction of outside air into an interior space for purposes of health, comfort or structural cooling.

Weatherstripping -- foam, metal, or rubber strips used to form a seal around windows, doors, or openings to reduce infiltration of outside air.