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Minimum Energy Dwelling (MED) Workbook:

An Investigation of Techniques and Materials
for Energy Conscious Design

Department of Energy

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Minimum Energy Dwelling (MED) Workbook

An Investigation of Techniques and Materials
for Energy Conscious Design

Project Sponsors: Department of Energy
Washington, D. C.

Southern California Gas Company
Los Angeles, California

Mission Viejo Company
Mission Viejo, California

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Prepared for: Department of Energy
Washington, D. C.

Date: December 1977

Contract No.: EY-76-C-03-1198

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COMMUNITY RELATIONSHIP	33	Community Relationship, included in the General Considerations category, concerns the complex topics of housing types, transportation, land use, urban and residential developments, community service and income groups, with emphasis on the amount of energy use which occurs as the inter-relationships of each vary. Particular attention is

COMFORT AND CLIMATE

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given to the Mission Viejo development in Mission Viejo, California, which will include two Minimum Energy Dwellings. The method of analysis is applicable to any residential development or new town endeavor.

Comfort and Climate qualifies as a general consideration in that every construction effort must take into account both the micro-climate and the needs and desires of man as the occupant in order to create a comfortable, energy conscious dwelling. A general discussion of the earth's relation to the sun and the variety of climatic conditions which results from the basis of a detailed explanation of applied psychrometrics and the human comfort zone. The Mission Viejo micro-climate is discussed in detail explaining those factors necessary in analyzing any given site. Emphasis is placed on taking advantage of the positive aspects of a micro-climate in order to minimize environmental impact by passive means.

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It is necessary when dealing with energy consumption to isolate by category the primary uses and consumption patterns. Residential Energy Usage, included in the General Considerations category, accomplishes that task. The various end uses of energy on a residential scale are explained and compared in a national energy use scenario and profile of a typical Southern California family. Of additional interest is the breakdown of energy consumption by income group.

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The necessity of insulation has long been taken for granted in the building industry. However, the MED Workbook examines the degree to which cost effective application of insulation can be taken before it becomes a detriment. Fine tuning a building's thermal barrier is examined for a variety of climatic conditions. Numerous charts and illustrations clarify by comparison some long standing questions concerning thermal properties, product life, application desirability and cost effectiveness.

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A major portion of the design effort during the MED Project has been the degree with which heavier and more massive building construction can enhance energy conservation. The chapter on "Mass" examines the effect of changing building color, wall materials and configuration, and orientation in order to reduce thermal impact by passive means. The principle of time lag is explained and used in conjunction with diurnal cycling and cool air economizer cycles in order to minimize mechanical space conditioning. Understanding of the phenomenon of mass in a building construction is a major step in achieving an autonomous Minimum Energy Dwelling.

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Sun and Windows is a gathering together of the wealth of information already available on the subjects in a format which compares the different types and shading methods in an orderly cost-effective manner. An explanation of the sun angle calculator is included to enable the user to determine precise heat gain or shading problems in order to more correctly choose a shading device, or design a better window configuration. Bead wall systems and movable shutters and shading devices are also included. Emphasis is placed on orientation, window surface area and the resultant heat gain or loss in order to accurately determine the impact each plays on energy consumption.

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Internal Loads is a chapter which elaborates on the generally misunderstood influence of internally generated heat. The magnitude, duration and general nature of internal heat sources are examined to illustrate the potential influence of internal loads as a beneficial factor in minimizing energy consumption. A detailed study of a typical family is included to further examine the patterns of heat generation for three different day-use occupation patterns. Appliance design and modification is also discussed to show how heat can be economically saved, withdrawn or both.

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SOLAR COLLECTORS	273	The chapter on solar collectors deals primarily with the evacuated tube collector which was chosen for the Minimum Energy Dwelling. A wealth of new information about the component has resulted from its inclusion in the project. Also included in the "Solar Collectors" chapter are comparisons of various flat-plate collectors, operating efficiency, mounting procedures, tilt, heat ejection, area sizing, operating temperatures and pressures, and draindown procedures. The user will find the "Solar Collectors" chapter a valuable resource for selecting and evaluating solar collectors for a variety of applications.
MECHANICAL SYSTEM	301	The mechanical system for the Minimum Energy Dwelling has evolved over a wide range of variable during the course of the project. Included in the discussion of the "Mechanical Systems" chapter are two Munters Environmental Control (MEC) Units, the Yazaki Absorption Unit, and the integral domestic hot water heater and storage tank. The MED mechanical system utilizes evacuated tube collectors, an absorption cooling unit, and air handler with provision for cool air economizer cycles and a conventional gas-fired booster heat for auxiliary heat. The domestic hot water forms the mechanical system's storage tank. The arrangement typifies a residential solar heating and cooling system. The system description and mode diagrams, therefore,

		provide a valuable state-of-the art evaluation of current residential scale solar applications.
PLUMBING	339	Included in the "Plumbing" chapter are a general description of the biospheres, hydrological cycle, the nature and importance of potable water sources, and a residential end-use study of potable water by a typical family. The chapter concentrates on methods of water conservation incorporating grey water re-use systems, flow restriction devices and minimum consumption practices. Also included is a study of numerous waste disposal fixtures and methods. Two families are compared to illustrate the importance of user awareness in water conservation efforts.
CONSTRUCTION	375	Two MED homes were built during the summer of 1976. Shown in this chapter are construction photographs of the home during assembly. The text relates to areas which should be taken into consideration by a builder when incorporating new energy-conserving techniques. Methods of improvement for construction of the home and the mechanical system are delineated. A time strip of construction photographs give the reader an appreciation of the construction process and time sequence.
GLOSSARY	424	A listing of explicit definitions for the technical, obscure or foreign words used in this report.

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ABSTRACT

The Minimum Energy Dwelling Design Workbook is based upon information gathered during the design phase of the Minimum Energy Dwelling.

The intention of the Project, which is sponsored by the Southern California Gas Company, the Energy Research and Development Administration, and Mission Viejo is to substantially reduce energy use by the incorporation of energy conservation and solar techniques in a single-family detached dwelling. The Project will demonstrate to builders, as well as to the general public, a number of technological innovations which can, at reasonable cost, be included in a dwelling design.

The problem facing Southern California Gas Company, along with most other gas utilities, is ever decreasing amounts of gas at increasing prices. The dwelling designed has approximately 1,150 square feet, which is consistent with current home building trends. Through the optimum use of energy conserving appliances, insulation, window and wall shading, exterior coloring, and thermal mass, the yearly energy usage has been reduced by over 50%.

Of the remaining 50% of the energy required for heating, cooling and domestic hot water, the majority is supplied by the solar energy system. Three hundred twenty square feet (270 effective) of evacuated tube collector are incorporated into the building structure. The hot water provided by the collectors is used to run an absorption chiller for cooling, the domestic hot water, and the heating system.

The remaining energy requirements are met by an auxiliary natural gas energy system and a cool air economizer cycle. The Minimum Energy Dwelling is one of the first attempts to design a dwelling system which, if successful, can have a far-reaching impact upon energy usage in the Southern California area.

INTRODUCTION

During the design of the Minimum Energy Dwelling (MED), the use of different types of energy-conserving home building techniques were investigated. Many were not included in the final design because of inappropriateness to the climate, cost, buyer resistance, or technical problems. The value of sharing both the final design and the decisions which led up to the final design, has been recognized and is included in this Minimum Energy Dwelling Design Workbook. The intent in writing the Workbook has been to comprehensively present all the important issues dealing with energy conservation in dwellings.

The Design Workbook is presented in three segments.

General Considerations

The first three chapters establish the contextural relationships within which the Minimum Energy Dwelling is placed. Any given design project begins with certain fixed characteristics. In this case, it was to design a single-family detached living unit for the standard home-buying public in a Southern California development. Each one of the given assumptions has an effect upon possible energy savings

and energy use. These parameters are detailed, and the range of their implications are explained.

Building Design

The building, to be designed properly, must be capable of modulating the flow of energy from the inside to the outside to keep the occupants from getting too hot or too cold. With the increasing price of fuel necessary to run mechanical equipment, the design of the building skin has received more attention. Five chapters deal with appropriate techniques.

Mechanical Design

The mechanical system is designed to meet the needs of the occupants which cannot be handled by the building design. The use of advanced mechanical systems is detailed.

The Minimum Energy Dwelling Design Workbook is the product of many individuals' and companies' efforts.

The foresight of the Southern California Gas Company has made it a leader among the energy companies for new techniques in the conservation and development of new sources of energy.

Also cooperating in this effort were the Mission Viejo Company, a housing development company in Mission Viejo, California, where the test homes are built; and the Department of Energy, which supplied funds for dissemination of the results to interested individuals or corporations within the building industry.

The Minimum Energy Dwelling Design Workbook has resulted in a wealth of information for the reader, and will help to understand the forces which affect an enclosure's thermal environment.

Acknowledgments-Burt, Hill & Associates

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Diane M. Dubyak	Copy Editing & Final Typing
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THE MINIMUM ENERGY DWELLING

Illustrated is an overall view of the Minimum Energy Dwelling taken from the air. The project is the result of an extensive commitment to energy conservation by the Southern California Gas Company, the Energy Research and Development Administration, and Mission Viejo. The project has been underway for over two years and has resulted in a wealth of information.

The Minimum Energy Dwelling (MED) research is an energy conservation data-gathering and demonstration effort sponsored jointly by the federal government and private industry. The major goal is to reduce energy consumption in a typical southern California home by at least 50%, and simultaneously to encourage the American building industry to adopt MED's energy-saving features.

Principal MED sponsors are the federal Energy Research and Development Administration; Southern California Gas Company, Los Angeles, Calif.; and the Mission Viejo Company, Mission Viejo, Calif.

(1) MED uses available energy-saving building techniques and materials, along with advanced household appliances and a solar/natural gas central energy system for space heating, cooling and water heating. MED is not a "Twenty-first Century" home.

Through data-gathering, analysis and

demonstration, it is dedicated to fostering the construction of energy-efficient homes in the not too distant future.

An important part of the overall research is this workbook written for architects, engineers and builders to provide detailed information about MED. Included in this workbook are ways to save energy in building design and construction, site selection and building materials.

If present trends continue--and they are likely to do so--a typical homeowner's energy costs will become a proportionally greater amount of his total living costs each year. Probably the most effective way to combat this situation is to reduce overall energy consumption. Residential energy conservation can both extend the life of existing energy supplies and hold down increases in living costs.

The Minimum Energy Dwelling (MED) research project, conceived in 1975 by the Southern California Gas Company, is designed to demonstrate that the living standards and comfort enjoyed at home by today's average family can be maintained or even improved, while

the family's total energy consumption is reduced by at least 50%.

(2) The MED research program centers around two specially constructed single-family homes in Mission Viejo, Calif. It is a joint venture of the Southern California Gas Company, the Mission Viejo Company and the federal Energy Research and Development Administration (ERDA), Office of Conservation.

A major goal of the research effort is to encourage residential builders to incorporate MED's energy-saving concepts in their future developments. These concepts include energy-saving techniques in MED's design, construction methods and building materials, and the use of solar energy in tandem with natural gas for space heating, cooling and water heating.

The MED research also is designed to demonstrate that exterior and interior air and noise pollution can be decreased, privacy can be improved and a generally higher standard of living can be maintained at the same time.

MED uses currently available equipment which is either cost competitive or makes sense on a lifecycle cost basis. The one exception is the solar-gas energy system, which is more expensive than conventional equipment. However in MED, a lot of natural gas is being saved by using solar as a primary energy source, with gas as a back-up. It is expected that solar energy equipment will become increasingly cost competitive with conventional energy systems in the future.

Of vital importance to the MED Project is that the Mission Viejo Company has extensive data on residential construction costs in its area, placing the company in an excellent position to gather detailed cost data on MED and compare them with similar information on traditional homes. Mission Viejo Company acted as MED cost controller during the design stages and also supervised construction.

(1) Minimum Energy Dwelling

(2) The MED Home And Its Surroundings

As a progressive residential building developer, Mission Viejo Company wants to explore ways of conserving energy in its housing. ERDA and the gas company are involved because of their commitments to energy conservation and to fostering the growth of solar power.

After an agreement was signed by Mission Viejo Company and the gas company, the utility obtained a \$230,000 contract with ERDA.

Two identical MED houses have been designed and built for both research and demonstration purposes. They blend into the normal architecture of Mission Viejo so that the home-buying public can relate to them as to any other typical home in the Mission Viejo community. (4) Most of MED's energy-saving features are "built-in" and thus are not readily visible, except for the rooftop solar collectors.

One of the 1,150-square-foot MED homes is a demonstration model. The second is occupied by a "typical" family buying its first home. For research purposes, Mission Viejo Company characterized this family as a working father, a non-employed mother, and one child.

The family's energy usage is being measured to determine the performance of the home's conservation features. This performance is being compared to another home at Mission Viejo. The non-MED home will be exactly the same style and size as the MED homes, but without the energy-saving features.

The MED Project is using an architectural firm, Burt, Hill & Associates of Butler, Pennsylvania, a recognized expert in the solar and energy conservation fields. Burt Hill architects are working closely with their counterparts at Mission Viejo Company and engineer-researchers at the gas company.

- A. PATIO COVER TO SHADE WINDOWS AND SLIDING GLASS DOORS
- B. SOLAR COLLECTORS
- C. TILE ROOF FOR ADDITIONAL MASS
- D. EXTRA THICK EXTERIOR WALLS TO ALLOW FOR MORE INSULATION
- E. MEMBRANE BENEATH STUCCO TO ELIMINATE AIR INFILTRATION
- F. DOUBLE-PANE WINDOWS WITH SHUTTERS BETWEEN PANES
- G. WINDOWS SHADED WITH VERTICAL WINGS
- H. SLAB INSULATION
- I. HOUSE FINISHED WITH LIGHT-COLOR PAINT

(3) Exterior Energy-Saving Features

(4) Construction Of The MED Home

(5) The Exterior Vapor And Air Infiltration Barrier

(3)(6) The final design of the MED homes contains many ideas which contribute to energy savings:

- Exterior walls are built of 2" x 6" studs spaced farther apart than normal (24"). This allows for more insulation and a stronger structure, while using the same amount of wood found in typical home construction (2" x 4" studs on 16" centers). Rafters are built with 2" x 10" wood members.
- The slab floor and the two-foot underground footings under exterior walls have been poured with two inches of insulation laid along the inside edge of the footing and under the slab. Slab insulation extends two feet into the interior living space.
- A putty-like sealer (mastic) has been placed between the sill plate and concrete to reduce outside air infiltration.
- Areas which are difficult to insulate after exterior walls have been closed in, such as corners and around windows, were insulated early in the construction process.
- The roof extension (eave) is lengthened for better shading over windows and walls.
- Vertical shading "wings" protrude from exterior walls on each side of the windows to reduce the amount of sun hitting the windows. Double-pane windows, with adjustable shutters between the panes, allow the sun to be blocked out.
- Patio covers are used to shade the large sliding glass doors at the rear of the home. A shaded entryway protects the front windows.
- (5) Under the Stucco exterior, plastic, rather than standard

- A. WATER FLOW CONTROL DEVICES ON KITCHEN AND BATHROOM FIXTURES
- B. SOLAR ASSISTED DOMESTIC WATER HEATING AND SPACE HEATING AND COOLING EQUIPMENT
- C. DOUBLE ENTRY DOORS TO REDUCE INFILTRATION
- D. ADVANCED ENERGY SAVING KITCHEN AND LAUNDRY APPLIANCES
- E. MAGNETIC INSULATION STRIPS ON ALL DOORS
- F. FURNACE THERMOSTATS WITH AUTOMATIC SETBACK DEVICES AND ECONOMIZER CYCLE TO COOL HOUSE DURING NIGHT WITH OUTSIDE AIR

(6) Interior Energy-Saving Features

building paper, is wrapped around the wood structure. This serves as another positive barrier against outside air infiltration and moisture.¹

- Insulation is thicker than normal, with higher resistance value in walls (R-19) and attic (R-30).
- The front door is foam-filled steel with magnetic weatherstripping. This reduces air infiltration and increases the standard door insulation normally used in California construction. In addition, double-entry doors are used--one leading to an entry area and a second leading into the living room.
- The domestic water system, which supplies the kitchen and bathrooms, uses one pipe which blends hot and cold water at the water heater. It then distributes the desired

water temperature for a particular use at a particular outlet in the home.

- Energy saving, water-restrictive devices are used on all domestic water outlets in the home.
- Red tile is used on the roof to lengthen the time it normally takes to heat up the home's living space on warm days.
- Household appliances have energy conservation features, such as a pilotless ignition system on the kitchen range, heat pipe water heaters and night setback thermostat on the furnace. Heat rejected from the refrigerator compressor and condenser coil is channeled outside during the summer and into the home during the winter.

¹Caution: This is a Southern California research house. The usual recommended use of plastic barrier is in the inside face of the outside wall (see page 134, 135) in order to avoid trapping moisture within the wall cavity.

(7) The Comfort Control System

- The landscaping and exterior paint were all planned to help maximize energy conservation.

The MED homes are heated and cooled with solar energy and the domestic hot water is preheated with solar energy. (7) The comfort control system uses natural gas as the backup fuel for the solar-generated energy supply. Natural gas is used only when the solar energy is insufficient.

One important feature of the comfort control system is an "enthalpy" system. This system senses inside and outside humidity and temperatures. It basically brings in cool outside air and flushes hot air out of the home when necessary. This is particularly useful in a climate such as the one at Mission Viejo where the days are often warm and dry and the nights cool and damp. With the enthalpy system, the MED homes purge hot air and bring in cool air at night.

Generally, the comfort control equipment is oversized for a home with MED's energy-saving features, but it is the smallest of its kind that is commercially available today.

(8) Evacuated tube solar collectors

mounted on each roof gather the solar energy. A total of 320 square feet of collector panels is used on each house. With a storage capacity of about 500 gallons per home, the solar system can provide all the energy needed at night after a clear, sunny day. Storage tanks are located below ground level in insulated concrete vaults in each garage. They "store" the solar energy collected during the day in the form of hot water.

Heating and cooling are accomplished through a device known as a "single coil air handler". It has either chilled or hot water running through it. The hot water is supplied directly from storage. Chilled water comes from a hot water-fired absorption chiller. The units selected for the MED Project produce three tons of cooling with 195° water from the solar system. This is more than sufficient to cool a house with the energy-saving features and size of the MED models.

If the solar-heated water in storage is not hot enough (for either cooling or heating purposes), natural gas supplies the energy to heat or cool the MED house.

Domestic hot water is preheated by solar energy and then delivered to an experimental "heat pipe" water heater. A heat pipe is an efficient, energy-saving means of transferring heat.

The water heater brings the water up to the desired temperature, if it is not already hot enough.

A special panel controls the heating and cooling, enthalpy and solar systems. A night setback thermostat is used to control the MED home's demand on the comfort control system during the evening.

Research

All energy applications and the distribution of energy within the MED homes will be monitored and separately analyzed throughout the life of the project, which will be at least a 12-month period.

(9) The gas company's research department is responsible for on-site computer data gathering and analysis. A specially designed instrumentation system will measure the effects of the different energy conservation techniques.

Both MED homes are specially wired to monitor their energy variables. The occupied home is used to validate calculations, and the demonstration unit is used for periodic cross checks. The third, conventional home contains some instrumentation for comparison of how a normal home uses energy under given climate conditions.

This data-gathering system continuously monitors the energy consumed by the MED homes. It also measures the amount of energy supplied by solar, gas and electricity.

Another evaluation procedure analyzes the temperatures across the walls, ceiling, and slab ("thermal response"), and checks the infiltration rate of air into the home. Measuring devices (thermocouples) are installed

(8) The Evacuated Tube Solar Collectors

(9) Installation Of The Instrumentation System

in the walls to check for temperature. Moisture sensors are also included in the walls. All of these measurements will be taken periodically with portable measuring equipment. These measurements will be compared with similar readings in the standard (non-MED) home.

A marketing survey eliciting responses from both the building industry and the general public will be conducted as part of the MED evaluation process.

Results of the research project will be shared with other gas utilities and the general public throughout the nation via government, industry and trade association channels.

Builders, developers and equipment manufacturers will be informed of the project through tours of the site and by way of results to be reported in trade journals and at conferences sponsored by various public administration groups such as the American Society of Public Administration and the International City Managers Association.

Many features used in the MED homes--exclusive of the solar system--can be adopted almost immediately by builders. These features are commercially available right now and need only to be adopted by the building community.

Builders around the country already are attempting their own MED-like homes on a smaller scale. Ultimately, it is up to the building industry, researchers and the energy utilities to make these concepts a routine part of residential construction.

Mission Viejo Company, for example, plans to use many of MED's energy-saving features in the company's own future construction. Plans call for building energy-efficient homes which are more adaptable to future use of solar energy when it becomes economically feasible. With MED's features, solar energy can be more easily added

to an existing dwelling and have more of a conservation impact.

Concepts already earmarked for future Mission Viejo Company construction include overhead plumbing to facilitate future solar installations, full R-19 insulation in walls, greater attic insulation, weatherstripping on magnetic steel doors, and 2" x 6" studs.

This detailed workbook was prepared by Burt, Hill & Associates, the Project's architectural consultants, for other builders interested in learning how to build a MED home.

The MED partners consist of the following:

Southern California Gas Company, Los Angeles, California--A subsidiary of Pacific Lighting Corporation (NYSE), is the largest natural gas distribution utility in the United States, based on the number of customers served.

The utility has more than 3.4 million service connections in 12 southern and central California counties--an area of more than 22,000 square miles. One out of every 13 natural gas customers in the United States is served by Southern California Gas Company.

The company is actively encouraging its customers to conserve energy and has participated in a number of special projects, such as MED, that are consistent with its goal "...to support or conduct research directed to more efficient uses for gas, to energy conservation and to an improved environment."

Mission Viejo Company--Formed in 1963, Mission Viejo Company, a wholly owned operating company of Philip Morris Incorporated, New York, New York, is the developer of Mission Viejo, a planned community located about 50 miles south of Los Angeles, in Orange County, California.

Emphasis is on development of a totally planned community with a variety of housing styles affordable by a broad segment of the population, a balanced community conducive to social interaction and community identity.

Mission Viejo has a population of approximately 10,000 families. This is expected to reach 30,000 by 1990. The development is situated on 10,000 acres and is a blend of open spaces, residential and recreation areas and small business, industrial and shopping centers.

Mission Viejo Company is also developing homes in Colorado and central California.

As a major residential builder, Mission Viejo Company is in an excellent position to help foster MED goals.

The Department of Energy (DOE)--Created in 1975, DOE brings together in a single agency the major energy research and development programs of the federal government. In 1977, legislation was passed by the U.S. Congress and signed by President Carter making Energy Research and Development Administration part of the new Department of Energy (DOE). These programs are aimed at finding ways to increase the supply of energy as well as to conserve energy that is already available.

DOE programs are carried out by contract and in cooperation with private industry, universities and other government agencies. The MED Project is consistent with DOE's charter to work with private industry to foster energy conservation and solar energy development.

To determine the expected energy consumption of the Minimum Energy Dwelling, a detailed computer study was performed.

The program was developed by the Westinghouse Corporation in Pittsburgh, Pennsylvania. In order to obtain the most accurate energy performance estimates for a home or building, the hourly requirements are calculated throughout the year and summarized month by month and yearly. For each hour, the following items are calculated:

- . Windows
 - . Radiation
 - . Conduction
- . Walls
- . Roof
- . Infiltration
- . People
- . Electrical
 - . Lighting
 - . Appliances

Shown in Figure (10) are the positions of the windows on the Minimum Energy Dwelling. The matrix below the window placement diagram quantifies the pertinent data for each window, which are numbered 1 through 7. All of the information is needed to accurately predict the performance of a window.

In this particular program, a weather tape from the national weather service was obtained for El Toro, California. El Toro is the nearest weather station to Mission Viejo. The tape contains the weather conditions for the most statistically average year, in this case 1966, and is broken down day by day and hour by hour.

From this weather tape, the sky conditions can be obtained, and the estimated gross amount of solar energy can be calculated. The actual amount of radiation reaching the interior of the house is determined by subtracting from the gross solar energy the amount absorbed by the shading device or deflected by the physical properties of the glass.

The energy transfer through the wall and roof is dependent upon the outside air temperature and the solar energy impinging upon the wall in a manner

WINDOW NUMBER	1	2	3	4	5	6	7
WIDTH FT.	5.25	2.75	2.75	6.00	5.00	2.75	2.75
HEIGHT FT.	4.67	4.67	4.67	6.67	6.67	4.67	4.67
AREA FT. ²	24.5	12.84	12.84	40.02	33.35	12.84	12.84
SHADING FACTOR	0.50	0.50	0.50	0.41	0.41	0.50	0.50
U-VALUE BTU/FT ² (°F)	0.73	0.73	0.73	0.62	0.62	0.73	0.73
TRANSMISSION DIRECT	0.85	0.85	0.85	0.77	0.77	0.85	0.85
ABSORPTION DIRECT	0.07	0.07	0.07	0.16	0.16	0.07	0.07
TRANSMISSION SCATTERED	0.77	0.77	0.77	0.69	0.69	0.77	0.77
ABSORPTION SCATTERED	0.07	0.07	0.07	0.16	0.16	0.07	0.07
DENSITY lb./FT. ²	0.30	0.30	0.30	0.61	0.61	0.30	0.30
A-VERTICAL LEFT FT.	0.00	1.00	1.00	0.00	0.00	1.00	1.00
B-VERTICAL RIGHT FT.	1.00	1.00	1.00	0.00	0.00	1.00	1.00
C-LEFT PROJECTION FT.	0.00	1.50	1.50	0.00	0.00	1.50	1.50
D-RIGHT PROJECTION FT.	26.0	1.50	1.50	0.00	0.00	1.50	1.50
E-TOP PROJECTION FT.	5.00	2.50	2.50	8.00	8.00	2.50	2.50
F-OVERHANG LEFT FT.	2.00	20.0	14.00	23.75	7.00	37.00	33.00
G-OVERHANG RIGHT FT.	2.30	22.00	28.00	9.00	24.75	24.50	28.00
H-Feet to Left FT.	0.00	2.75	0.00	0.00	0.00	3.50	0.00
I-Feet to Right FT.	2.33	0.00	2.75	0.00	0.00	0.00	3.50
J-Feet to Top FT.	0.50	0.00	0.30	0.50	0.50	0.50	0.50

(10) Window Characteristics

ENCLOSURE CHARACTERISTICS								
	STUCCO INSULATED	SLOPED ROOF	CEILING	SLOPED ATTIC	DOOR	STUCCO UNINSULATED	COLLECTOR UNINSULATED	COLLECTOR INSULATED
U-VALUE OF WALL AT CAVITY	.052	.029	.032	.337	.106	1.42	.336	.029
U-VALUE OF WALL AT STUD	.128	.066	.121	.067		.132	.067	.066
R-VALUE OF WALL AT CAVITY	19.23	34.48	31.25	2.97	9.43	0.70	2.98	34.48
R-VALUE OF WALL AT STUD	7.81	15.15	8.26	14.92		7.58	14.92	15.15

ZONE 2	E-NE SLOPED ROOF	387.6 57.9						
	W-SW SLOPED ROOF	169.6 25.3						39.1 5.8
	N-NW WALL	49.4 7.4						
	N-NW SHADED BY GARAGE	215.6 32.2			20.0			
	E-NE WALL	225.0 34.0						
	W-SW WALL	158.1 23.6						
	S-SE WALL	217.7 32.5						
	ATTIC FLOOR		324.7 48.5					

ZONE 1	S-SE WALL					36.7 5.5		
	N-NW WALL					10.8 1.7		
	N-NW SHADED BY GARAGE					12.0 1.8		
	E-NE SLOPED ROOF			79.9 11.9				
	W-SW WALL			264.5 39.5			66.6 13.0	
	ATTIC FLOOR			324.7 48.5				

1. THE U-VALUE OF THE PART OF THE ENCLOSURE WHERE NO WOOD FRAMING MEMBER EXISTS.
2. THE U-VALUE OF THE WOOD FRAMING MEMBERS IN THE ENCLOSURE TYPE.
3. THE R-VALUE ($\frac{1}{U}$) OF THE PART OF THE ENCLOSURE WHERE NO WOOD FRAMING MEMBER EXISTS.
4. THE R-VALUE ($\frac{1}{U}$) OF THE WOOD FRAMING MEMBERS IN THE ENCLOSURE TYPE.
5. THE AREA OF THE WALL ENCLOSURE NOT CONSISTIN OF WOOD FRAMING MEMBERS.
6. THE AREA OF THE WOOD FRAMING MEMBERS IN THE ENCLOSURE TYPE.

ALL U-VALUES INCLUDE INTERIOR AIR FILM BUT NOT THE EXTERIOR AIR FILM.

(11) Enclosure Characteristics

similar to the method used for calculation of the glazing areas. The fundamental difference is the property of density which delays the energy flux to the interior of the home by a calculated amount of time.

The enclosure characteristics are shown in Figure (11). The table is divided into two parts labeled Zone 1 and Zone 2. Zone 1 is the attic in the Minimum Energy Dwelling and Zone 2 is the living areas. In order to obtain the most accurate numbers, the energy transfer must first be calculated through the attic and then through the ceiling and into the living space. Each wall or roof construction is broken into two parts for a given orientation as shown in Figure (11). Each wall or roof construction can be broken into two major components: the stud framing and the insulation. The framing members comprise only 13% of the total wall construction, but since the heat loss is greater through the wood than through the insulation, it must be calculated. As can be seen in Figure (11), the resistances to the flow of energy through the stud is from one-half to one-third the value which is obtained for the insulation.

The infiltration for the MED is calculated by the inter-polation of two methods. One of the two estimates the size of known gaps which allow for the flow of outside air into the interior. Cracks which can occur around windows and doors are obvious areas, and known rates can be obtained from various manufacturers. The other method entails the use of general averages which have been obtained from actual testing of completed buildings.

The calculation of infiltration is an inexact science and depends greatly on the construction quality obtained from workmen, but an estimate must be made in order that a complete energy transfer picture can be obtained. The infiltration rate is modified according to the wind speed. For MED, the estimated infiltration is 144 cfm @ 15 mph

winds. The infiltration rate is increased or decreased by 9.6 cfm for every one mile per hour change in the wind speed.

The actual energy load is related to the infiltration rate and the temperature and moisture content of the air. The weather tape for the location supplies the values for the wind speed and air conditions as they change hour by hour.

The activities of the people using the home are also needed for the input to be as accurate as possible. The people in a space generate heat which affects the heating and cooling requirements. For the MED home, the heat production from people is shown in Figure (12). The values were obtained by interviewing the people who will live in the MED home and determining the type of activity and time of occurrence.

Along with people, the heat production from the appliances and lighting is estimated. Figures (13) and (14) show the heat production for weekdays and weekends for winter and summer. The humps which occur pertain mainly to the turning on of appliances during mealtimes.

The primary difference between the winter and summer heat production is the heat ejection system on the refrigerator. During the heating season, the heat from the refrigerator is transferred to the living space, and during the summer, the heat is rejected to the exterior. Since the refrigerator operates 24 hours a day, the effect on heat production can be substantial. The effect can be noted by comparing the average hourly load in each graph. In Figure (12) the value obtained is slightly less than 2,000 BTU/Hr. In Figure (13), for the summer, the heat input total is reduced by over half to 750 BTU/Hr. average hourly load.

The last major input for the computer program is the thermostat settings for the comfort control center. The

(12) People Heat Production For Weekday And Weekend

(13) Winter Lighting & Appliance Heat Production For Weekdays and Weekends

(14) Summer Lighting & Appliance Heat Production For Weekdays and Weekends

(15) Winter Thermostat For Heating Or Cooling

settings assumed for computer modeling are shown in Figures (15), (16) and (17). Figure (15) shows the winter thermostat setting. During the day, the heating thermostat is set for 68°F., and at night the thermostat is set back to 60°F. The cooling thermostat is positioned at 80°F. for mechanical and solar cooling day in and day out. However, if the outside air is cool (70°F.) and dry during the night, the economizer (mechanical ventilation) is turned on.

The only difference between the winter and summer thermostat (16) settings is the nighttime cooling temperature setting. During the summer, the thermostat is set at 65°F., and during the winter at 70°F. The reasoning behind the change is to prevent the unneeded cooling of the house during the winter months. If the thermostat was set lower in the winter, the house would be cooled to 65°F. at night only to require heat in the morning to re-establish comfort at 70°F..

Figure (17) illustrates the enthalpy sensor setting for the thermostat. For the Minimum Energy Dwelling computer modeling, the broad line on the diagram was used for the assumed setting. Therefore, anytime the thermostat control system is tested to determine if outside air rather than mechanical cooling can be used, the outside air is checked against this curve. If the outside air temperature and the relative humidity, when plotted on this chart, falls to the right of the curve, the outside air will not be used for cooling, and the mechanical cooling will be operated to meet the load requirement. If it falls to the left, the economizer will begin operation.

For the computer modeling, April through November were considered to be the cooling and December through March the heating season.

The result of all the preceeding input is shown in Figure (18) and is the output of the extensive computer

(16) Summer Thermostat For Heating Or Cooling

(15) Enthalpy Sensor Setting

(18) Yearly Energy Requirements For The Minimum Energy Dwelling

modeling. As can be seen in the figure, energy is not required the majority of the time and appears on the figure as the large flat area in the middle of the graph. The majority of the cooling load occurs in the early morning hours between midnight and sunrise. The reason the cooling load begins at such unusual hours is primarily due to the building materials. As designed, the heat impinging on the building is delayed from entering the interior by the combination of insulation and mass. The maximum heating occurs in January during the early morning hours. This is primarily due to the set up in thermostat each day. The maximum cooling required is during the month of September. Because of the nighttime occurrence of the cooling load, the outside air economizer can be used most effectively and, therefore, minimize the need to operate the mechanical cooling system.

The minimal amount of energy required for heating and cooling is further emphasized in Figure (19). Out of a total of 8760 hours in a year, heating or cooling is required less than 12% of the time. The load being so low is due to the relatively mild climate and proper design of the home.

The net energy requirement for heating is 1×10^6 BTU and $.95 \times 10^6$ BTU for cooling. An extremely low energy requirement and a very worthwhile result. The actual energy needed to meet the building requirements will be different due to the operating efficiency of the various pieces of equipment, but will still remain relatively small.

The different components such as the occupants of the home, which were outlined earlier, can have a positive or negative effect upon the net energy requirement. As can be seen in Figure (20), during heating, the occupants, the electrical component (appliances and lighting), and the window solar (light coming through a window) all have the effect of reducing the energy requirement of the home. The reason

8760 HOURS/YEAR

(19) Hourly Requirements For Heating and Cooling

CROSS BTU'S 2,202,000/YEAR
NET BTU'S 1,037,000/YEAR

(20) The Heating Requirements By Use

CROSS BTU'S 1,735,000/YEAR
NET BTU'S 946,000/YEAR

(21) The Cooling Requirements By Use

why this occurs is due to the fact that if heating is required, any appliance, lighting, people or sunshine will help reduce the heating needed to a lower value; in this case, by nearly 40%.

(21) A similar condition occurs when cooling is required. In this case, however, the items contributing a positive benefit are heat loss through windows (window conduction), infiltration, and electric (due to the refrigerator heat rejection system).

The components can be observed in greater depth in Figures (22) through (26). Each of the graphs are plotted to illustrate the energy effect for heating and cooling. As an example, Figure (22) is divided into two segments: positive and negative. In reading the graph, the positive area above the zero indicates the component is a detriment to the space conditioning of the house. A negative condition is a benefit and should be maximized to as great an extent as possible.

In Figure (22), the heat loss through the windows during times when heat is required is a major detriment. As shown by the broken line, the maximum load occurs during January. The total net BTU requirement is smaller due to sunlight coming through the windows.

Although heat loss is a detriment in heating, a benefit from the heat loss through the windows is obtained when cooling is required. In future designs, this benefit/detriment relationship should be further exploited. In this case, a good choice might be insulating shutters with single-pane glass. The insulating shutters, if placed over the windows at night, would prevent the greatest amount of heat loss during heating. However, during the day when cooling is a more likely occurrence, the heat loss through single glazing would be greater.

(22) Monthly Energy Requirements - Windows

(23) Monthly Energy Requirements - Wall

(24) Monthly Energy Requirements - Occupants

(25) Monthly Energy Requirements - Appliances & Lighting

(26) Monthly Energy Requirements - Infiltration

(27) Monthly Energy Requirements - Building Total

The best solution is highly dependent upon climate and use and, therefore, no standard solution will fit for every situation. In fact, if not carefully considered, a particular technique, such as using single glazing, can be very detrimental to the overall energy requirements of the home.

Figure (23) shows the performance of the wall during a year. The wall is a detriment to both heating and cooling continuously. However, the graph does not illustrate at which time during a day the greatest effect occurs. The heat gain during cooling occurs predominantly at night when the energy-efficient economizer (use of outside air for cooling) can be used.

Of the three remaining graphs (24), (25), and (26), the electrical (25) is the most interesting and includes all appliances and lighting. As designed, the electrical component is nearly always a benefit during both heating and cooling. The reason for the benefit during cooling is the refrigerator heat rejection system. During heating, the heat produced by the appliances and lighting helps reduce the energy requirement.

A total of all the preceeding graphs is shown in Figure (27). The solid black line is the energy requirement throughout the year. The total is obtained by the addition of the net BTU requirement for heating and cooling. The net is obtained after subtracting those items which help reduce the energy load from the gross BTU requirement.

The Minimum Energy Dwelling is a superbly designed house requiring the absolute minimum in mechanical conditioning. A strong theme throughout the MED Workbook is proper design. In Southern California, near coastal areas, homes can be built which require no cooling equipment, solar or standard, and minimul heating systems.

COMMUNITY RELATIONSHIP

Mission Viejo, located in Orange County, 50 miles south of Los Angeles, is a planned community development. The community includes swimming pools, recreation centers, tennis courts, a hospital, medical centers, schools (elementary through junior college), a library, a cinema, a bowling alley and bus service. In recent years, the community has been one of the most popular developments in the United States. Lotteries have had to be used in order to be fair to families who want to purchase a home.

It is interesting to muse about human circumstances in prehistory many years before our survival kit expanded so rapidly with new techniques. Man's possibilities for survival were outlined by space, time and information in that order of importance. For him, as with all species that hunt and forage, the elements for his survival were contained within the immediate literal space--a range or zone of space that encompassed an adequate food supply. The literal space for the early primates which arose between 70 and 35 million years ago was the tree environment of tropical forests. Here, the present shape of man's body can be vaguely recognized in those creatures which developed by the need to quickly and skillfully leap from tree to tree within the foraging zone. A grasping capability with the hands and feet evolved while their rapid transport about this discontinuous realm of leaves and branches pressed the need for improved stereoscopic

vision. Over millennia, the eyes drifted from sides to the front of the head, and the vision centers in the brain enlarged. The sense of smell acquired less significance, and the olfactory nerves dwindled. More time passed and primates diversified; competition increased. By optimizing body weight and muscle power, the lighter apes eventually dominated the tree zone. They remained there to become the supreme arboreal aerialists. The heavier apes (who later became intellectuals) were forced to the ground. Because the ground zone yielded less food per unit area, these creatures with larger appetites were forced to extend their range. In their wider search for food, they ventured into the savannas and encountered a more varied environment that required more adaptive techniques and offered greater opportunities to use learned behavior.

In this new hunting and foraging zone, the element of time became increasingly important for the hominid survival, especially the idea of a future. With their erect posture, pre-men could survey a wider stretch of grassland and delay all action until conditions seemed safer for continuing the hunt. After a kill, which was partially eaten on the spot, the remain-

ing portion could be carried to the home base to be shared with others. Tens of thousands of years later, greater efficiency developed as men organized into hunting bands and brought down bigger game using pre-planned strategies and more effective weapons. Still, until recently, man remained in his natural element, interlocked in the ecosystem on more or less equal footing with other animals, hunting and being hunted.

His place in the system changed quite dramatically with the development of agriculture. He could feed back learned information about plant growth (by experimentation or accident) into a system that worked for him. Again, the sensation of a future was vital. Unlike most animals that live entirely in the present immediately gratifying their needs whenever possible, man could interpose a delay; he could invest present effort to receive future value. In doing so, he found the benefits of agriculture to be greater and much more dependable than the chance operation of hunting. He was able to contrive an "artificial" abundance.

From this point on, he no longer had to fit in as other creatures do. His posture was "outside" the system, active rather than reactive, in much the same way that geological activity was the major force to which climate and biology always adjusted. But the reshaping of continents and the raising of mountains, though awesome and extensive, occurred over millions of years. Man's term of activity has been dissimilar. His cultural evolution has accelerated so quickly that, in terms of geological time, his developments appear not to be evolutionary but catastrophic. Civilized man, still in the shape of a hunter, has been able to quickly contrive vast, global, energy-intensive support systems that seem highly artificial in comparison to his recent grubbing and drubbing out on the savanna.

"The tragedy and the magnificence of Homo Sapiens together rise from the same smokey truth that we alone among the animal species refuse to acknowledge natural law."

Robert Ardrey/ The Social Contract

"The destruction of this planet would have no significance on a cosmic scale: to an observer in the Andromeda nebula, the sign of our extinction would be no more than a match flaring for a second in the heavens: and if that match does blaze in the darkness there will be none to mourn a race that used a power that could have lit a beacon in the stars to light its funeral pyre. This choice is ours."

Stanley Kubrick

Presently, the elements of space, time and information still outline man's survival activity, but are important in the reverse order. In the new world of commerce and technology, each individual's "hunting ground" has expanded to the limits of the earth. Space becomes meaningless for survival because a global interdependence circulates goods and services. But each of us still lives and works in a small world. It is small in terms of information about the true impact each of us has on the survival elements of material and energy resources that we can't see scattered worldwide. For instance, when one looks about at the possessions in his home, he may be vividly aware that it all "came out of his pockets", but is blind to their truer origins--the unseen inputs of energy that enabled their manufacture and transportation.

In the end, the true worldwide inventory of resources cannot be seen, but must be assessed in some manner. Achieving this will depend largely on our ability to gather reliable information about available quantities. Careful distribution of this wealth, in present and future years, will encompass a different set of problems.

Increments, Systems and Information

We have a strong awareness of energy consumption only in the confines of our immediate life space. While driving, we watch the fuel gauge needle swing toward "E"; or at home we hear the furnace kick on frequently during cold spells. These and other fuel-burning appliances about us are the end sources of energy use; they are the individual increments that make up a less noticeable community or worldwide system of energy use.

Energy conservation measures begin at these incremental points in order to upgrade the general efficiency of the system. For instance, the MED Project was launched to improve a particular increment, the single-family house, within the existing system of housing.

Whether a particular system is appropriate or can be improved or changed with respect to energy is the issue of this chapter.

We can see in recent history that man has been clever with bits or increments of technology, but awkward with more complex systems of interaction which are more difficult to assess and control. The task is made easier by using powers of abstraction to simulate behavior. In the case of energy use in a community, mathematical models and statistical analysis can fully and accurately diagram and quantify energy use patterns to uncover critical areas where conservation efforts can be most effective. Such informational tools will become increasingly important to planners who must calculate the true impact an aggregate of buildings will have on non-renewable energy resources.

"Inside to Out", "Outside to In"

In order to calculate impact or design with faith in their solutions, planners must gather information in the form of facts and numbers to describe or define the patterns of energy consumption at all levels. From there the data is analyzed and the problem is attacked. Starting within the system at the increment level, the problem is solved "inside to out", bit by bit. In the real world, this is how the present pattern of energy consumption will be rationalized into a new and better system.

Conversely, the problem can be attacked from "outside to in". Analyzing total community-wide energy use yields insight into what the ideal systems should be. If given the opportunity to build fresh, new, large-scale developments, the "ideal" systems could be launched into the real world from the start, eliminating the need to "fix them up" later. Needless to say, these opportunities are rare if they exist at all. Nevertheless, research efforts continue to explore this "outside to in" method. Even if

the opportunities never materialize or the proposed systems cannot truly respond to the needs, the effort is worthwhile. Spin-off discoveries and methods will insure a more rapid evolution of real world systems towards greater efficiency.

Housing Models

The pleas for energy conservation can be answered by individuals at the increment level, but specific improvement in the system will be guided by governmental bodies which control building development by taxation, zoning ordinances, research funding, and other prohibitions or incentives. They can positively direct the process from within the system only by first accurately defining it. In this area of concern, the Federal Government has wisely funded research that describes different types of building development by comparing their various costs.

In 1974, the Council of Environmental Quality, HUD, and the Environmental Protection Agency received 271-page report, The Costs of Sprawl,¹ prepared for them by the Real Estate Resource Corporation, a well respected organization within the building industry. The study outlines in detail the monetary, energy, and personal costs of different neighborhood and community models that are intended to simulate real world situations. The building blocks used to construct each model included various conventional housing types:

- . Single-family
- . Townhouse
- . Walk-up Apartment
- . High-rise

With these, neighborhoods of 1,000 units each were devised. (1-6) Ten neighborhoods, in turn, were mixed to form six community types for analysis. (7-12) The cost differences among the

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

(1) Type A - Single-Family Homes, Conventional Development Plan

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(2) Type B - Single-Family Homes, Clustered. (This Type More Closely Corresponds To The Mission Viejo Development)

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

Public Facilities

Recreation

Vacant Land

Public & Semi-Public

Underdeveloped

Single Family Conventional

Single Family Clustered

Townhouse Cluster

Walk-up Apartments

High Rise Apartments

(3) Type C - Townhouses, Clustered

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(4) Type D - Walk-Up Apartments

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(5) Type E - High-Rise Apartments

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(6) Type F - 20% Each Of The Five Previous Types (A Through E)

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(7)

Type I - Planned Mix Community

Consists of a housing mix of 20% of each type shown in the neighborhood analysis (single-family conventional, single-family clustered, townhouses, walk-up apartments, and high-rise apartments). Thus, there are 2,000 housing units of each type in this community. Neighborhoods are contiguous and large areas of open space are preserved.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

Public Facility

Commercial Land

Schools

Single Family Conventional

Single Family Clustered

Townhouse Cluster

Walk-up Apartments

High Rise Apartments

(8) Type II - Combination Mix Community

Assumes that 50% of the community is constructed as planned unit developments with contiguous and related land uses, while 50% is built in the typical "sprawl" suburban pattern. The housing mix is the same as for Type I.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

Type III - Sprawl Mix Community

(9) Development occurs somewhat randomly in a "leapfrog" manner with many small parcels of passed-over, vacant land remaining. The housing mix is the same as in Types I and II, with 20% of each type of housing.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(10) Type IV - Low Density Planned Community

Seventy-five percent of the dwelling units are single-family homes clustered around cul-de-sacs; 25% are conventional single-family dwellings. Neighborhoods are contiguous, as in Type I, but densities are lower, resulting in less undeveloped, vacant land. Open spaces are preserved and land uses are comprehensively designed and inter-related.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

Type V - Low Density Sprawl Community

- (11) Seventy-five percent of dwelling units are conventional single-family homes; 25% are clustered single-family units. There are small parcels of passed-over land separating neighborhoods, but no land is left vacant or undeveloped. This type represents the most prevalent form of development currently practiced in suburban fringe areas.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(12) Type VI - High Density Planned Community

Ten percent of the dwelling units are clustered single-family homes, 20% are townhouses, 30% are walk-up apartments, and 40% are high-rise apartments. Housing types are mixed in contiguous neighborhoods. Much vacant land remains. Considerable proportions of open space are planned, and land uses are related.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

neighborhood and community types have their origins in the basic building types and can be seen immediately in the cost per square foot comparison. (13) As these various building types are brought together to form communities, the costs of land, roads, and utilities mount according to the aggregate building configurations and their density. In a single graph, all these individual costs characterizing each neighborhood or community model can be compared to those of the other types. (14) (15)

The major conclusions are not that surprising. For a fixed number of households, "sprawl" is the most expensive form of residential development in terms of economic cost, environmental cost, natural resource consumption and many types of personal cost. Better planning is shown to reduce all incremental costs. Planning results in savings, but density is a much more influential cost determinant. The greatest cost advantages occur when higher density planned communities are compared with low density sprawl. Increasing densities will increase some costs, but not nearly proportional to the increased number of households per unit area. Discounting the energy costs of materials and construction, the most relevant conclusion of The Costs of Sprawl are the figures for electric and gas consumption. (16-19) By planning high density communities instead of permitting sprawl development, the consumption of electricity and gas can be seen to fall by 40%.

These findings can be used to assess the merits or detriments of the Mission Viejo/ Cordova Development (20) (21). Contained within its boundaries is a net buildable area of 138 acres. Four hundred ninety-six lots are proposed which yield a density of 3.6 units per net subdividable acre. This planning type corresponds most closely to the single-family clustered neighborhood type. Therefore, similar conclusion outlines for that prototype might be drawn for the Mission Viejo

1. Planned development of all densities is less costly to create than sprawl in terms of environmental costs, economic cost, personal cost, and energy consumption. These differences are particularly significant in terms of costs borne by local government.
 - a. Planned community development saves 4% in costs for housing, roads, utilities, and land over sprawl development with the same housing mix.
 - b. Planned development is likely to decrease the total cost burden to local government by as much as 1/3 because a larger population of land and facilities for open space, roads, and utilities is likely to be provided by the developers.
 - c. Savings in operating costs borne by government for public services, education, recreation, sewage, police, etc. are 5% to 6% of total cost.
 - d. Planned development shows significant environmental advantages over sprawl through:
 - 20% to 30% less air pollution resulting from reduced automobile travel
 - Conservation of open space
 - Preservation of significant wildlife and vegetation habitat
 - Improved site design to minimize noise impact
 - Careful land use design so as to minimize the amount of soil disturbed and paved over (thus lowering slightly the volume of storm, water run-off, sedimentation, and water pollution).
 - e. Other benefits of planning:
 - Fewer miles of road are likely to fall within areas with poor air movement or on poor soils
 - Fewer dwellings will be directly affected by noise and air pollution from expressways and arterial roads
 - Less soil would be eroded as there would be virtually no development on steep slopes or flood plains
 - Less woodland would be cleared, minimizing the adverse effects of development on the vegetation and wildlife habitat
 - f. Energy consumption, because of reduced automobile travel, will be from 8% to 14% less in planned development than in unplanned development. Water consumption is essentially the same in planned and unplanned developments unless special conservation measures are planned.
2. Economic and Environmental Costs (as well as resource consumption) are likely to be significantly less at higher densities to house and service a given population (1,000 household). Some personal costs, however, may increase with increasing density.
 - a. Total per dwelling unit cost (including residential, open space/recreation, schools, roads, utilities and land) range from \$48,900 for single-family conventional housing of two units per acre to \$20,700 for high-rise apartments at ten units per gross acre.
 - The cost of housing is least for walk-up apartments (five units per gross acre), being only 37% of housing costs at a density of two units per gross acre. Housing costs at a density of ten units per acre are somewhat higher than for walk-up apartments, but is still only 47% of the housing costs at two units per acre
 - Even when all the different types of dwelling units contain the same inside living area, the cost of walk-up apartments is only 57% of the cost of single-family houses.
 - The cost of roads and utilities for housing at ten units per acre is 80% less than at two units per gross acre.
 - The amount of land required is substantially reduced (even though the cost per gross acre tends to be higher for increased density)
 - b. Operating costs per unit for electricity and gas decrease significantly as density increases because less energy is consumed per unit.
 - c. The total costs likely to be borne by local government are reduced as much as 62% in denser developments because of the low cost of roads and public utilities. Public operating costs may be reduced by 73%.
 - d. Increased density reduces total environmental costs but increases the concentration of pollution.

- e. Energy and water consumption may be reduced by approximately 40% in high density developments.
 - The reduced energy consumption results from both reduced automobile transportation and reduced heating and cooling requirements.
 - The reduced water consumption results primarily from reduced lawn watering
 - f. Some personal costs may increase with denser developments.
 - At higher densities, noise impacts are likely to be more severe and overall satisfaction with the residential environment tends to decrease
 - On the positive side, higher density living increases leisure time available by reducing household maintenance responsibilities
 - Psychic costs, such as those associated with a loss of privacy may increase with higher density. However, good design can mitigate many of these problems
3. Thus, while planning results in cost savings, density is a much more influential cost determinant. Clearly, the greatest cost advantages occur when higher density planned developments are contrasted with low density sprawl.
- a. Total costs for the high density planned community are 56% of those for the conventional low-density sprawl development.
 - b. Savings in land cost amount to 43% with savings of 40% for streets, and 63% for utilities.
 - c. Operating and maintenance costs are approximately 11% less per year than the low density sprawl development. Savings are largely due to less road and utility pipe lengths and reduced gas and electric consumption in a high density community.
 - d. Costs borne by local government may decrease by almost 50% and operating and maintenance may decrease by 13%.
 - e. Total air and water pollution and other forms of environmental degradation are similarly reduced. Air pollutants from automobiles are reduced 50%. Those from space heating and other natural gas uses are reduced 40%. Sediment is reduced 30% and total storm water runoff 20%.
 - f. Energy consumption is reduced 44% and water consumption 35% in high density planned communities as compared to low density sprawl communities.
 - 4. Variation in certain basic study assumptions lead to the following
 - a. Doubling or tripling the population assumed in the base analysis would allow the community to support additional services--e.g., locational and other specialized services, regional parks, community health clinics and public transportation. Diseconomies of scale would be experienced with regard to solid waste collection; some operating economies are likely to be realized for schools, police, fire, libraries, and government administration. Significant economies (both capital and operating) would be found for solid waste disposal and sewage and water treatment.

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

"As one went to Europe to see the living past, so one must visit Southern California to observe the future."

Alison Lurie

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

Innovative Energy Legislation

The city of Davis, California is one community that is setting an example by demanding energy conservation at both increment and systems level. In the past three years, 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 the new code will save approximately 50% 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 design and administration procedures were instituted. These proposed changes have been published in a report² drafted by Living Systems, a group of planners, with the help of an Innovative Project Grant from HUD. If implemented, the resolutions in the report cannot compact the city into a maximum energy-conserving system as might be ideally conceived, but take major steps to improve efficiencies within the given planning context of detached single-family housing. These guidelines, of course, can help direct other communities in the same direction.

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

	SINGLE FAMILY CONVENTIONAL	SINGLE FAMILY CLUSTERED	TOWNHOUSE CLUSTERED	WALK-UP APARTMENTS	HIGH-RISE APARTMENTS	
AVERAGE STRUCTURE COST PER SQUARE FOOT	\$ 18.58	\$ 18.58	\$ 12.68	\$ 11.18	\$ 16.37	
STRUCTURE COST PER UNIT WITH 1,200 SQUARE FEET	\$22,296	\$22,296	\$15,212	\$13,416	\$19,644	
PAVING/PARKING (PER UNIT)	584	449	194	266	261	
LANDSCAPING (PER UNIT)	255	145	61	44	15	
UNITY CONNECTORS (PER UNIT)	1,585	1,408	795	276	183	
EFFECTED COSTS	PER DWELLING UNIT CAPITAL COSTS (BASE ANALYSIS % OF A)	\$32,146 -	\$31,774 99%	\$16,263 51%	\$11,766 37%	\$15,188 47%
	PER DWELLING UNIT CAPITAL COSTS (SENSITIVITY ANALYSIS % OF A)	\$24,720 -	\$24,298 98%	\$16,263 66%	\$14,002 57%	\$20,103 81%
TOTAL COSTS	TOTAL PER DWELLING UNIT CAPITAL COSTS (BASE ANALYSIS % OF A)	\$46,283 -	\$43,662 94%	\$25,555 55%	\$19,599 42%	\$18,796 41%
	TOTAL PER DWELLING UNIT CAPITAL COSTS (SENSITIVITY ANALYSIS % OF A)	\$38,857 -	\$36,236 93%	\$25,555 66%	\$21,835 56%	\$23,731 61%

(13) Cost/Sq. Ft. Comparisons Among
Conventional Housing Types

NEIGHBORHOOD DIRECT COST ANALYSIS

1,000 UNITS

(14) Neighborhood Direct Cost Analysis - 1,000 Units

COMMUNITY DIRECT COST ANALYSIS

10,000 UNITS

(15) Community Direct Cost Analysis - 10,000 Units

	Housing Pattern (1,000 Units)					
	A	B	C	D	E	F
	Single-Family Conventional	Single-Family Clustered	Townhouse Clustered	Walk-Up Apartment	High-Rise Apartment	Housing Mix (20 Percent Each A - E)
Capital Costs						
Underground cable	\$ 85,320	\$ 56,564	\$ 36,024	\$ 21,494	\$ 12,727	\$ 40,290
Profit, Overhead, Engineering	<u>25,596</u>	<u>16,969</u>	<u>10,807</u>	<u>6,448</u>	<u>3,818</u>	<u>12,087</u>
Total Capital Costs	\$110,916	\$ 73,533	\$ 46,831	\$ 27,942	\$ 16,545	\$ 52,377
Operating and Maintenance Costs						
Per Year	\$218,874	\$218,874	\$142,833	\$111,878	\$101,191	\$158,730

(16) Neighborhood Cost Analysis - Electricity

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

	Housing Pattern (1,000 Units)					
	A	B	C	D	E	F
	Single-Family Conventional	Single-Family Clustered	Townhouse Clustered	Walk-Up Apartment	High-Rise Apartment	Housing Mix (20 Percent Each A - E)
Capital Costs						
Pipeline	\$124,200	\$ 82,340	\$ 52,440	\$ 40,812	\$ 24,165	\$ 64,791
Overhead, Profit, Engineering	<u>37,260</u>	<u>24,702</u>	<u>15,732</u>	<u>12,244</u>	<u>7,249</u>	<u>19,437</u>
Total Capital Costs	\$161,460	\$107,042	\$ 68,172	\$ 53,056	\$ 31,414	\$ 84,228
Operating and Maintenance Costs						
Per Year	\$201,301	\$201,301	\$138,809	\$108,854	\$ 93,247	\$148,474

(17) Community Cost Analysis - Electricity

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

	Community Development Pattern (10,000 Units)					
	I	II	III	IV	V	VI
	Planned Mix	Combination Mix 50 Percent PUD, 50 Percent Sprawl	Sprawl Mix	Low Density Planned	Low Density Sprawl	High Density Planned
Capital Costs						
Underground Cable						
Neighborhoods	\$ 402,900	\$ 402,900	\$ 402,900	\$ 637,530	\$ 781,310	\$ 244,020
Improved Vacant Areas	19,973	29,957	39,037	28,448	75,935	14,119
Semi-Improved Vacant Areas	14,454	30,282	48,177	22,024	33,036	11,013
Subtotal	\$ 437,327	\$ 463,139	\$ 490,114	\$ 688,002	\$ 890,281	\$ 269,152
Overhead, Profit, Engineering	109,332	127,363	147,034	172,000	267,084	67,287
Total Cable Cost	\$ 546,659	\$ 590,502	\$ 637,148	\$ 860,002	\$1,157,365	\$ 336,439
Transmission Lines	333,348	333,348	333,348	333,348	333,348	333,348
Transformers	216,000	216,000	216,000	216,000	216,000	216,000
Total Capital Costs	\$1,096,007	\$1,139,850	\$1,186,496	\$1,409,350	\$1,706,713	\$ 885,787
Operating and Maintenance Costs						
Transmission/Distribution	\$ 660,140	\$ 660,140	\$ 660,140	\$ 885,681	\$ 885,681	\$ 531,754
Power production	1,100,234	1,100,234	1,100,234	1,476,135	1,476,135	886,258
Total Operating Costs	\$1,760,374	\$1,760,374	\$1,760,374	\$2,361,816	\$2,361,816	\$1,418,012

(18) Neighborhood Cost Analysis - Gas

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

	Community Development Pattern (10,000 Units)					
	I	II	III	IV	V	VI
	Planned Mix	Combination Mix 50 Percent PUD, 50 Percent Sprawl	Sprawl Mix	Low Density Planned	Low Density Sprawl	High Density Planned
Capital Costs						
Pipeline						
Neighborhood	\$ 647,910	\$ 647,910	\$ 647,910	\$ 928,050	\$1,137,350	\$ 406,320
Improved vacant land	32,613	48,917	63,744	41,411	110,538	27,931
Semi-improved land	27,444	57,948	91,476	41,817	62,727	20,910
Subtotal	\$ 707,967	\$ 754,775	\$ 803,130	\$1,011,278	\$1,310,615	\$ 455,161
Overhead, Profit, Engineering	176,992	207,563	240,939	252,819	393,185	113,790
Total Capital Costs	\$ 884,959	\$ 962,338	\$1,044,069	\$1,264,097	\$1,703,800	\$ 568,951
Operating and Maintenance Costs						
Cost per year						
Residential	\$1,484,740	\$1,484,740	\$1,484,740	\$2,013,010	\$2,013,010	\$1,184,592
Non-residential	161,080	161,080	161,080	161,080	161,080	161,080
Total Operating and Maintenance Costs	\$1,645,820	\$1,645,820	\$1,645,820	\$2,174,090	\$2,174,090	\$1,345,672

(19) Community Cost Analysis - Gas

SOURCE: Real Estate Research Corporation, The Costs of Sprawl, 1974.

(20) Vicinity Map - Mission Viejo Planned Community

(21) Location of Minimum Energy Dwellings in
Mission Viejo Tract #8504

The suggested policy changes are conveniently organized into five different areas:

- . Land Use Planning
- . Transportation
- . Landscaping
- . Administration Programs
- . Home Environment

A glance at the table of contents (22) of the draft report gives a condensed outline of the proposed policy changes. In order to clarify their intentions, the draft report has been summarized.

Land Use Planning--The most significant and longlasting decisions a city makes is in the area of land use planning because it affects the environmental quality of the community. noise levels, transportation patterns, air pollution levels, and the conversion of agricultural lands. 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.

It is obvious that reducing lot sizes will reduce the size of redevelopments, thus decreasing travel distances to and from the city and saving agricultural land. In conjunction with this, the maximum use of the sun's energy can only be achieved when buildings are not shaded by one another. The right of a homeowner to receive the full benefit of the sun may be largely affected by his neighbors. The new ordinances proposed at Davis reckon with these situations in three ways:

- . Establishing solar rights for each owner
- . Increasing setback flexibility
- . Deregulating fence setback requirements

If made law, the ordinances could be enforced by requiring developers to build all new houses within the boundary of a space envelope that eliminates

I. LAND USE PLANNING

- A. An Ordinance Increasing Setback Flexibility and Reducing Minimum Lot Size
- B. An Ordinance Deregulating Fence Setback and Construction in Davis
- C. An Ordinance Establishing Solar Rights in New Residential Development in Davis
- D. An Ordinance Setting New Street Width Standards

II. TRANSPORTATION

- A. Resolution Supporting Further Development of Pedestrian Facilities
- B. Resolution Supporting Further Development of Bikeways and Bicycle Facilities to Encourage Bicyclists in Davis
- C. An Ordinance to Reduce the Hazards Caused by Street Trash
- D. A Resolution Supporting Improved Bicycle Access to Sacramento

III. LANDSCAPING

- A. A Resolution Supporting Increased Tree Shading in Existing Development
- B. An Ordinance Amending Section 29-160 to Require Shading For Parking Lots
- C. An Ordinance to Allow Use of Different Treatments for Parking Areas
- D. An Ordinance Requiring Functional Landscaping in New Commercial Development

IV. ADMINISTRATIVE PROGRAMS

- A. A Resolution Supporting City Efforts to Improve the Understanding and Application of Energy Conservation Techniques
- B. An Ordinance Adding New Functions to the Environmental Advisory Committee for the City of Davis
- C. Energy Conservation and the City Vehicle Fleet

V. THE HOME ENVIRONMENT

- A. An Ordinance Prohibiting and Nullifying Restrictive Covenants or Regulations that Ban Use of Clotheslines and Setting Requirements for Clotheslines in Multi-unit Dwellings
- B. An Ordinance Restricting Use of Gas, Electric, Oil, Propane, Kerosene, Gasoline, or Butane Swimming Pool Heater
- C. A Resolution Supporting Work at Home

(22) Contents of "Planning For Energy Conservation -

SOURCE: Living Systems, Planning For Energy Conservation - Draft Report, 1976.

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, but new setback regulations alone will not create conditions for standard envelope shapes. Because orientation of buildings varies widely, standard envelope shapes are unworkable. To alleviate planning difficulties, Living Systems is preparing a booklet, A Guide to Solar Orientation, Solar Rights, and Envelope Zones, to help future developers prepare zones appropriate for each lot. This may not be enough to eliminate conflicts. For instance, a homeowner may demand that his neighbor's trees be cut down to encure his sun rights. The landscape program may also conflict with solar rights legislation.

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. Construction and maintenance energy include heavy equipment operation, asphalt, and energy for making concrete for sidewalks. Maintenance costs include patching and street sweeping. Other costs must be accounted. Water runoff from streets increase flood potential and thus investments in flood control programs and sewage treatment plants. Urbanization often forces farmers to less productive land that requires increased fertilization, water, tillage, and transportation.

An even greater cost can be attributed to the effect of streets on the microclimate during the summer. On a sunny 90°F. day, pavement temperatures can reach 140°F. The effect on nearby buildings and cars is an increased air conditioning load. It is estimated that by narrowing the streets, air temperatures could drop about 10° and

thus reduce air conditioning requirements by 50%. The energy costs in extra materials and maintenance could also be saved.

Transportation--Approximately 45% of the energy consumed in California is used to move automobiles, air planes, trains, buses, 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. The 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 proposed 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 and pleasant. 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% 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 micro-climate to increase use in the summer. The resolution requires that 25% of the city's 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 eliminate trash placement in the street to 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 whether an individual walks, cycles or uses an air conditioned car. The glaring, hot, unshaded asphalt will 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. The additional plant life will also require huge amounts of water. This could offset some of its benefits.

- Existing Developments--Existing wide, unshaded streets would be retrofitted with deciduous trees along their edges and in islands in the middle of the street. (23) The goal is to achieve 50% shading on all existing streets within 50 years.

- Parking Lots--In order to reduce the thermal stress on people, cars and buildings, the shading of parking lots will be required. A minimum of 50% shading on August 21st within 15 years of planting will be the target. Trees used for shading must meet longevity, density, pollution tolerance, and maintenance requirements.

- Different Treatment in Parking Lots--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

PROPOSED RETROFIT

EXISTING

(23) Retrofitting Excessively Wide Streets With Shade Trees

SOURCE: Living Systems, Planning For Energy Conservation - Draft Report, 1976.

between. Bricks or turf blocks fit this category, although gravel and cobbles are also recommended.

Turf-blocks are also interesting as an alternative paving material. (24) They are precast concrete grid units measuring 17-1/2" wide by 23-1/2" long and 4-3/4" high and weigh approximately 75 pounds each. A unit contains 9 soil chambers and 20 raised protuberances for vehicle wheel contact. When the upper chambers are filled with soil and grass is sown, the upper area is composed of 73% grass and 27% concrete. The lower bearing area is 20% concrete. As the grass grows the support areas become hidden and the effect from a distance is one of a lawn rather than a parking lot. It is more difficult to define parking spaces and lanes because painting is impossible. But this is a minor point that can be solved with upright signs or posts. These alternative types of paving, combined with shading from trees or arbors will do much to control temperatures in parking lot areas.

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% of the site with an expected 15-year growth pattern. The method of compliance required submission of a landscaping plan showing the amount of shading on August 21st at 8 p.m., 12 noon, and 4 p.m. An average of 50% shading of all exposed horizontal surfaces (excluding roof) is required within 15 years.

Administration Programs

Besides requiring new residential and commercial development to be more energy conscious, the municipal government should rationalize its own use of energy. In Davis 5% of the electricity

FOUNDATION-LIGHT
VEHICLE PARKING

FOUNDATION-HEAVY
VEHICLE PARKING

(24) Turf-Block (Quickset Concrete Products, Inc., San Jose, California)

SOURCE: Living Systems, Planning For Energy Conservation - Draft Report, 1976.

consumed is for pumping water and 1% 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 analyze and 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.

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 refrigerators and refrain from using unneeded household appliances. These conservation measures cannot be legislated, but the researchers do propose three more ordinances which supercede 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 these clothes lines and would require all new multi-unit developments to provide the necessary 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 are proven, available, and more economical than other systems, the only heat source allowed for swimming pools will be solar energy.
- . Work At Home--The last resolution encourages the use of the home as a working environment. Since 50% of the energy used in Davis is for the automobile, it makes more sense to move parts and paper than people. Therefore, it supports the widest possible use of residential areas for working and small businesses.

Attitudes That Merge "Increment" and "System"

The state government of California is headed on the same tract toward energy conservation as Davis. Its proposed methods for attacking the problem are found in Building Value, Energy Design Guidelines for State Buildings³ by Bender/de Moll, prepared for the Office of State Architect. It offers many suggestions for improvement at all levels. Most significantly, it illustrates novel ways of clearly picturing the way an incremental point of consumption reverberates through the system. Possessed with this type of awareness, the authors expose as inadequate "initial cost" valuation of buildings and replace it with four new economic performance measures: Valuation as a Real Estate Investment, as an

³de Moll, Bender, Building Value, Energy Guidelines for State Buildings, prepared for the Office of the State Architect, California, November, 1976.

- 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."

SOURCE: Bender/deMoll, Building Value, Energy Guidelines for State Buildings, 1976.

Energy Structure, as a Total Operating Entity, and as a Public Investment. These are clever methods of valuation that can force public and private builders to account for the energy costs they generate throughout the community system. Each method corresponds to different horizons of responsibility for the real costs that result from our activities, but they can be used to complement and reinforce each other. For instance, when using Evaluation as an Operating Entity, the cost of building is viewed in conjunction with the total cost of the activities it shelters. In these terms, building and maintenance costs are 2% and 6% respectively, of the total costs. More than 90% goes 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% 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.

Fifty-three individual guidelines are developed from 106 sources and are categorized with respect to the four economic performance measures. Some are particularly telescopic in their sight toward ultimate resource impact. "Source-Stream Analysis" compares delivered energy for a particular task with different delivery systems. Resource multipliers (numerical factors) for various fuel types are used to calculate total energy used for a particular end result. For example, to get the 2800 BTU required for a shower, one must start with 4500 BTU of gas heat, or 10,000 BTU of coal-fired electricity. The multiplier for Nuclear Fission Electric (LWR) is 7.88. Twenty-eight hundred BTU at the end point times a factor of 7.88 along the delivery stream is 22,064 BTU at the source.

Another guideline encourages the matching of energy quality with the particular application. Different kinds of energy have different capabilities and different qualities. Some are more concentrated (a gallon of gasoline vs. a cord of wood). For instance, high quality natural gas can be burned for water and space heating, but solar energy makes more sense because it delivers temperatures in the range needed for these functions.

Since only a small portion of our total energy use requires high quality, we can use less expensive and less limited renewable energy sources (solar, waste heat, plant fermentation) for many applications, allowing us to save our limited high quality energy for special needs. Coal, natural gas, petroleum, and hydro-electricity can be reserved for the high-temperature processes, special applications, and future use rather than operating hot water heaters.

"Energy cascading" is associated with energy quality and should be used wherever possible to make multiple and fullest use of remaining energy quality of waste energy from each application. For example, the waste heat from generating electricity to operate our lights and the heat released from the lamps themselves can be used to heat buildings. That heated or cooled air can then be used to preheat or cool the incoming ventilation air. The heat exhausted by air conditioners can be used to preheat hot water. With these techniques, total energy plants for buildings can be devised which, in some instances, could cut fuel consumption in half.

Other guidelines examine the energy input in building materials, heat storage in building materials, natural day lighting, recycling benefits, parking management that discourages automobile use, processes that favor employment over capital or energy expenditures, and other conservation potentials.

These and other guidelines awaken us to the far reaching effects originating from resource consumption in our immediate life space.

"Outside to In" - Total Initial Design

Both the Davis draft report and Building Value report from the California OSA have suggestions about churning the existing system to reform it as much as possible. Another more drastic strategy is to completely build new cities. At the University of Southern California, Los Angeles, Ralph L. Knowles, author of Energy and Form,⁴ has been carrying out research in this area in conjunction with the Department of Architecture. He emphasizes two major concerns. First, all planning must recognize the city as a complex organic entity similar to plant and animal life or eco systems which grow in size and transform by greater diversification of its parts. The parts can be observed to mature at different rates and reach different levels of organization within various domains of its area. In abstracting this behavior, the ground work is laid for comprehensive large-scale new city building that does not frustrate this natural occurrence. The analogy to nature can be extended to view the original prime city plan as the genetic code which will guide and nurture the growth of the city through hundreds of years of development.

The second general concern is to conform the city's growth patterns to energy-conserving arrangements without diminishing the full richness of the city complex. The main intention would be to passively mitigate large seasonal variations in temperature which must ordinarily be overcome by mechanical means.

The implication is that if these two major planning concerns could guide future growth, then the city could be ideally built. As the two responses

⁴Knowles, Ralph L., Energy and Form, An Ecological Approach to Urban Growth, The M.I.T. Press, Cambridge, Massachusetts, and London, England, 1974.

intertwined as form, the city would become a duality of energy efficiency and self-correcting growth behavior. In comparison, conventional construction is hopelessly random and uncontrolled. It is characterized by incremental building--single building projects undertaken here and there to replace old buildings or pioneer new areas. These projects, small in comparison to the whole city, are separately initiated by the economic circumstances of the particular owner who is concerned with initial cost and rates of return, and the character of the buildings are often strongly influenced by the current fashions in architecture. When viewed through time and across an entire metropolitan area, the pattern of development is chaotic and energy-intensive functions are separated, the texture is sparse and residential areas are scattered outside the city. To Knowles, this entrenched mode of building is inadequate for our time and must be replaced with opposite view points. He advocates: "First an economic purpose for urban growth that stresses long-term costs of development; a large-scale view of a community as a set of associations in which the diversity of community needs is met not by supplying ever increased mobility, but by building closer contact diversity into the arrangement; and an aesthetic based on form as a natural adaptation for survival".

The first purpose of design which stressed long-term payback lies in the face of established notions that may change in times of crisis when maximum energy efficiency will depend on large initial investments.

The second purpose of providing "the close-contact diversity essential for a rich community life" can be achieved compactly and efficiently in space to go hand in hand with energy conservation. The functions of housing, working, and shopping, currently separated in space but connected by the automobile, would be brought together. This would end the daily migrations of many people over larger distances. By care-

ful planning, all amenities including community and privacy, which can now be only sought out with the aid of automobile travel, could be incorporated in one place.

The third purpose described--that aesthetics should be based on "form as a natural adaptation for survival"--would be of symbolic value to the new city dwellers. This type of aesthetic attitude is more essential than merely investing building with a shallow prettiness. In contrast, a noble aesthetic emerges when purpose is clarified by form. The form originates from and makes reference to the functional requirements without confusion; it "pictures" the needs and requirements it yields to. Aesthetic form then becomes the visible trace of the particular set of forces acting to shape it. This can be related to the city scape. If the forms of the buildings in a city are a clear basic response to the cyclic variations of nature, then, by only inhabiting a place one could make clear sense of its origin. The shapes and processes of the built environment would be grounded in apparent forces which reflect the character of life itself.

The image of a settlement which lends a clearer understanding of these ideas, especially energy conservation, is the Pueblo Bonito at Choca Canyon, New Mexico. Knowles has chosen it as an example of community planning and energy efficiency. Even though it is nearly a thousand years old and almost completely ruined, archaeologists have been able to logically reconstruct its original form. With the drawings that illustrate what it once was like, one can imagine its people as a thriving, diverse, community contained within its compact, semi-circular plan; people who could, by the rhythm of nature, find beauty in the purpose of their city form. This obviously designed form which fosters community spirit, a strong sense of place, and aesthetic appreciation is first given by the survival requirement of efficient use of solar radiation.

(25) Plan, Old Pueblo Bonito

SOURCE: Ralph L. Knowles, Energy and Form, 1974.

(26) Old Pueblo Bonito In Chaco Canyon With Cliffs To The North

SOURCE: Ralph L. Knowles, Energy and Form, 1974.

(27) Plan, New Pueblo Bonito

SOURCE: Ralph L. Knowles, Energy and Form, 1974.

The story of its form and construction is interesting. The pueblo underwent two stages of development. Old Bonito, (25)(26) dated at 919 A.D., was crescent shaped with its axis to the southeast at an azimuth of 150° . It measured 300 feet across the opening and 120 feet deep from the mouth of the opening to the outside of the curving walls on the north. The buildings were stepped terraces, three tiers high and averaging 37 feet in depth. About 1050 - 1060 A.D., the old Bonitans welcomed into their pueblo a group of strangers from another region. These new people immediately launched an extensive building program to expand the pueblo, employing the advanced construction techniques they brought with them. During the next twenty years, they expanded the settlement to a semi-circle 520 feet at the wide point on its south face. (27)

When modeled and tested under a heli-don simulating the sun, both the old and new Pueblo forms are found to be remarkable solar collectors that mitigate seasonal variations in insolation. (28) (29) But the new Bonito form significantly improves the old one. It exhibits generally high stable winter efficiency (8 a.m. to 4 p.m.) in the way it receives and transmits the sun's energy. The summer profile shows higher efficiency to dissipate the night chill, while summer afternoon efficiency of the structure drops off as the ambient air temperatures rise and less solar energy is required. (E_t is the amount of energy being transmitted to the interior of the pueblo. E_m is the energy that might be transmitted if all available surfaces were receiving energy at 100% efficiency; as if the sun's rays were normal to them.) So clear are the intentions of the new builders that the success of their design could hardly be attributed to chance.

Other pueblo settlements demonstrate efficient solar collection but in a different way. Individual buildings at the Acoma settlement (30) are efficient, but their aggregate, structured

by a grid pattern, is a lower level of organization and in the end is less energy efficient as a whole. This point about organization is a strong one with Knowles who explains, in his characteristic prose, why Pueblo Bonito must be considered one of the major achievements of pre-Columbia America: "The ultimate level of attainment of a steady state is increased by high levels of organization. Bonito is a clear example of an arrangement that must grow to pre-determined limits before purpose can be fully attained. As expansion takes place, the system becomes increasingly differentiated; its parts take on special tasks. With the placement of the last generative increment and the completion of the form, the fullest extent of purpose is achieved. The final degree of optimization is high and remains fixed."

This is not the case with the Acoma settlement "which maintains a fairly steady level of optimization after the placement of the first significant increment and throughout the entire building process. Specialization by parts of the settlement does not increase, so the level of organization tends to remain constant. These building arrangements, like natural systems in general, demonstrate an inverse relationship between the level of organization and the optimization of the specific purpose. During growth, the lower level of differentiation produces an early but low level of optimization, as Acoma; a higher level of differentiation during the growth process results in a later achievement of purpose, but a higher level of optimization as at Bonito." The "specific purpose" implicit in these conclusions is energy conservation. Knowles dwells mainly on Bonito as a highly organized physical object which responds to a few determinants, mainly the movement of the sun and the available technology. He leaves us to speculate about the unseen political forces which first organized the building process, solicited or forced wide

(28) Efficiency Of Old Bonito In The Way Surfaces Receive And Transmit Solar Energy To Interior Spaces. Generally High Stable Efficiency (8 a.m. - 4 p.m.) In The Way New Bonito Receives And Transmits Energy

SOURCE: Ralph L. Knowles, *Energy and Form*, 1974.

(29) Plan Of Acoma Settlement

SOURCE: Ralph L. Knowles, Energy and Form, 1974.

"... to the end that our buildings will grace the land, praise our culture and by their nature be not only good neighbors to the earth but sensible consumers of its bounty."

Dr. Harold B. Gores

its commitment to a long-term building program.

The ultimate purpose of his research is to innovate good city design, and at the end of his book, Knowles illustrates models of proposed city form (31) that grew out of his studies of Bonito and the Owens Valley ecosystem. These are preceded in the text by extensive design process elements that respond to the degree of complexity of a number of micro-climatological influences rather than the full range of urban design issues.

In fact, much of the work presented can be regarded simply as a highly involved shading study. Thermal stress is dealt with mainly in terms of surface-volume ratios which are used to determine the density of the city, and total city form is shaped by solar orientation. There is little mention of different building materials which have different thermodynamic behavior and internally generated heat is ignored. Since the energy picture seems incomplete, one is anxious to know how these additional factors could refine or change the forms. Still, corrected city models, generated strictly from total energy concerns, may be illusory. Their energy-conserving arrangements must also be congruent with the spectrum of non-energy based program requirements that shape cities.

In The End...

Describing the complete interaction of all forces in the modern city will require additional years of research by many others to complement Knowles' work. At that point, confidence in solving wholistic city design will be established by persons working mainly in research institutions. Implementation of these new ideas will depend on government and politics, a separate sphere of operation.

It is difficult to imagine that the primitive Bonitians, people of limited means, could achieve so much. Today it is nearly unimaginable that a similar

modern project, fashioned from common concerns and long-term commitment, could be launched and completed. The process is frustrated by the long established ways that things get built and by the individual self-interests and profit motives of each segment of the building industry which at times are at cross purposes. Combined with the fact that the physical variables have vastly increased, there is little wonder why no latter-day Bonitos exist. Research, however, must continue in order to point out "what to do" when seemingly intractable political and economic conditions are finally pressed by the urgent need to rationalize energy consumption.

(30) Megastructure Configuration Inspired By Knowles Theories.
View From The West. Model Generated And Built By
M. Klingerman, D. Moser, And R. Selvidge

SOURCE: Ralph L. Knowles, Energy and Form, 1974.

DAY SETTING

50 60 70 80

Honeywell

VENT AUTO ON HEAT OFF COOL SYSTEM

COMFORT & CLIMATE

The Minimum Energy Dwelling has a sophisticated comfort control center. Included in the center are two thermostats and a time clock. One thermostat performs the daytime setting, while the other is used for the nighttime setting. In future models, all functions will be controlled by a single compact control center. The use of the outside ventilation system is also controlled at this single point and can result in substantial energy savings. The role of thermostat setting and energy consumption is investigated in this chapter on comfort and climate.

The role of climate has, in the past, been a strong influence on mankind's society and dwellings. The introduction of mechanical heating and cooling for human comfort has dampened our ability to perceive the environmental effects of building.

Because of this loss, modern man must learn scientifically and through discussion what primitive man knew intuitively.

As inhabitants of earth, we reside on a planet whose unique relationship to the sun provides us a myriad of variations within a range of environments unrivaled anywhere in our solar system. As we travel through space in relative complacency, we rarely contemplate the enormous forces acting upon us or the consequences that would ensue if the relationship were altered. We are subject to the constant influ-

ences of various phenomenon having enormous magnitudes.

Contrary to common knowledge, the earth has five motions in space. The earth is retained in orbit as the sun's gravitational forces act upon the combined earth-moon mass, the center of which is 3,000 miles from the center of the earth, or 1,000 miles below the earth's surface. In addition to its daily rotation around the polar axis, the earth also revolves monthly around the center of the earth and moon. This is a result of the earth's constant effort to equalize the gravitational pull of the moon as it orbits our planet, a movement analogous to the adjustment one makes when swinging a heavyweight in a horizontal circle by shifting one's body weight over the heels.

Also, the earth revolves around the sun at 18-1/2 miles per second, making the circuit in 365-1/4 days. The earth speeds along in space with the rest of the solar system at 12 miles per second toward the star Vega. As it travels, its rotation also exhibits an extremely slight wobble, much like that of a spinning top as it slows down, which takes 26,000 years to complete.

Finally, our entire galaxy, with its billions of stars is rotating in space, with our part of the solar system traveling at 170 miles a second. But, regardless of our position in space, the earth is constantly in orbit around, and therefore, under the thermal influences of the sun.

(1) The sun, source of most of the earth's heat, is a sphere of glowing gases, 93 million miles away. This colossal atomic furnace bombards the earth with the equivalent of 126 trillion horsepower every second. This, however, is but half of one billionth of the sun's total energy output. Most is lost in space, only traces of which reach other planets beyond our own. This enormous amount of energy is transmitted through space in a form similar to that of radio waves. Upon reaching the earth's atmosphere, they are either reflected, absorbed or transmitted to the earth, about 45% of which is changed into heat.

It is the atmosphere that allows us to exist under the impact of this energy. Acting as automatically as any thermostat, it regulates the earth's temperature by prohibiting the sun's total energy from reaching the earth's surface, and by screening out harmful rays. It also acts as an insulating blanket which keeps most of the absorbed heat from escaping at night. Without the atmosphere, our planet would experience conditions similar to that of the moon, which is subject to 212°F . "days" on the sunlit side, and -238°F . lunar "nights" on the dark side. (2) We are so positioned relative to the sun that the seasonal tilting of $23\text{-}1/2^{\circ}$ of our planet results in the formation of polar ice caps which exist simultaneously with the tropic environments of the equatorial regions. Yet, the physical distance between a line tangential to the equator and a line passing through the north or south poles (the radius of the earth) is only about $1/23,500$ that of the total distance to the sun. An analogy can be formulated in an attempt to further comprehend the fra-

IF THIS WERE THE SIZE OF THIS PERIOD. THE SUN THE EARTH WOULD BE THE SIZE OF THIS PERIOD.

(1) Sun-Earth Relationship

A - DISTANCE TO SUN

B - RADIUS OF EARTH

(2) The Precarious Position Of Tropic and Artic Climates

(3) Interlocking Fields Of Climate Balance

SOURCE: Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (copyright (c) 1963 by Princeton University Press) Reprinted by permission of Princeton University Press.

gility of our precarious position if one realizes that if the distance from the center of the earth to the surface could be traversed in one minute; the remaining distance of 93 million miles to the sun would require over 16 days.

Despite these incredible distances, the sun is close enough to enable rays to heat the earth's enormous ocean and atmospheric masses to the extent that their movement, in collaboration with the sun's impact on the earth's land masses and daily rotational cycle, combine to create a constant dynamic state which is responsible on a global scale for our seasonal changes and infinite variety of climatic conditions.

Climate

Man has been conscious of the climatic aspects of his environment for centuries. Ancient scientists and mariners were conscious of the varied climatic zones present on earth, and the effect the sun had on each. Because no mechanical means of environmental conditioning was available, man was forced to develop building techniques using local materials which could minimize the thermal stresses of a given micro-climate. This approach commonly known as "passive" is what man relied on for thermal comfort until the dawning of the industrial age.

(3) The inter-relationship of climate with architecture, biology and technology has been responsible for economic and sociological changes in man. Throughout geological time, as climate belts shifted positions on the globe, man was forced into widespread migrations. This occasionally resulted in wars which drastically altered population distributions of entire civilizations. The shifts also brought about more positive results, however, as they were responsible for a great cross-fertilization of ideas and cultures and, hence, significant advancements in civilizations.

The evolution of man has not enabled him to escape entirely the effects of climate. We are subjected constantly to the physiologic efforts of our environment despite the technological advancements which have enabled us to mechanically alter our immediate surroundings. Patterns of illness and death follow closely the cyclical rhythms of seasonal changes, especially in the temperate climates. Most acute diseases and a number of chronic ones such as respiratory illness, influenza, etc., occur more frequently in the cold, moist fall and winter months. A wide variety of intestinal infections such as dysentery, poliomyelites and typhoid are found to be more prominent in the hot, dry summer season. This is especially true in the tropics where the danger of contracting such diseases is compounded by the contact with animals and insects by man in a lightly clothed state.

Also, various aspects within certain climates have roles of varying importance. Humidity for example, has an increasingly detrimental effect on the prevalence of communicable diseases of all types. Heat, especially over long periods of time, may result directly in heat stroke--an often fatal occurrence.

Collectively, the effects of seasonal weather changes contribute to the seasonal patterns of diseases by affecting man's temperament and the amount of outdoor or indoor activity one will do on a daily basis, resulting in varying degrees of susceptibility.

In order to address ourselves to the problems of thermal comfort and man's efforts to achieve it, we must investigate the different types of climates found on this planet, the characteristics of each and the parameters they impose as man attempts to acclimate to each. After doing so, the subject of human behavioral response in reference to a given micro-climate will be discussed at length.

(4) Climatic Zones

In Olgyay's Design With Climate¹, the earth's environs are ordered into five basic climatic zones. Although the classification of the earth's climatic zones has been successfully accomplished in a number of ways, the technique of using climate and vegetation as criteria and showing their inter-relations seems most appropriate for environmental designers. (4) The zones are listed as such:

- Hot & Humid
- Hot & Arid
- Temperate
- Cool
- Cold

Environmental designers, though, are most concerned with the homo-climate; that is, the level of human comfort accommodation or deprivation inherent in each of the above climatic regions

and how they relate to human need. Studies by Jean Dollfus² have revealed that dwellings are defined less by national boundaries than by climatic zones. This results in definable indigenous climatic qualities associated with a particular vernacular. The impact of the environment is best seen on the most pragmatic levels where inhabitants must rely heavily on the passive approach to thermal comfort. Without the benefit of mechanical conditioning, man is forced to his own ingenuity to reinforce the desirable qualities and suppress the detrimental aspects of a given micro-climate in order to remain in his own narrow

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

²Dollfus, Jean, les Aspects de L'architecture Populaire dans le Monde, Albert Norance, Paris, 1954.

thermal comfort zone. These efforts become apparent when considering some of the more well-known design solutions associated with various climatic regions.

(5) In the tropical regions of Africa, Asia, Australia, Polynesia, and the Amazon region of South America, man's efforts to thwart the debilitating effects of intense heat and torrential rainfall with its accompanying high humidity are personified in the raised thatched-roof hut. Under such conditions, the roof is of utmost importance, and the walls are either minimal or omitted because high sun angles reduce the importance of solar orientation. Wind direction is of increasing concern. This building configuration provides for maximum shading and the optimization of the cooling breezes. Elevating the structure protects against constant dampness serves to lift up the floor level further into the wind, and provides protection against dangerous animals or reptiles.

Abundant local materials such as tall grasses and pole stalk are readily available and require little maintenance--an important consideration when monsoon winds and accompanying storms make frequent reconstruction necessary. Little seasonal variation in the daily extremes occur in the equatorial region. Because of this fact, few modifying devices are employed, as the predictable nature of the weather enables inhabitants to deal directly with anticipated conditions. Consequently, few innovations have been investigated and housing has remained relatively unchanged through time.

The dry regions of the world present quite a different set of environmental design parameters which in turn result in distinctly different solutions from the equatorial zone. The absence of moisture in these regions results in intense radiation exchanges, extreme temperature ranges and dehydrating winds. (6) These conditions are countered by massive walls to provide

(5) Hot-Humid Shelter

(6) Hot-Arid Shelter

insulation and thermal lag (concepts explained in further detail in subsequent chapters). Close grouping of dwelling units is frequently employed to minimize exposed areas further reducing the solar influence.

Orientation is of the utmost importance as careful trade off between wind and sun exposure become critical. This problem is compounded by the fact that the terrain in these regions is usually of a dry, sandy nature devoid of ample vegetation capable of deflecting the winds. As a result, abrasive sand storms must be considered and coped with in the architectural solution.

The decisions manifest themselves further in the final configuration of windows and other openings necessary for light and ventilation, usually resulting in narrow, strategically located penetrations. It is in the dry, arid regions that domes and vaulted roofs have become popular. The area of the envelope of a hemispheric vault is three times that of its base. The extreme heat of the sun is distributed evenly over the rounded surface. The curved form presents a minimum of surface area at right angles to the sun at any given time during the day increasing the possibility of reflecting the sun's rays. The hemispheric shape also allows for the wind to flow over and around the domed form with a maximum of contact and a minimum of eddying, or low pressure turbulence, enhancing the wind's cooling capabilities.

The warm temperate zones of the world most closely approximate the conditions considered comfortable by the average man. Found on all continents in the middle latitudes, the temperate zones are characterized by moderate temperatures and somewhat limited temperature extremes. This is due in part to their frequent occurrence along the coastal regions of the continents. As a result, most enjoy ample rainfall through the seasons, or at least the benefit of comfortably

moist winds and the moderating effect of the ocean's masses. Because the temperate climates impose fewer thermal demands on buildings and inhabitants, there is a variety of possible environmental solutions providing a corresponding diversity of architectural configurations.

In the past, the typical dwelling unit of this region in North America was the wigwam. (7) As a conical structure, it effectively shed wind and rain and was easily heated from a central source. It could be readily transported, an essential asset considering the migratory nature of its inhabitants. Unlike the closely grouped structures of the hot-arid and cool regions, dwellings of the temperate zone were more freely scattered, with the peripheral units merging into the surrounding landscape. Dwelling units 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 door 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.

The cool, forested regions of the northern latitudes demand a greater effort in maintaining thermal comfort than the more moderate regions of the temperate zones. It is interesting to note that the inhabitants of the cool, snow belts adapted many of the techniques used by those in the hot-arid regions in their efforts to conserve heat. By adapting a communal lifestyle, they were able to group or join their dwellings in order to minimize exposed surfaces and reduce the chilling impact of northern winds and cold air masses. Mutual benefit was derived by locating the firepits along a center aisle creating a concentrated heat source. (8) In

(7) Temperate Shelter

(8) Cool Shelter

addition, some tribes such as the Kwakiutl Indians of British Columbia incorporated an air-insulating space into their heavy timber residences by constructing them as double shells.

In the summer the outer shells were removed to increase ventilation and desirable infiltration, serving to keep the units as cool as possible. The effectiveness of this technique is discussed in the Chapter entitled "Insulation".

Some tribes anchored long poles atop low pitched roofs to retain moderate snow amounts as an insulating blanket. Orienting with the long axis east to west with small overhangs will maximize solar gain through the south wall. The thick timber slab siding and heavy roof cladding attributed to a more massive structure especially when caulked or coated with stucco-like mixtures of clay and earth. The massiveness of these units, as well as those of the hot-arid regions attributed greatly to their thermal lag capabilities. This passive phenomenon dealing with the collection, retention and redistribution of heat is discussed in greater detail in the Chapter entitled "Mass".

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 interesting to note that the key to that survival is due primarily to the use of snow and ice which are themselves unusual and uncompromising, and yet are, in fact, the only materials found in any readily available quantity in the Arctic. The Eskimos have learned to take advantage of this situation to their own benefit. The igloo with its dome shape and low profile serves to deflect the Arctic wind. Entrances are oriented away from pre-

vailing 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 from Arctic winds.

Another favorable attribute of the igloo is that it may be constructed quickly, however crudely, providing adequate shelter from severe and sudden Arctic storms. It is also inexpensive, completely disposable, and easily reconstructed, satisfying the needs of its nomadic users.

These are but brief descriptions and discussions of the earth's basic climate zones and man's adaption to each. Within each, man has formulated solutions which vary in approach and in effectiveness. Yet within each zone man strives to attain one singular goal. That is to minimize thermal stress and maintain conditions conducive to a healthy, comfortable existence.

In order to more fully comprehend how man reacts to his environment on a micro-climatic level, we must first familiarize ourselves with the physiological workings of man himself. The following section deals with the physical limits of comfort inherent in man as a species, a subjective discussion of thermal comfort and the use of psychrometrics in determining zones of thermal comfort for any given micro-climate.

The ability to describe human comfort and climate depends upon the knowledge of psychrometrics and the relationships on a psychrometric chart. (9) A psychrometric chart graphically portrays the conditions of air temperatures and humidity. Detailed information on the properties of moist air are available on the chart. A complete working knowledge of all aspects of the chart is not necessary. It would be to our advantage, however, to briefly discuss pertinent information

(9) Skeleton Psychrometric Chart

SOURCE: Carrier Air Conditioning Company, Carrier System Design Manual, Part 1 Load Estimating, 1972.

(10) Sling Psychrometer

in order to familiarize ourselves with the chart and interrelationships of the psychrometric functions in general. A complete description of all aspects of the ASHRAE Handbook Of Fundamentals, Copyright 1972, pages 102-106.³ Figure (9) represents the psychrometric chart devoid of numerical values. It serves as a schematic basis for the information presented as discussed in the following definitions:

- Dry-Bulb Temperature--The temperature of air as registered by an ordinary thermometer.
- Wet-Bulb Temperature--The temperature registered by a thermometer whose bulb is covered by a wetted wick and exposed to a stream of rapidly moving air. This may be determined by the use of a sling thermometer or psychrometer as illustrated in Figure (10).
- Dewpoint Temperature--The temperature at which condensation of moisture (fog) occurs when air of a given specific humidity is cooled.
- Relative Humidity--Ratio of the actual water vapor pressure of the air to the saturated water vapor pressure of the air at the same temperature.
- Moisture Content--or Specific Humidity--The weight of water vapor in grains or pounds of moisture per pound of dry air. A grain of moisture is equivalent to one thousandth of a pound.

The dry bulb, wet bulb, dew point temperatures and relative humidity are so related that if two properties are known, the other two properties may be determined. When air is saturated, dry bulb, wet bulb and dew point temperatures are all equal. An example of how

³ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1972, pp. 102-106.

the psychrometric chart is used in determining the properties of a given air condition is as follows:

- Step 1 - Figure (11) illustrates the assumption of 75°F. air as would be read by a typical thermometer. It is a dry bulb reading and found along the lower border of the psychrometric chart.

- Step 2 - Figure (12) shows a selection of a given 60°F. wet bulb temperature. The wet bulb temperature is located along the curved boundary of the graph. This line is also known as the dew point, or saturation line. This may be determined through the use of a sling psychrometer, Figure (10), or given problem data. The resultant intersection defines a point from which all other data may be determined, as in,

- Step 3 - Figure (13) provides us with a relative humidity level of 40%.

It should be reiterated that the dry bulb and wet bulb temperatures, moisture content, and relative humidity are of primary interest to architects and environmental designers.

We will, however, concern ourselves with the problem of condensation and vapor barriers in the Chapter entitled "Insulation". The wet bulb temperature at which air, as defined by the sample point, will condense and give up its moisture may be found by projecting horizontally to the left and reading directly from the curved dew point saturation line.

The psychrometric chart allows the description of a "zone" of air conditions in which man may comfortably exist. This is of favorable consequence as we would have an extremely difficult time existing if our body had to maintain itself within the limits of a single point as described in the example of use of the psychrometric chart. This would imply an almost impossible task mechanically as well. Equipment would be forced to

1. THE VERTICAL DRY-BULB TEMPERATURE (75°) LINE IS FOUND ALONG THE BOTTOM SCALE.

(11) Dry Bulb Temperature

SOURCE: Carrier Air Conditioning Company, Carrier System Design Manual, Part 1 Load Estimating, 1972.

2. THE WET-BULB TEMPERATURE (60°) IS FOUND ALONG THE DIAGONAL SCALE. ITS INTERSECTION WITH THE DRY-BULB LINE WILL DEFINE A POINT.

(12) Wet Bulb Temperature

3. THE DEFINED POINT IS COTERMINAL WITH A CURVING RELATIVE HUMIDITY LINE (40%).

(13) Relative Humidity

(14) Human Comfort Zone As It Relates To Outdoor Conditions

cycle constantly in an enormously energy-intensive effort to maintain a point oriented comfort zone. If man were to exist solely in the out-of-doors, he would be entirely dependent upon the elements for thermal comfort. (14) By projecting the human comfort zone as described by Olgyay onto a psychrometric chart, it is possible to determine the natural forces which would be necessary to provide man with thermal comfort through passive means. The thermal comfort zone is loosely defined in an objective sense as lying between 70°F. and 80°F. dry-bulb temperature and roughly between 20% and 70% relative humidity. Below 70°F., warmth from the sun is required for total comfort. Naturally, the colder the dry-bulb temperature, the more sun is required.

Immediately above 70°F. dry-bulb temperature (DBT), man resides in rela-

tive comfort provided some shade is present in order to minimize perspiration and accompanying discomfort.

Beyond 80°F. DBT and above the upper humidity limits of the normal comfort zone temperatures, some cooling is required. Wind may be used to augment the natural evaporative cooling processes provided by the thermo-regulatory capabilities of the body's vasomotor system. Below 20% humidity, the dry air conditions are usually noticeable enough to be perceived as such and may result in dehydration of the mucous membranes sufficient to cause nosebleeds or an uncomfortably dry throat if experienced during sleep. Above the comfort zone, humidity conditions prohibit any degree of activity without discomfort. The moisture-laden air is reluctant to accept any further amount of vapor, diminishing the effectiveness of

(15) Historic Indoor Design Temperature

evaporative cooling through perspiration. This results in an unpleasant state in which the subject becomes extremely wet with beads of moisture forming on the skin surface.

A great deal of effort has been focused on determination of a more accurate description of the comfort zone. A brief history of thermal comfort research reveals the early efforts of Houghton and Yaglou,⁴ who in 1923 proposed the first effective Temperature Scale dealing with the psychrometric aspects of human comfort. It was somewhat inaccurate due to the over-emphasis of relative humidity at low temperatures and the under-emphasis of the same at higher temperatures.

(15) In 1961, studies by Nevins⁵ revealed a gradual increase in 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. 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 a dependency on mechanically-controlled environments. In the same time period, a marked increase in energy consumption per capita has also taken place.

In 1950, the American Society of Heating and Refrigeration Engineers (ASHRAE) re-examined its Effective Temperature Scale. They showed that relative humidity has a negligible effect on comfort until relative humidity of 60% at temperatures of 65°F. were reached. Refinements of

⁴Houghton, F. C. and Yaglou, L. P., *Transactions*, Vol. 29, "Determination of the Comfort Zone," ASHVE Research Report No. 673, American Society of Heating and Ventilation Engineers, New York, 1923, p. 261.

⁵Nevins, R. G., *Psychrometrics and Modern Comfort*, (Presented at the Joint ASHRAE-ASMC Meeting, November 28-29, 1961.)

(16) Kansas State Index - Subjective Comfort Evaluation
Human Comfort Zone

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

this type were results of continued studies such as the Kansas State University experiments. (16) Under closely supervised test conditions conducted in ASHRAE's test chambers, 1600 lightly-clothed students were exposed in groups of ten--five men and five women at a time--to incremental changes of 2°F. between 60°F. and 90°F. at each of eight relative humidity increases of 10% between 15% and 85%. Subjects rated thermal comfort on a scale of 1 to 7--from cold to hot. All subjects reported comfort between 62°F. and 98°F. The average seemed to be 79°F. at a relative humidity of 50%.

As a result of the Kansas State experiment, it was determined that men feel warmer than women at any temperature/relative humidity combination during the first hour. It was also noted that humidity is sensed more readily by men than by women. (17)

But, perhaps the most important result was the data from which lines of equal thermal sensation were derived, indicating conditions where combinations of temperature and humidity resulted in similar thermal sensations. This led to the realization by physiologists that the sensations of comfort and temperature are perceived differently on a physiological or physical basis and that they should be discussed separately.

Physiological thermal neutrality is a result of the body's constant thermal regulatory efforts. This enables the maintenance of a comfort zone which ASHRAE defines as "that state of mind which expresses satisfaction with the thermal environment". Therefore, in order to grasp the total scope of human comfort, the topic must be approached on two different levels--one objective and one subjective.

(17) Lines Of Equal Thermal Sensation

Objectively, thermal comfort may be clinically analyzed with the physiological implication of thermal comfort roughly determined through laboratory testing. Physiologically, the comfort zone is the range of conditions under which the thermal regulatory mechanisms of the body are in a state of minimal activity. The averaged results of large-scale human observation under varying conditions has provided us with an approximation of the human comfort zone and the physical limits of human endurance.

Having such information enables us in an academic sense to design systems which will provide tolerable conditions within man-made environments. This is accomplished within the realm of physiological evaluation by the use of applied psychrometrics. This is the science involving the thermodynamic properties of moist air and the effect of atmospheric moisture on materials and human comfort. Similar thermal sensations may be realized by manipulating various components of the psychrometric chart. By the same token, through testing it has been determined that given a specific set of psychrometric conditions, a specific sensation will result. As opposed to physiological responses which may be determined objectively, the determination of subjective sensory perception depends on the individual and varies within the individual at different times. Subjective evaluation by an individual in turn depends on the singular experience of thermal sensation and the amount of perspiration present. Man responds to thermal sensation rather rapidly with equilibrium usually occurring after approximately 15 minutes. At that point, the subject returns to a "steady state" and remains so until other forces alter the environment once again.

It has been determined through tests that human beings have a high degree of thermal sensitivity immediately above or below one's neutral zone and are capable of perceiving small gradations of thermal comfort. Another

aspect of subjective thermal evaluation deals with man's perception of his thermal environment under varying conditions; that is, the difference in comfort afforded by a particular set of thermal conditions as experienced by a subject in a passive or sedentary state and the same subject under conditions of work or other stimuli resulting in varying degrees of stress.

As previously mentioned, an additional aspect of subjective thermal sensation evaluation deals with the noticeable perspiration or readings. This results in the necessity of tedious deciphering of the psychrometric conditions in order to achieve what may still be an inaccurate evaluation. For this reason, most environmental designers ignore the impact of noticeable perspiration in formulating a subjective criticism of thermal comfort.

It should be noted at this point that thermal comfort and thermal balance are not the same. Thermal balance can be achieved under varying degrees of discomfort through their thermal regulatory processes of the body. (18) Wherever a state of equilibrium is reached, that is the balance of the body against the elements, one may find a state of thermal balance. This is often tolerable, but should not be confused with thermal comfort, the state in which the body normally prefers to reside. The following is a discussion of how the body maintains its thermal comfort zone in the physical, or objective sense.

Man is a warm-blooded animal. Under normal situations we maintain a deep body temperature of 98.6°F . The body's principal source of heat is the burning or oxidation of food elements. This process, commonly known as metabolism, varies in intensity from person to person, corresponding to varying physical characteristics of individuals, but always striving to maintain the approximate 98.6°F . deep body temperature common to all humans.

(18) Thermal Balance Of The Human Body

(19) Physiological Heat Exchange

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

Given a sedentary state the deep body temperature will remain in a "steady state". Quite often, however, man finds himself performing work, losing heat by evaporation or exchanging heat by evaporation or convection. Between rest and exercise, the above processes may result in a deep body temperature ranging from 97°F. to 100°F. Generally, the study of heat exchange between the body and the environment and its effort to maintain thermal comfort fall into two different categories: the Passive System and the Control System.

The passive system deals primarily with the natural exchange of heat through conduction, radiation, and convection between the body and environment. It concerns the heat flow from the central core to the skin's surface via the vascular mechanisms of the body; i.e., the circulatory system, and the heat flow from the skin's surface to the environment through surface radiation or conduction between the body surface and the environment.

The control system encompasses the blood flow to surface tissues, and sweating and shivering necessary for maintaining normal circulation. The control system is activated when the body can no longer maintain itself within its comfort zone and recognizes the need for increased activity or an alternative means of restoring thermal balance.

As we shall see, the passive system and the control system combine to provide the body with its capabilities to maintain thermal comfort as required. (19) It is noteworthy to recognize that in so doing, the body strives to expend a minimum of energy or caloric consumption by resorting to passive means first, and calling on its control system only in situations of sensory overload or undue stress. We shall investigate briefly how this is accomplished so that we may further understand why we respond to the environment as we do. The following

discussion will also provide us with a better understanding of the impact of manipulating the psychrometric aspects of our micro-climate.

When man strays from the sedentary state, he may, of course, go one of two directions--either he will become too warm or too cold. We are most familiar with the effects of "over heating" as man more often subjects himself to work or exercise than to conditions resulting in a natural cooling process.

The body's first line of defense against abnormal heating is the vaso-motor regulation of his body in order to increase heat dissipation. This is accomplished by vasodilation, or the increase of two to three times the amount of blood normally found in the surface tissues of the body. This is achieved by the expansion of the surface capillaries and increased cardiac activity until the surface temperature of the skin is one or two degrees Fahrenheit below that of the deep body tissues. This process increases the temperature difference between the skin and the surrounding air, thus increasing the rate of heat exchange. If this function fails to provide the body with sufficient cooling to exist in relative comfort, the body shifts from radiant cooling to evaporative cooling through perspiration. (20) If man remains in a sedentary state, sweating will normally begin when the deep body temperature reaches approximately 100°F. Man at this point begins to lose efficiency and will continue to do so as internal body temperature rises. The subject will also continue to perspire in an effort to increase evaporative cooling. This process is effective to a point, after which the skin area becomes saturated or covered with perspiration. The resulting effect is one which produces a state of extreme discomfort due to the decrease in cooling efficiency and, in part, to the psychological reaction to existing in an uncomfortably wet and generally undesirable state.

(20) Body Temperature And Human Health

SOURCE: M. David Egan, Concepts In Thermal Comfort, (c) 1975, p. 5. By permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Rising deep body temperatures have more serious implications as well. Ironically, cardiovascular efficiency decreases as the heart tries to meet the body's mounting cooling demands. Blood pools in the skin and muscles as the subject "flushes". Consequently, the chambers of the heart do not completely fill, and the heart becomes less efficient. The cardiovascular system's effort to saturate the peripheral tissues with blood for cooling result in the circulatory deprivation of the internal organs and glands of the body. This often results in nausea and lightheadedness, clear signs of the thermal overloads.

Dehydration contributes to further weakening as it upsets the composition of the blood and lessens the amount of moisture in the tissues. Hyperventilation or overbreathing washes out more CO₂ than usual resulting in the constriction of the veins and capillaries feeding the brain. If the deep body temperature is allowed to rise to between 105°F. and 108°F. unconsciousness will result. High core temperatures near the brain stem in the neighborhood of 109°F. to 110°F. will result in damage to the hypothalamus, and heat stroke--frequently fatal--will result.

The body also has passive and controlled responses which it uses to combat over-cooling. The first reaction of the body to over-cooling is that of constriction which it resorts to in order to slightly slow down circulation so that all the food energy can be used by the cells. This increase in metabolism can correct for only a few degrees drop in deep body temperature. This is the limit which the body can adjust for by passive means. When the internal temperatures reach 94°F. or 95°F., the brain triggers the involuntary response of shivering. The intent is to increase muscle activity and use the resulting heat activity expended to warm the body as a whole. As a deep body temperature drops to 90°F., vasoconstriction of the circulatory system

becomes more intent and widespread. Internal organs are sacrificed as the circulatory system concentrates its heat in the body's periphery and extremities. Consequently, treatment for exposure is usually required if one is subject to these conditions for long.

As cooling continues, the subject must resort to stamping feet and warming fingers and hands with his breath in order to keep the blood circulating. Shivering becomes more intense and speech impaired. A normal man has the capability of generating six times the normal heat production by violent shivering. At this point, however, the subject is rendered useless and some form of physical damage has already taken place. As the deep body temperature approaches 80°F., the subject is usually humped over and rigid, having succumbed to the numbing external effects of the cold as well as the mind's tendency to malfunction and hallucinate. Unconsciousness may have already occurred. If not, irreversible damage resulting from deep body exposures to 70°F. temperatures will almost certainly result in unconsciousness. The body will continue to chill down to 60°F. which is generally accepted as the lowest temperature man can experience for even short periods of time with any hope of recovery.

It should be noted that these limits, although representative of the majority of humans, vary from person to person, dependent upon sex, age, and the physical conditioning of the individual. Also, they deal with responses to rapid change situations and not gradual subjecting of the individual to a given thermal condition. Inherent in man is the ability to extend his limits of tolerance by gradually acclimating to heat stress conditions or accustomizing to stress conditions resulting from exposure to cold. Acclimating to regular heat stress conditions usually has less profound effects on the body than accustomizing to cold, though both are achieved to a greater degree when the

subject undergoes gradual, regular exposures.

Acclimating to heat stress conditions is a process in which the cardio-respiratory functions of the body are gradually improved through exposure and conditioning to the point where they can more quickly and efficiently dissipate increased heat loads. It involves the expansion of the blood vessels, reduction of fat levels in the body and the gradual widening and clearing of the pores.

Physical conditioning also improves stamina and the individual's ability to perform in environs of intense heat and humidity. A common analogy to this process is man's perception of thermal comfort during seasonal changes when he experiences an abnormally hot or cold day in the midst of normal spring and fall temperatures. The sensory perception of these occasions is quite different from that which one would experience on a day with identical conditions during the regular seasons of winter and summer.

Man also possesses the ability to adjust to sustained cold. This is achieved by basic changes in the endocrine glands and other internal organs which attribute to higher metabolic rates and the corresponding increase in "non-shivering" heat production. A higher sensation of comfort is also maintained due to increased blood flow levels. Through diet, individuals may sometimes add fat as an insulation or elect to grow facial hair as added protection.

Thus far, the discussion has concentrated on the inter-relationship of climate and human comfort. Man must either submit to these elements or provide shelter for himself which he can control by passive or mechanical means to suit his personal comfort preferences.

The concept of "comfort zone" implies a range of thermal conditions under which man can survive comfortably.

The degree of comfort is a matter of personal tolerance. Being less demanding about how warm or cool one feels results in a natural extension of the comfort zone. Whether or not it is completely enjoyed depends entirely on the individual.

However, allowing more generous limits in heating and cooling demands increases the climatic range in which passive techniques can maintain the comfort zone and reduces the size of the mechanical conditioning equipment necessary and reduces its operating time. Both of these conditions result in decreased energy consumption. In order to illustrate the impact of manipulating the comfort zone on energy consumption, a computer study of the MED house was performed. For this particular study, all conditions remained the same except for the thermostat settings--the limits which the mechanical equipment tries to maintain. The study was based on a comparison of a narrow $4\text{-}1/2^{\circ}\text{F.}$ comfort zone between 72.5°F. and 77°F. , a wider 12°F. comfort range between 68°F. and 80°F. , and a "point" zone set at 75°F. , allowing no deviation.

Computer analysis proved the logical assumption that maintaining a specific temperature (75°F.), 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 passive phenomenon such as infiltration, solar gain, mechanical and people loads, etc., all of which vary constantly on a day and night basis.

(21) Extending the upper and lower limits to 77°F. and 72.5°F. respectively resulted in an average savings of 11.7% when compared to the point comfort zone at 75°F. A temperature fluctuation of $4\text{-}1/2^{\circ}\text{F.}$ would not be easily discernible to an individual,

(21) Comfort Zone Between 72.5°F. And 77°F.

(22) Comfort Zone Between 68°F. And 80°F.

but would result in enough idle time in the mechanical equipment operation to realize the 11.7% energy reduction.

A further enlargement of the comfort zone to between 68°F. and 80°F. would be definitely noticeable by most individuals, but not necessarily uncomfortable. Allowing a 12°F. range in the home may be tolerated quite well by dressing to suit the conditions. In the winter, when the inside temperature would most likely tend to drop to 68°F. if allowed, 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. (22) Allowing a 12°F. range between 68°F. and 80°F. would enable a 46% savings compared to that consumed to maintain 75°F.

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 equipment "rolls with the punch" of the thermal heating and cooling loads.

(23) Comfort Zone With Daytime Set Up And Nighttime Set Back

The Figure (23) illustrates the different upper and lower limits as they would occur throughout the day. There is an underlying logic in this approach in addition to the thermostat settings moving with the diurnal thermal cycle. During the evening hours, cooler temperatures are permitted. This is of little consequence, however, as inhabitants are usually asleep and may cover themselves until comfortable. Also, many people prefer cooler temperatures for sleeping. In the afternoon hours, the lower and upper temperature settings are raised.

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 those outside, cooler outdoor air at ambient temperatures maybe used to assist in 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 on any given day. (24) 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 (25), the demand for energy varies throughout the year. The lines shown are representative of the comfort zones as discussed herein. The theory of moving comfort zones and adjusting thermostat settings may be extrapolated to include variations on a yearly, 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.

Man decides where he lives and what conditions he exists under. When he chooses to create and inhabit a particular piece of architecture, he submits himself to thermal stresses which are a combination of micro-climatic conditions and the effect on the interior those conditions have after being 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.

In order to minimize thermal loads and associated energy consumption, an effective marriage between the dwelling and the environment must be accomplished.

The Southern California Gas Company, by instituting the Minimum Energy Dwelling (MED), has undertaken such a

(24) Comfort Zone With Daytime Set Up And Nighttime Set Back

(25) Energy Use Comparison Of Different Comfort Zones

venture in Mission Viejo, California. The purpose of the MED Project is to reduce the energy consumption of a detached single-family dwelling by at least 50%, while maintaining or improving the living standard and comfort level of the inhabitants. In order to do so, a detailed investigation of Mission Viejo's micro-climate must be made in order to facilitate an effective marriage between the dwelling and the environment. The discussions which follow examine the meteorological aspect of the environment in Mission Viejo, providing us with the climatic parameters upon which we shall base future architectural decisions.

Mission Viejo Micro-Climate

The State of California as a whole provides us with the widest range of climate found in the continental United States. By virtue of its varied topography and position on the globe, California contains significant areas with climates ranging from hot-arid to cool-forest.

Situated between 32° and 42° North Latitude in the north-south directions, and 124°-30' West Longitude and 114°-30' West Longitude in an east-west direction, California is third in size behind Alaska and Texas. It claims the highest and lowest points in the continental United States with Mt. Whitney at 14,495 feet above sea level and Death Valley at 282 feet below sea level, respectively. It has within its boundaries the vast percentage of the American Pacific Coastal waters as well as the western reaches of the American mountain ranges in the Sierra Nevadas and Sierra Madre Mountains, as well as the Mojave Desert.

The Pacific Ocean is responsible for the coastal weather patterns. Lush valleys and forested mountain regions are the result of moisture-laden air from the Pacific rolling up the western side of the mountain ranges in the northern-central portion of the state,

creating ample rainfall in those areas while depriving the eastern portion of the state and most of Nevada from enjoying the same. Southern California enjoys the combined effect of the Ocean influence and solar impact of the lower latitudes. This produces a balmy, moderate climate with limited seasonal extremes. It is in this region that we find Mission Viejo, site of the Minimum Energy Dwelling Project.

As defined in Olgyay's Design With Climate¹, Mission Viejo's climate is designated as warm-temperate. A more specific classification would be Mediterranean-Marine with some characteristics of Mediterranean-Continental as defined by D. Givoni in Man, Climate and Architecture.⁶ Located at 33°-30' North Latitude and 117°-40' West Longitude, Mission Viejo lies approximately 50 miles southeast from downtown Los Angeles and five miles inland from the Pacific Ocean. As a result of its proximity to the Pacific, summer conditions in Mission Viejo are typified by moderate, diurnal temperature ranges of 20°F. and daytime average temperatures of about 75°-82°F., which may rise on hot days to 84°-94°F., though usually for short periods of time. Evenings are cool with minimum temperatures of between 62°-70°F. Vapor pressure remains relatively low at .5" Hg. Relative humidity readings commonly occur between 50% at noon and 90% at night. Wind velocities during the day are relatively low at 5-8 mph, declining to almost 3.5 mph in the evening. Wind direction is usually westerly, from the ocean, shifting to the south and east at night.

Winter temperatures usually remain above freezing with an average daily minimum temperature of about 49°F. Daily variations drop the monthly average minimum to 37.4°F. in the

¹Ibid.

⁶Givoni, B., Man, Climate and Architecture, Elsevier Publishing Company, Ltd., New York, 1969.

(26) Climatic Comparison

winter season. Temperatures rarely fall to 31°F. or freezing conditions. This data is from the El Toro weather station which is five miles from Mission Viejo.

(26) Because of Mission Viejo's location, it has relatively average conditions when compared with other selected California cities. Because of this fact, Mission Viejo is a prime location for investigation energy conserving techniques.

The preceding information defines Mission Viejo's micro-climate in an average sense. It is important that we examine the meteorological data in much greater detail. In so doing, we will be able to determine to what extent the climate will affect the design solution. The reader is asked to consider and contemplate the implications of the following data in light of the variability inherent in each. In so doing, the reader will gain a greater understanding of the complications involved in designing a facility which responds to the extremes of seasonal variation in an energy-conscious manner.

An investigation of any micro-climate should begin with an examination of the solar influences. Mission Viejo enjoys a variety of sun conditions throughout the year resulting in the limits listed in the previous paragraphs of this Section.

The limits of the sun's movements at Mission Viejo are defined by its location at 33° North Latitude. (27) On June 21st, the summer solstice, the sun rises 118° east of true south, or 28° north of due east at approximately 5:00 a.m. This limit or "solar azimuth" is repeated symmetrically about true south on the west side for sunset conditions with the sun setting 28° north of west at approximately 7:00 p.m. The sun reaches the highest point of its yearly cycle at solar noon on June 21st when it attains a solar altitude of 80°.

(27) Solar Geometry

Winter conditions in Mission Viejo are quite different. On December 21st, the winter solstice, the sun does not appear until 7:00 a.m. when it climbs above the horizon at 62° east of south. The lowest altitude the sun attains in its yearly cycle occurs at solar noon on December 21st, when the sun reached a solar altitude of 35° . The sun then completes its movements symetrically about true south by setting 62° west of south at approximately 5:00 p.m.

The Figure (28) depicts in greater detail the monthly radiation conditions. The inclusions of H and K_d relate the amount of direct radiation and the percentage of diffuse or indirect radiation. More specifically, H is the total amount of radiation striking one square foot of horizontal surface on the earth in one day. It is only a fraction of the radiation available outside the earth's atmosphere. H is usually stated as an average monthly figure for any specific location.

K_d is the diffuse component of the total H figure. Incident diffusion is a result of the sun's rays striking or inter-acting with elements in the earth's atmosphere. As a result of the scattering, diffuse sunlight (K_d) is multi-directional, unlike the more direct H radiation.

Figure (29) illustrates the yearly frequency of occurrence of varying conditions of humidity and wet bulb temperatures. Figures (30), (31), and (32) illustrate a further breakdown of the mean conditions for January, April and August. The frequency of occurrence is based on one dot representing $1/10$ of 1% of the total time in a 30-year period and serves to emphasize the variety of conditions possible on a seasonal basis. Superimposed on the charts is the comfort zone as disussed in the previous Sections. Of interest is the apparent relation of human comfort needs on a homo-climate level in reference to what is climatically available. This cannot be

(28) Monthly Radiation Conditions

(29) Yearly Percentage Frequency Of Occurrence -
El Toro, California

(30) January Percentage Frequency Of Occurrence -
El Toro, California

(31) April Percentage Frequency Of Occurrence -
El Toro, California

(32) August Percentage Frequency Of Occurrence-
El Toro, California

(33) Monthly Mean Psychrometric Chart

taken at face value, however, for extensive studies in computer analysis have revealed that the influence of the building skin in conjunction with internal loads drastically alters the position of the comfort zone in relation to exterior conditions. The impact of this phenomenon is of considerable importance and a major factor in determining the final building composition and sub-systems included therein. The chapters dealing with internal loads and mass will discuss this phenomenon at length.

Figure (33) illustrates the monthly mean conditions for Mission Viejo as they would appear on the psychrometric chart. Each monthly cycle represents the average range of temperature during a day. At sunrise, the humidity is the greatest and dry bulb the lowest. As the day progresses, the dry bulb temperature increases and the

relative humidity drops to a low point during mid-afternoon. The cycle then returns to the starting point.

A wealth of information can be obtained by the plotting of climatic data on a psychrometric chart. The psychrometric chart has a great value in graphically portraying and comparing divergent values in many numerical tables. This information can be easily seen rather than the tedious comparison of numbers. If this method is determined to have wide application, it could be easily generated by the U.S. Weather Bureau for other climatic areas. The graphs presented here were hand plotted using published data, but they could easily be generated by a mechanical plotting mechanism connected in tandem with a computer climatic weather tape.

The psychrometrically plotted climatic data can be compared with the plotted comfort zone. The psychrometric chart can be broken down into four inter-related areas in relationship to the comfort zone. The area to the left of the comfort zone in the lower dry bulb temperature range is an area in which, if the outside temperature falls, would require heating; to the right, cooling is required. All weather conditions above the comfort zone require the dehumidification of the air while all those below require humidification.

The monthly mean psychrometric chart is the most useful of the five charts for the designer. Notice first the short range of dry bulb temperatures in which the average weather conditions occur. From a mild 48°F. to a low upper limit of only 80°F. , this tightness of range is due to the close proximity of the Pacific Ocean and its moderating effects.

A comparison with the monthly mean psychrometric chart and the yearly percentage frequency of occurrence reveals that practically all of the weather in a 30-year period falls between 38°F. and 90°F. ; an indication of a very mild climate. In fact, only a single month's mean data pushes past the extended comfort zone. The distance between the average high and low temperatures is a measure of the diurnal temperature swing. The design implication of the distance between high and low points gives an early indication of the effectiveness of heavy construction in a particular climate. The greater the swing, the better the possibilities. A 20°F. swing or greater is a good indication that a major effort should be focused on delaying the energy influx from the building's interior.

The tilt of an average monthly line is an indication of the change in moisture content during the day. In this case, most of the months are fairly level, portraying a constant moisture content throughout the day. The

moisture content may remain the same, but the relative humidity changes constantly during the day. Notice the month of August. The relative humidity cycles on the average range between 50% and 90%. A level cycle is an indication of a relatively balmy climate, whereas a line tilting from lower left to upper right indicates a more humid environment. The distance above the comfort zone shows the need for dehumidification.

Care must be taken not to assume a fixed position of the comfort zone. As shown on the psychrometric chart, the comfort zone is not related to any particular building type or building skin. The addition of these two variables can influence energy consumption dramatically. A case in point is the MED home in Mission Viejo, California. Again, looking at the yearly percentage frequency of occurrence, the majority of the time the dots fall in the area requiring heating in relation to the comfort zone.

Insulation has the effect of moving the comfort zone down the dry bulb line. The greater the insulation, the greater the move downward. Insulation restricts the flow of heat and retains the heat generated by the appliances and the body metabolism of people on the inside of a space. Assuming a well-insulated and well-constructed home, and a lifestyle for a family of four, the lower end of the comfort zone is shifted to around 45°F. Heating is not required until the temperature is 45°F. or below. Because heat is retained, air conditioning is needed at lower temperatures, typically at about 65°F. Imagine the positioning of the comfort zone adjusted for building type and building skin presents a different picture in relation to heating and cooling requirements. Now nearly all of the frequency of occurrence dots are on the cooling side of the comfort zone--a complete reverse of what would be expected by just considering the standard comfort zone and climatic

conditions. At Mission Viejo, the effect of moving the comfort zone has a pronounced effect on the heating and cooling requirements because of the relatively mild climate.

The notion of a moving comfort zone is very dependent on building type and building skin. A school, for instance, because of all the students and warm machinery, if well insulated, may not require any heating until the outside temperatures approach 20°F.

The movement of the comfort zone is, at this point, fairly intuitive in logic, but can yield a great deal for the design philosophy of the building. By understanding the relationships of energy conservation, the building skin can retain or reject heat as directed by a particular building type or climate. The psychrometric chart can help direct the designer in the proper direction.

Another apparent contradiction would be the shift in ambient air temperatures with the extremes (T_A) occurring in August, two months after the summer solstice. This may be attributed directly to the gradual warming of the earth. As the summer progresses, the mass of the earth is subject to warmer diurnal cycles, enabling it to retain more and more of its heat until the lag begins to act in conjunction with the seasonably warmer air masses to produce warming conditions later in the summer as opposed to the June 21st summer solstice.

Figures (34) and (35) serve to illustrate well the variation in Mission Viejo's wind characteristics. The reader should pay particular attention to the winter/summer changes and direction in temperature over a given day as represented by the graph of January and August wind characteristics. The difference in temperature and direction of prevailing winds in Mission Viejo is due to the combined effects of the seasonal warming and cooling of the earth and the presence of the Pacific. Land warms faster

(34) Wind Characteristic Matrix - January

(35) Wind Characteristic Matrix - August

(36) Daytime Wind Direction

(37) Nighttime Wind Direction

than water during the day and cools faster at night. The air above such surfaces is warmed or cooled accordingly and local winds result. In Mission Viejo, this effect can be seen in Figure (36) which depicts the winds coming from the west or ocean in the day, and in Figure (37) which depicts the shift to an easterly direction at night. This is more noticeable in August, or summer, when the intensity of the sun results in a greater heating of the land masses. In January this is not the case, and the ocean nullifies some of the effect. As a result, its shift is less pronounced and of shorter duration. The sun's intensity is also responsible on a seasonal basis for the wind temperature and wind speeds, which are greater in the summer than in the winter. On an average annual basis, the prevailing winds in the Mission Viejo region are normally from the west. A matrix providing more detailed information concerning Mission Viejo's wind conditions is presented in Figure (38). They serve to further illustrate the variability of wind and its characteristics and are deserving of the reader's attention.

In direct relation to the solar and wind influences of the Mission Viejo region is the occurrence of fog, smoke or haze, and precipitation. It may be noted from Figures (39) and (40) that the frequency of occurrence of these conditions varies on a monthly basis with the changing seasons. They are for the most part, in direct response to solar intensity, moisture content and air temperatures synonymous with seasonal change.

In January, cooler temperatures and relative humidities in connection with moderate winds allow for fairly equal time periods of fog and smoke or haze. There is a perceptible shift between the two conditions, however, with the changeover to smoke and haze occurring in the mid-afternoon hours.

In the summer, as depicted in Figure (40) for August, the shift is much

(38) Average Wind Conditions - January & August - El Toro, California

(39) Atmospheric Conditions Matrix - January

(40) Atmospheric Conditions Matrix - August

more pronounced and well defined with the fog being "burned off" relatively early in the morning. This is due to the increased intensity attendant to the summer sun positions and longer periods of exposure.

Unfortunately, Mission Viejo suffers from its proximity to the Los Angeles metropolitan area which is a primary source of smoke and haze which Mission Viejo experiences. Smog conditions are more acute in the summer due to the complications arising from increased heat and humidity which react with auto emissions and other industrial discharge to reinforce the formation of acids and pollutants.

The designer must address himself to the wind conditions and air quality in considering orientation, ambient air temperatures, roof and facade configurations, window sizes and other exterior skin penetrations when dealing with ventilation. Careful examination of wind characteristics in the preliminary stages of design will result in the more intelligent selection of ventilation equipment for the living and attic spaces, and will enable the designer to more accurately predict the effectiveness of economizer cycles. Air quality studies will determine the need for air conditioning and infiltration permitted. These topics will be discussed in the Chapter "Ventilation and Infiltration".

Precipitation is moderate in Mission Viejo and does not affect to any degree the process or final solution. For this reason, it will not be dealt with at length in this publication. Any specific information not included in this report may be obtained from a climatic atlas⁷ or the National Weather Bureau in Los Angeles.

Having familiarized ourselves with the climatic conditions in Mission Viejo, we may now proceed with an investiga-

⁷Climatic Atlas of the United States, U.S. Department of Commerce, Washington, D.C., June, 1968.

tion of the various components of the dwelling's skin. By more fully understanding the importance of each and how they function in relation to one another, the designer will have a better comprehension of their role in energy conservation.

RESIDENTIAL ENERGY USAGE

The family and their living habits have an effect upon energy consumption both at home and in the community. The typical family who is living in the Minimum Energy Dwelling, which is being monitored, consists of a working husband and non-working wife both in their late twenties and one pre-school child. The hope in testing is to use the house as it will be used by a typical home buyer, going in and out all day with doors opening and closing rather than locked up.

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

In the past, splitting a cord of firewood or stoking the coal stove 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 on 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 be

less contemplative and more comprehensive about quantifying and comparing the different amounts of energy consumed by every appliance and machine owned by a family. This is the first step toward a clear view of the total energy usage of American families and the determination of the best opportunities for energy conservation.

Uniform Comparisons Among End Uses

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, these fuel quantities should be converted to a common thermal unit. An informative booklet, Patterns of Energy Consumption in the United States,¹ does just that. The book divides the total United States energy consumption into four sectors:

- Residential
- Commercial
- Industrial
- Transportation

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

Within these sectors, detailed estimates of energy usage for different 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 energy consuming industries.

Since there is no metering or other regular means for measuring fuel and energy use in highly discreet applications, much information about end use consumption was estimated or inferred. Electricity and gas in the home are measured on a total basis and not for individual appliances.

Residential Energy Consumption By End Use

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

Space Heating.	57.5%
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%
TOTAL	100 %

Four applications--space heating, water heating, cooking, and refrigeration--account for more than 80% 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 were implemented.

These statistics from the Office of Science and Technology do not show energy usage by a typical family but

(1) Sectoral Energy Consumption

(2) Residential End Use Percent Of Total Consumption

NATIONAL AVERAGES

1. Car: assumes 848 gallons of gasoline X 140,000 BTU/gallon. (Energy Policy of the Ford Foundation: Final Report, Ballinger Publishing Company, Cambridge, Massachusetts, 1974, p. 115.)

2. Space Heating: Office of Science and Technology, Patterns of Energy Use in the United States, U.S. Government Printing Office, 1972, p. 42.

3,236	Trillion BTU Natural Gas
- 2,988	Trillion BTU Petroleum Products
6,224	Trillion BTU
60.4	Million Households
3.4	Electrically Heated Dwellings
57.0	Million Gas or Petroleum Heated Dwellings

6,224 Trillion BTU — 57 Million Households = 109.2 Million BTUs/Household.

3. Water Heating: Unit Consumption. Stanford Research Institute, For: Office of Science and Technology, Patterns of Energy Use in the United States, U.S. Government Printing Office, 1972, p. 44.

4. Cooking: Unit Consumption. Ibid., p. 47.

5. Refrigeration: Unit Consumption. Ibid., p. 49.

6. Clothes Drying: Unit Consumption. Ibid., p. 53.

7. Miscellaneous:

Color Television: Unit Consumption. Ibid., p. 56.

Air Conditioning: Unit Consumption. Ibid., p. 59.

Dishwasher: Unit Consumption. Ibid., p. 60.

Washing Machine: Unit Consumption. Ibid., p. 61.

Lights and Small Appliances: Unit Consumption. Ibid., p. 62.

(3) National Family Profile Yearly Energy Usage

by end use only. These numbers were derived from census figures and sales records which outline the total number of the particular appliance or end use. If the total United States yearly consumption for each appliance was estimated, then dividing by the total number of appliances in use in the United States would give the average unit consumption per year for each. Since these numbers relate only to appliances and not their owners, trying to construct a scenario of energy consumption for a typical family involves making a decision about which appliances are likely to be used in the home.

Selecting the consumption figures from each end use category would then construct a picture of total family consumption. In order to make these national statistics relevant to the MED Project, the list of end uses should reflect those operating in the MED--space heating, space cooling, gas water heating, gas cooking, gas clothes drying, refrigeration, television, lighting, and small appliances. The use of automobiles should also be considered in these statistics.

Figure (3) assumes these MED-type uses and illustrates, with figures from Patterns of Energy Consumption in the United States¹, an aggregate of national averages for unit consumption. Figures for typical gasoline consumption of an average family were drawn from A Time to Choose, America's Energy Future², the Energy Policy Project of the Ford Foundation. The largest portion of the energy usage is related to the car, closely followed by space heating. Further below in importance is water heating, refrigeration, and cooking. Because of their small contribution to energy consumption, the colored television, dishwasher, and washing machine have been included in the miscellaneous category.

²A Time to Choose, America's Energy Future, Final Report of The Ford Foundation's Energy Policy Project, Ballinger Publishing Company, Massachusetts, 1974.

In terms of absolute energy consumed, this figure represents a total of 308,000,000 BTU per year per average household. The percentages generated for each category in the energy pie are the averaging of many different family types and climate areas of the country. Realistically the individual components can vary greatly. For instance, the space heating requirements for Minnesota are much different than those for Southern California.

The generality of national averages is of little use in understanding residential energy consumption by the standard Cordova home. By using statistics from various sources including the Southern California Gas Company, a profile of energy use in that area can be developed. Yearly consumption figures from the Southern California Gas Company are available for standard appliances, instead of dryer and water heaters. The annual heating and cooling requirements have been generated by the day-by-day computer analysis of the standard Cordova over the course of a year. The income level of a typical Cordova buyer which has been calculated at \$17,000 per year will enable an estimate of gasoline consumption. Figure (4), taken from A Time To Choose, America's Energy Future,² represents gasoline consumption by income level. Adjusting the Cordova income level to a 1968 level was necessary in using this graph.

Figure (5) illustrates the likely yearly energy usage by a Cordova family. Those items such as lighting, refrigerator, and other miscellaneous uses were assumed to be comparable to national averages since the area of the country will not affect their use. The figure for gasoline consumption assumed a two-car family. The Mission Viejo Development is located in an area that required one to drive to work, and individual homes are located

²Ibid.

(4) Gasoline Consumption By Income Group

CORDOVA FAMILY PROFILE

Car: assumes middle income, two-car gasoline consumption at 1300 gallons X 140,000 BTU/gallon. (Energy Policy Project of the Ford Foundation: *A Time To Choose, America's Energy Future*, Ballenger Publishing Company, Cambridge, Massachusetts, 1974, p. 124.)

Space Cooling: Westinghouse Heat Study Results for Standard Cordova X 1/5 C.O.P.

Space Heating: Westinghouse Heat Study Results for Standard Cordova X 1/6 C.O.P.

Water Heating: \$34/year ÷ \$1.60/1000 cubic feet X 1050 BTU/cubic foot (Southern California Gas Company - Average Customer Consumption).

Cooking: \$16/year ÷ \$1.60/1000 cubic feet X 1050 BTU/cubic foot (S.C.G.C. - Average Customer Consumption).

Clothes Drying: \$6/year ÷ \$1.60/1000 cubic feet X 1050 BTU/cubic foot (S.C.G.C. - Average Customer Consumption).

Refrigeration: Unit Consumption. Stanford Research Institute, For: Office of Science and Technology, *Patterns of Energy Use in the United States*, U.S. Government Printing Office, 1972, p. 49.

Television: Unit Consumption. Ibid., p. 56.

Dishwasher: Unit Consumption. Ibid., p. 60.

Washing Machine: Unit Consumption. Ibid., p. 61.

Lights and Small Appliances: Unit Consumption. Ibid., p. 62.

(5) Cordova Family Profile Yearly Energy Usage

far enough from shopping areas to also require a car. Since 58% of the wives are employed, a second car is practically mandatory. Because of this, the typical Cordova buyer is likely to consume 1300 gallons of gasoline per year compared to the national average of 848 gallons per year.

This graph shows an average total of 304 million BTU consumption per year per household. Even though this total is very close to the national average, the large differences between space heating, space cooling and gasoline consumption differentiates Southern California from typical American homes. For both sets of statistics, however, these three categories still remain the most logical areas for implementation of energy conservation techniques.

Who Consumes Energy in the United States

Neither the statistics concerning national averages or those of Southern California indicate which Americans consume quantities of energy. Some of the most interesting and enlightening statistics do not compare water heaters to televisions, but differentiate energy consumption of various income groups. In their report, *A Time To Choose, America's Energy Future*,² the Energy Policy Project of the Ford Foundation published statistics from 1972-73 comparing energy consumption among poor, lower-middle, upper-middle, and well-off families. In their report, they first characterized a "typical" American family:

"The American Dream may be a vision of several luxury cars and a split-level house loaded with labor saving appliances, but the reality is a bit more modest. A "typical" American family bares little resemblance to television's famous "American Family" the Louds of Santa Barbara, with their

²Ibid.

sprawling air conditioned contemporary house, four cars, swimming pool, and jet traveling children. Most American families live much more modestly. The "typical" American family lives in a five-room, single-family house. The house structure--some 1,200 square feet in size--usually contains some insulation, but chances are just about even that it has neither storm windows nor a basement. Only 15% have central air conditioning, although almost half have at least one air conditioning unit.

Inside, most American homes contain at least six essential energy-using items:

- Central Heat
- Electric Lights
- Hot Water Heater
- Stove
- Refrigerator
- Washing Machine

A television is present in almost every home, but it uses relatively little energy. Only half include clothes dryers, and one-quarter have dishwashers.

The automobile is also a feature of most households (about 80%) and 44% have two or more. The typical American family drives about 14,000 miles each year, and in 1972-73 got about 14 miles per gallon gasoline in local driving. Almost 9 out of 10 Americans use automobiles (theirs or others) to get to and from their jobs and almost three-quarters drive to work alone. The majority of heads of families (60%) take at least one car trip of 100 miles or more each year. One-quarter take at least one plane trip of 500 miles or more during the year.

The average American household, according to the survey, consumes a total of 341 million BTU of primary energy each year. This is the equivalent of 848 gallons of gasoline plus over 8,000 kilowatt hours (KWH) of electricity and 1420 cubic feet of natural gas per household. The average

"Energy is eternal delight."

William Blake

INCOME STATUS	AVERAGE INCOME	AVERAGE ANNUAL BTU'S PER HOUSEHOLD	AVERAGE ANNUAL COST PER HOUSEHOLD	PERCENT OF TOTAL ANNUAL INCOME SPENT ON ENERGY
POOR: TOTAL	\$ 2,500	207	\$375	15.2
Natural Gas		118	147	5.9
Electricity		55	131	5.2
Gasoline		34	101	4.0
LOWER MIDDLE: TOTAL	\$ 8,000	294	572	7.2
Natural Gas		129	153	1.9
Electricity		80	167	2.1
Gasoline		85	252	3.2
UPPER MIDDLE: TOTAL	\$14,000	403	622	5.9
Natural Gas		142	166	1.2
Electricity		108	213	1.5
Gasoline		153	453	3.2
WELL OFF: TOTAL	\$24,500	478	994	4.1
Natural Gas		174	200	.8
Electricity		124	261	1.1
Gasoline		180	533	2.2

(6) The Percentage Of Family Income Spent On Energy Declines As Income Increases

APPLIANCE	POOR	LOWER MIDDLE	UPPER MIDDLE	WELL OFF
STOVE	95	97	99	98
REFRIGERATOR				
Manual defrost	74	51	39	30
Frost-free	24	48	60	69
Total	98	100	100	100
SEPARATE FOOD FREEZER	23	30	38	47
DISHWASHER	3	13	39	55
CLOTHES WASHER				
Wringer	19	11	7	3
Automatic	44	64	84	90
Total	62	75	89	91
CLOTHES DRYER	24	46	70	81
TELEVISION				
Black and White	74	63	57	64
Color	27	48	63	74
Total	94	96	98	98
AIR CONDITIONING				
Window	17	34	35	33
Central	4	10	19	32
Total	22	45	58	64

(7) Percentage Of Households Owning Major Appliances Income Group

American family spends 6% of its income paying gas, electricity and gasoline bills.

Many significant facts are hidden behind these "typical" energy images. In a country as large and diverse as the United States, a description of the "typical" family can only be suggestive of the ways people actually live and is not sufficient for policy formulation. Thus, we must dissect the averages and look at the variations by income groups. Even within the United States, poverty- like wealth -actually covers a broad range of living circumstances. Some poor American families never achieve a reasonable level of economic well-being compared to other Americans. Others are very young families struggling upward. For them, poverty may be temporary. Many are old people whose financial status has deteriorated because their income failed to keep pace with inflation. The poor often combine poverty with other disadvantages such as racial discrimination, lack of education or training, or physical handicaps. Any energy policy involving price changes and conservation requirements must take special problems of the poor into account."

The report goes on to outline what percent of family income is spent on energy. Figures (6) and (7) from the Ford Foundation Report, defines four major groups according to annual income and the percent of family income spent on energy. This graph clearly indicates the variations in energy use and price according to income. Energy levels among the different groups are less pronounced than the differences among income. The poor consume nearly one-half of the energy of the well-off but have one-tenth as much income. They also pay more per unit of energy because as low volume users, their rates are higher.

The Cordova family's income lies slightly below the upper-middle average. Therefore, their percent expendi-

ture on energy is slightly more than 5.9%--in between the 15.2% for poor families and 4.1% spent by well-off families.

High rates for low volume use encourages consumption instead of conservation and can be regarded as a penalty for those who reduce consumption by conservation measures. In the light of resource shortages, this policy should be reversed. Owners of MED-like homes which achieve a 50% reduction in space heating and cooling needs should not be penalized by higher rates. Rather, the opposite should be instituted; lower rates for low volume use would reward and encourage owners to conserve.

The development of the statistics in this chapter on residential energy consumption has, first of all, a direct functional value. Knowing the amount of energy that is likely to be consumed by a typical Cordova homeowner will provide a yardstick of comparison for the new work that is being carried out in the MED Project.

One quick and easy method of determining the energy saving capabilities of the MED homes is to compare their monthly utility bills with conventional houses in the neighborhood that do not incorporate the MED's energy-saving techniques. This simple comparison is the ultimate test but it still would not outline, as this report does, the various amounts of energy that each end use is likely to consume.

The most conclusive picture of the MED performance will extend beyond monthly bills to depend on special sensing devices within the house that will record all aspects of energy consumption. A comparison of these with average statistics that have been developed for a standard Cordova would show the benefits of its design. Probably, the most conclusive statistics that could be developed, but which are outside the scope of this project, would be the comparison of

"We live in a vastly complex society which has been able to provide us with a multitude of material things, and this is good, but people are beginning to suspect that we have paid a high spiritual price for our plenty."

Euell Gibbons/Stalking The Wild Asparagus

the recorded data from the MED homes with that from a similarly instrumented standard Cordova which houses a family with habits similar to the MED occupants. At least one MED house, though, will be instrumented to record all aspects of its energy use. This type of information gathering can only begin after the MED is completely built and occupied. Until that time, any profile of the Minimum Energy Dwelling performance is only a forecast which relies on mathematical calculations to model its energy consumption.

A second, but indirect, function of these statistics is to impress the reader with the relativity of the MED effort to conserve energy. This is similar to the purpose of the "Community Relationship" discussion. Not only is it important to compare the specifics of the MED Project with national averages of typical family consumption in residences; but it is also important to realize that residential energy use is only a part of the total consumption in the United States. Space heating and cooling, the main focus of the MED Project, is just part of the total residential usage. Therefore, it must be kept in mind that the goal of reducing heating and cooling requirements by 50% in the MED home does not mean 50% of the total residential consumption figure.

Reducing gasoline consumption by driving more efficient cars and less miles will have a great impact on residential energy use. For instance, the use of a compact car may have a greater impact than any single energy conservation measure in the home. Although far less important than automobiles, the need for more efficient appliances and reduced use will contribute to the conservation effort occurring at all levels.

"If you want to change the world, start small."

Advertisement/Peace Corps

INSULATION

A 12" batt of fiberglass insulation was installed in the ceiling joists of the Minimum Energy Dwelling. The amount of insulation used is in excess of recommended amounts for this area of the country. A useful benefit of the MED testing may be the verification that by increasing the amount of insulation and using a nighttime ventilation system, the standard heating and cooling system for homes in this climate type could be eliminated.

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 the basic knowledge of its thermal behavior in conjunction with an extended view of the entire energy system operating within a building.

This type of design activity will answer the questions of where to place insulation within a building and how much should be installed. It can show that 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 environment to reduce the cooling load. Such deter-

minations can only be made through detailed study. In addition to this activity, the scores of available insulation types on the market, their properties and range of applications must be investigated before a designer makes final specifications.

In addition to good decision making, the quality of on-site insulation workmanship during installation and the protection of the insulation from moisture throughout the building's lifetime are of major concern if expectations of design are to be met. Obviously, the commitment to minimize energy consumption requires a total involvement in the properties and possibilities of insulation. It can be a detailed enterprise ranging from the computer programmer to the architect's field inspector.

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

- Radiation
- Convection
- Conduction

The purposes of installation then are to reflect the 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 expressed in BTU/Hr (Sq.Ft)(°F.). Insulation can be imagined as a dam or a screen which holds back some heat but permits some to pass through it. The "U" value would be analogous to the holes in the screen. Walls with high "U" values would be seen as a screen with loose weave and many large holes, while low "U" value walls have a tight weave and less open area for heat to escape.

The absolute amount of heat that would pass through these sieve-like walls with different open areas depends on the temperature difference across the wall. This temperature difference (ΔT) can be visualized as a "pressure" forcing heat to flow from the warm side to the cold side. As the magnitude of the temperature difference increases, the pressure increases and heat is squeezed or forced more readily through the free area of the sieve. The heat passing through the wall is measured in "British Thermal Units" with one BTU equal to the amount of heat it takes to raise one pound of water through 1°F. 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 temperature difference in degrees Fahrenheit can be used as that factor which, when multiplied by the "U" value and square

foot area, yields the absolute amount of heat flow through a wall. A particular wall is rated by the amount of heat in BTU that will pass through a square foot area in one hour under the conditions mentioned above. Besides the "U" coefficient, three other values--k, C, and R--are used to indicate the thermal transmission of a particular wall or material construction.

The conductivity value or "k" rates the passage of heat through 1" of material. Multiple inches of the material would divide the amount of heat passing through to be a factor of the number of inches of material. This value is "C", the conductance, and is found by $C = k/x$, where x is the thickness. The reciprocal of k or C ($1/k$, $1/C$) is the R value or the resistance. The resistance is seen as the number of square feet it takes for one BTU to pass through the material. Multiple inches of material would delay the arrival of the heat impact and would be reflected in a higher "R" value. The conductance value of a material of a number of different layers, if inverted, would show the resistance value. It is easily seen then, that the conductance or "U" value of a wall of multiple layers of different materials can simply be found by adding all the particular resistances of each component material and inverting the sum to yield the coefficient of heat transmission or "U" value.

Besides conductivity, other properties may influence the thermal behavior of the material. This includes specific heat, heat capacity, thermal diffusivity, the coefficient of thermal expansion, and temperature resistance. These properties are important in the study of the thermal behavior of the building's mass and will be investigated in the chapter entitled "Mass".

Types of Insulation

All insulation is rated according to its "U" value but is more conveniently

SILICEOUS VOLCANIC ROCK								
VERMICULITE								
MINERAL WOOL								
CELLULOSE								
UREA FORMALDEHYDE								
FIBER GLASS								
CELLULAR GLASS								
EXTRUDED POLYSTYRENE								
EXPANDED POLYSTYRENE								
URETHANE								
ALUMINUM FOIL								
<div> <p>EXCELLENT VERY GOOD</p> <p>POOR GOOD</p> <p>AVERAGE</p> <p><u>RATING SCALE</u></p> </div>								
<div> <p>THERMAL CONDUCTANCE</p> <p>MOISTURE TRANSMITTANCE</p> <p>FIRE RESISTANCE</p> <p>INSTALLATION</p> <p>RANGE OF USE</p> <p>MATERIAL COST</p> <p>DURABILITY</p> <p>AVAILABILITY</p> </div>								

(1) Insulation Matrix

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 classifications exist because of the physical nature of the insulating material, and also because the various insulations were developed or shaped to conveniently coordinate with the different types of construction, or to facilitate quick, easy, and thorough applications. The most common types of insulation and their properties are listed in Figure (1). A more detailed comparison occurs at the end of the chapter.

Flexible and Semi-Rigid Insulation

These types of insulation, designed 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 push against each other to form voids. The vast majority of the volume that the insulation displaces is air molecules 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. (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 usually vary between 2" and 6". Raw, unattached, unformed glass or mineral wool, in a "clumpy" consistency, can be "poured" to any thickness, and at times 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 space between stud framing to prevent convective air currents from circulating around the batts to transfer heat.

(2) Flexible And Semi-Rigid Insulation

Rigid Insulation

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

(3) Rigid Insulation

Pellet or Loose Fill Insulations

The nature of this insulation, granulated low density pellets, allows quick, easy installation by pouring.

(4) It can fill the voids in the cavity of masonry walls or framed walls and ceilings (if sufficiently leak-proof). 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 forms of loose fill insulations are Perlite and vermiculite. They are manufactured by similar methods where the Perlite or mica ore is subjected to high temperatures and expands the ore to nearly 20 times its original volume. These particles contain a large number of air 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

(4) Pellet Or Loose Fill Insulation

(5) Foamed Insulation

egg cartons. The sprayed fibers, offering a very low conductivity, will adhere to nearly every surface and are compatible with nearly all construction types.

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 polyhedral 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 fluorocarbon 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.

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 installation 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. (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 insulations 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. (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.

Special Types

The special types of insulation are manufactured to handle specially controlled temperatures and high temperature insulation problems which occur

(6) Foil Insulation

mainly in the realm of factory processes rather than normal heat flow in buildings. These types are insulating block, made of cork, expanded glass, 85% magnesia, and vermiculite; insulating refractory block or brick made of diatomaceous earth and kaolin (clay); heavy refractories made of fire clay, magnesite, and silica. The specialized insulations are used in refrigeration rooms, pipes, ducts, boilers, fire chambers of boilers, chimneys, etc.

Factors Affecting a Material's Thermal Conductivity

The conductivity of a material increases with greater density. If insulations are to perform at their maximum efficiency, then proper densities should be maintained. Depending on the degree of compaction of powdered loose fill insulations, their conductivity will vary from the manufacturer's rating, while a similar flexibility may be used to a positive advantage with the insulating concrete which can be custom manufactured to a wide range density and thus conductivity values.

Minimum densities are not always preferred. For instance, all the fibrous insulations have optimum density points which produce lowest conductivity rates. Any increase or decrease in density will always increase the conductivity. Beyond this optimum "fluffiness" on the microscopic scale, a decrease on the fiber's diameters, along with complete uniformity of spacing between the fibers at the near microscopic level will improve the conductivity value. Similar conditions exist for cellular insulations where different combinations of cell sizes and density will produce varying conductivities which can be reduced to their minimum values by optimizing the two variables. Conductivities are also affected by the variables of temperature and pressure with the effectiveness of insulation decreasing with temperature rises and decreasing pressure drops.

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. The presence of gaseous water vapors in the insulation does not affect it appreciably.

Only when the vapor condenses on the material does it radically change its performance. The continual buildup of water intensifies the problem by further reduction in performance and the physical deterioration of the insulation. The water may also freeze causing still more damage. The benefits of insulation then can only be as great as the amount of care imposed to protect the original properties of the product.

Vapor Barriers

The vapor barrier is nearly always used in conjunction with insulation to prevent the migration of moisture. The barriers which prevent this movement of moisture are classified according to dominant physical quality which describes them:

- 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 papers, 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.

Vapor barriers do not necessarily function to completely stop the flow of moisture, but act to reduce its rate of flow. 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, 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 surface where it is eventually vaporized when heated by the sun. This expansion to a gaseous state causes delamination of paint, formation of bubbles, and peeling.

The Effectiveness of Vapor Barriers

As with insulation, the performance of a vapor barrier depends on the properties peculiar to its material composition and also external environmental factors which can have modifying influences. Besides its permeance, or the rate of vapor transmission, the vapor barriers location within the insulation wall, floor, or roof section is of major importance. Since vapor always seeks equilibrium by migrating from areas of higher pressure to lower pressure, its movements must be stopped before it enters into insulation or structural members. Therefore, the vapor barrier must always be applied to that surface which is exposed to the higher vapor pressure, thus giving protection to material on the low pressure side in the wall section. That surface is usually referred to as the "warm winter" side and in the vast majority of cases, it is that side which faces the living space. In the cold months, this prevents the internal moisture of humidification from passing out into

the cold insulation of the walls and condensing.

The newer air conditioned buildings in hot-humid areas present a different kind of problem. The interior may have a lower vapor pressure than the outside resulting in a migration of moisture from the outside to the inside. In such cases, the placement of the vapor barrier should occur on the exterior. Further testing is now being performed to calculate its effectiveness. It may be found that no vapor barrier is needed. This is due to the non-occurrence of dew point temperatures.

Another environmental factor which can greatly reduce effectiveness and must be guarded against are punctures or other openings in the membrane that allow ready passage of moisture. As with unwanted infiltration, vapor transmitted with convected air currents may be its major means of movement through an insulated section. These openings may be caused by poor workmanship during application, poorly sealed joints and edges, improper fastening techniques, insufficient coating thickness, mechanical forces which would tear the membrane, and deterioration due to aging. Because stapling causes holes but is the most convenient method of installing vapor barriers, it should be done carefully. Laboratory tests have shown that stapling can increase vapor transmission as much as 20 times. If at all possible, a good glue should be used instead to secure the barrier and insure its perm rating.

Vapor Transmission

Most environmental factors can be controlled if care in design and construction is imposed on a project. The factor which doesn't change in a vapor barrier is its rate of vapor transmission or permeance which is characteristic of the material itself. These rates of flow are determined through laboratory testing and each

material is assigned a value according to its performance.

The way in which vapor passes through a barrier can be visualized similarly to the flow of heat through a wall. The barrier is likened to a sieve with an amount of free area according to its permeability. As the pressure difference between both sides increases, the vapor is forced through the barrier with greater rapidity. Water vapor acts independently of the air with which it is mixed. As a gas, it exerts its own pressure differences, it moves to seek equilibrium. In moving through a material such as a vapor barrier, it causes a vapor pressure gradient between the two zones of differing pressure. This situation is described as vapor diffusion. The design equation commonly used is:

$$W = \mu A \theta \Delta p / l$$

Where:

W = Total weight of vapor transmitted, grains

μ = Permeability, grains per (Hr) (Sq.Ft) (inch of mercury vapor pressure difference per inch)

θ = Time during which the transmission occurred, hours

Δp = Difference of vapor pressure between ends of the flow path, inches of mercury

l = Length of flow path (or thickness of specimen), inches

More often than not, it would be more convenient to deal with materials other than 1" thick. In this case, permeability (μ) is dropped from the equation by substituting the permeance coefficient, M. Since:

$$M = \mu / l$$

the flow equation is:

$$W = M A \theta \Delta p$$

MATERIAL	PERMEANCE (PERM) ^b
THERMAL INSULATION	
air (1")	120.0
cellular glass (1")	0.0
corkboard (1")	9.5
mineral wool (unprotected) (1")	116.0
expanded polyurethane-board (1")	2.0 - 8.0
expanded polystyrene-extruded (1")	6.0
expanded polystyrene bead (1")	10.0 - 30.0
unicellular synthetic flexible rubber foam (1")	.1 - .8
PLASTIC & METAL FOILS AND FILMS	
aluminum foil (1 mil)	0.0
aluminum foil (.35 mil)	.25
polyethylene (2 mil)	.81
polyethylene (4 mil)	.4
polyethylene (6 mil)	.3
polyethylene (8 mil)	.2
polyethylene (10 mil)	.15
polyester (1 mil)	3.5
cellulose acetate (125 mil)	2.0
polyvinylchloride unplasticized (2 mil)	3.4
polyvinylchloride plasticized (4 mil)	4.0 - 7.1
BUILDING PAPERS, FELTS, ROOFING PAPERS	
saturated and coated roll roofing (326) ^c	.24
asphalt saturated and coated vapor barrier paper (43) ^c	.6
asphalt saturated but not coated sheathing paper (22) ^c	20.2
15-lb. asphalt felt (70) ^c	5.6
15-lb. tar felt (70) ^c	18.2
LIQUID-APPLIED COATING MATERIALS	
paint - 2 coats	
asphalt paint on plywood	.4
aluminum varnish on wood	1.5 - 2.5
enamels in smooth plaster	.5 - 1.5
primers and sealers on interior insulation board	.9 - 2.1
paint - 3 coats	
exterior paint, white lead and oil on wood siding	1.5 - 5
exterior paint, lead oxide-zinc oxide and oil on wood	4.5

^a Values for permeance obtained from ASHRAE Handbook of Fundamentals, 1972. The data is provided to permit comparisons of materials, but exact values should be obtained from manufacturers

^b Permeance values are based on a wet cup rating where available. If only dry cup values were available, the value was multiplied by 5.05, a value parametrically obtained where both dry and wet cup values were shown. Difference between dry and wet cup is explained in the source mentioned above.

^c Basis weight in lb. per 500 sq.ft.

(7) Permeance Coefficient

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

(7) The permeance coefficient is in wide use today, and the rating of a particular material is designated by perms for the unit of permeance. The corresponding unit of permeability is the perm-inch for unit thickness.

In heat conduction, the resistance of a material to heat transmission is equal to the reciprocal of the conductance or conductivity. Similarly, the resistance to vapor transmission is equal to the reciprocal of the permeance of a material. To find the overall resistance of composite layers of materials as in a wall or roof, all the separate resistances are summed. The overall permeance also is the reciprocal of the overall resistance.

The design equation is used assuming no other forces are acting to unbalance the actual amount of transmission calculated with the variables in the equation. In reality, forces such as hydraulic pressure, capillary action, absorption and hygroscopicity also contribute to moisture migration, but because of their complexity, are very difficult to account for with mathematical expressions. Fortunately, in most building applications, the design equation using only vapor pressure differences will yield values accurate enough for the design of vapor barrier systems or prevention of condensation in insulated wall sections.

Problems of Installation

The other great environmental factors affecting insulation values besides water penetration are the special problems within construction that would interfere with its proper installation or disrupt its lodgement. These can be classified as the improper interface of the insulation with the other materials in the shell construction either by poor installation or improper detailing and lack of continuity and uniformity between the insulation proper, either in thickness, density, or jointure between individual modules. This latter problem can be readily solved by strict supervi-

sion of the tradesmen who install insulation to insure tight joints between batts, blankets, or rigid board; even distribution for proper densities, and uniform thickness. The proper attachment of insulation to the other materials includes special problems in construction methods or general problem areas in building types.

Convection Problems in Wood Frame Construction

Batt and blanket fibrous insulations are dimensioned to integrate with conventional 2 x 4 stud construction in order to fit snugly between the 16" or 24" centered studs. If, however, a blanket of insulation thinner than the depth of the stud is installed between studs, and gaps are formed on both sides, (between the insulation and the outside sheathing and between the insulation and interior wallboard) the insulative performance can be drastically altered. All gaps between batts or blankets within single modules should be closed also. Otherwise, air may possibly convect between both sides of the insulation causing increasing heat transfer. (8) Some manufacturers accommodate these conditions by suggesting the use of a foil-backed insulation which can be recessed in of the stud module against the exterior sheathing. An additional insulating air space with a reflective surface is created.

As mentioned before, the compaction of insulation can increase its conductivity. Therefore, a thick insulating blanket packed into a thinner wall section will increase the heat transfer rather than reduce it. A thinner uncompacted insulating blanket would have the maximum effect.

Blow Back In Frame Construction

In conventional frame construction, the attic space is most often ventilated by a split system of eaves and

(8) Stud Wall Construction

gable or ridge vents. The attic floor (ceiling of the space below) is usually insulated to the perimeter to meet the end of the vertical sidewall insulation. The problem arises at the soffit vent which introduces air to the attic space. If the action of the air passage is not properly segregated from the insulation with its need for immobility, the insulation (poured or batt) may be blown back toward the attic interior by the force of the air, exposing unprotected areas of the attic floor. In addition, well designed vents which decelerate the wind velocity and deflect driven rain and snow should be chosen in order to protect the nearby insulation from water saturation.

Figure (9) illustrates a solution to this problem as proposed for the Minimum Energy Dwelling. A piece of molded polystyrene rigid insulation is fitted snugly between the rafters and tacked into place. A piece of wood lath, nailed to the rafter, supports its top end. This allows free air circulation but keeps the insulation still.

(9) Blow Back Protection

Masonry Construction

If the space in a cavity wall or the cores of masonry units are to be filled with poured insulation, then no obstruction should be present to interfere with complete filling. No holes in the wall should exist to prevent the leakage of any insulating material or the entry of water.

Vibrations in the wall during construction should be minimized to reduce the settling and its resulting compaction of insulation near the bottom of the wall and cavitation at the top. Most pouring insulations are waterproof in that the condensate is not absorbed into the insulating particles, but is

shed from its surface until it reaches the bottom of the cavity. Here, the water is conducted away through weep holes which are plugged usually with the original rope used to make the hole in the mortar joint. This arrangement allows the water to pass through the rope but prevents the insulation from leaking through the wall.

Rigid board insulation, when used with masonry construction, is usually installed on the inside wall. Using this construction, the insulation is protected from the weather, but still should be tightly glued or mechanically attached to assure continuity of protection. At times, rigid boards are placed on the outside of the wall and thereby exposed to the deteriorating forces of freeze-thaw cycles. The board should be securely attached, tightly joined at their edges and then covered with a water resistant material such as stucco, which will prevent water entry.

More advanced methods are presently being explored for insulation concrete masonry units. Polystyrene core fillers are now being marketed which are installed in the cores at the factory and require no work by the masons. A future possibility may be the filling of the cores at the factory with a foam insulation. A problem still existing is the thermal bridge created by the webbing in the concrete block allowing the unobstructed flow of energy from either the outside or inside.

Problem Areas In Buildings

- Overhangs--Uninsulated overhanging floors reduce thermal efficiency and could result in frozen pipes if any are located in the overhang. The interior of a house, also, 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.

(10) Polystyrene Concrete Block Filler

• 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 gaps between the rough framing opening in the wall and the actual dimensions of the window, thus ensuring total insulation across the entire wall area. If windows project, as with bay windows, they fall in the same category as overhanging floors and roofs. All wall, ceiling, and floor areas surrounding the window must be completely insulated.

• Slab Edge--For slab-on-grade construction, a 1" thick by 12" wide edge of perimeter insulation is recommended to reduce heat loss and increase comfort for those people at work or rest near the perimeter of the building. (10) The insulation should be the rigid type to prevent compaction, resist water penetration, and be carefully secured in place during construction. When the concrete is poured, it should be gently placed around the perimeter to prevent disruption of the placed insulation. (11) The rigid boards are placed vertically along the block foundation wall. Earth or gravel is backfilled against it, and then horizontal pieces are wired to the verticals at the corner. If the foundation wall is being poured, the insulation will act as formwork. When the concrete is poured against the rigid boards, they must be held from buckling with backfilled earth. Wiring the horizontal and vertical boards at their corner will add stiffness and help prevent the insulation from moving or floating upward in the liquid concrete.

The first sketch in Figure (11) approximates the actual condition which was built for the Minimum Energy Dwelling. Slab-edge insulation is an uncommon practice in Southern California and is being tested to access its effectiveness. The detail shown is not an ideal method of installing slab insulation because of the uninsulated area which occurs between the inside floor sur-

face and the exterior. As shown, no insulation exists through the slab creating a less than ideal condition. An alternative which alleviates this problem is shown in the second sketch in Figure (11). The insulation is placed on the exterior of the foundation wall to the bottom of the sill plate. This placement eliminates the thermal bridge and may be simpler to install. Placed over the top of the insulation is a piece of continuous flashing which fits underneath the exterior siding material and extends to ground level.

A third variation which is not pictured would be the placement of the thermal break on the interior side of the sill plate. In this method, the insulation is brought up from the top of the footing to the top of the foundation wall. The floor slab is separated from the foundation by the insulation creating a thermal break.

When an appropriate amount of insulation is installed along the foundation wall, no additional insulation needs to be placed under the floor slab. Even if required, it need not extend any further than three feet from the slab edge. The ground under the slab, if unaffected by a high water table, will stabilize at a constant temperature close to room temperature, and no heat gain or heat loss will occur.

The amount of slab-edge insulation required changes with the climate and the type of insulation. Standard practice has been to install three inches of polystyrene in cold northern climates, and reduce to one inch in climates in which minor freezing occurs each year. The MED home, because of its experimental nature, was built with two inches of polystyrene. It was felt that because of the rising cost of fuel, the addition of slab-edge insulation may be beneficial in climates previously disregarded. Actual testing is being performed to verify this assumption.

(11) Slab Insulation

(12) Sill Sealer

• Sill Plate--Another insulating problem occurs at the sill plate. (12) A thermal break between the foundation wall and the stud wall is achieved by using a special putty-like sill sealer, or batt-like insulation. Besides its thermal benefit, these products help reduce the rate of infiltration air that may penetrate this joint.

In MED, a putty-like sill sealer was used. It was available in one-inch rolls with a removable paper backing for ease of installation. A detailed discussion of its application is included in the "Construction" chapter. In MED, the sill plate was an area of major concern. An exterior polyethylene sheet vapor barrier was placed between the sill plate and the top of the wall at the double header. Therefore, the only large potential area of infiltration was at the sill plate. This was eliminated by the sill plate sealer.

Insulating the Minimum Energy Dwelling

During the design phase, a simulation was performed on the MED Project to compare the effect of insulation on the energy consumption of the building. A desk-top micro-computer was used for calculating the various options.

The computer printout is arranged to isolate the thermal behavior of major building shell components and internal energy sources. With this capability, any changes in these variables can be readily monitored, and their implications estimated to direct the decisions about energy reduction. Using this Minimum Energy Dwelling as a format, an effort was launched to vary insulation amounts to determine the effectiveness of no insulation or a maximum amount of insulation that can possibly be incorporated within a building structure of this type. The optimum amount of insulation would fall somewhere between the two extremes.

Proposing these alternates, assembling data, computing, and finally tabulating the results yielded several graphs which allow a number of comparisons across the total energy system operating in the house. The goal throughout the Minimum Energy Dwelling Project has been managing reduced energy consumption through design. This presupposes the guidance of a single enveloping principle--going beyond simple recognition of energy relatedness in buildings to find hard mathematical techniques for computing the effects of each energy variable. Maintaining this principle permits a focus on insulation and parallel review of the greater picture of energy behavior. The graphed computations of Figures (13) through (18) reflect this--different amounts of insulation and different times of the year are compared, and individual isolated shell components are inter-related, all with regard to relative influence in the whole energy picture.

The first task in this involved process determined the effect of no insulation. Figure (13) illustrates the extreme consequences in heat gain of such a lack. On a typical sunny July day, 404,000 BTU, which must be removed by cooling, are generated both by internal sources and the impact of radiation and conducted heat. Within the graph's circle, various sectors represent component heat sources. Those components which can be insulated are grouped together and bound by the heavy black line. Thus, one can easily read the relative influence of each:

West Wall	10%	South Wall	3%
East Wall	10%	North Wall	1%

With the roof contributing 41% to the cooling load, the remaining 35% are "uninsulated" sources. The need for some insulation, especially in the roof, is glaring. Figure (14) proposes moderate insulation with striking results. Two and three-quarter inches of batt insulation with a 3/4" air space, plus 1" of rigid

JULY 21 - NO INSULATION
TOTAL BTU = 404,000

(13) Daily Energy Usage

REGULAR INSULATION COMPARED TO
NO INSULATION FOR JULY 21, 32° N. LAT
TOTAL BTU = 160,000

(14) Energy Usage Comparison

(15) Energy Usage Comparison

polystyrene sheathing is added to the walls. Five and one-half inch batts are placed in the roof. The absolute amount of gain drops to 160,000 BTU, equivalent to a 61% reduction. This reduction also produces a dramatic shift in relative importance of the insulated components now in the building. The new account is 21% of the load.

At this point, a corresponding shift in focus toward infiltration, appliances, or windows would be appropriate. Nevertheless, a second step was taken to further reduce the influence of heat gain through the walls and roof. These parts were heavily insulated with 5-1/2" batts and 1" rigid polystyrene, and 9-1/2" and 1" polystyrene respectively. Figure (15) records the result. The effect is a reduction by 14,500 BTU to a low of 145,500 BTU, an insignificant drop compared to the first step. This amounts to a further reduction of only 4%. Clearly, this small benefit must be weighed against the cost of the significant amounts of insulation needed to produce the effect.

(16) Daily Energy Usage

Another study was undertaken to illustrate the changing importance of the insulation at different times of the year. Moderate insulation (regular) was used in every case and tested on typical days in July, December and April. (16) (17) (18) Although absolute amounts of energy consumption changed, with a July cooling load dominating, the relative contributions of the insulated components were nearly the same: 25% in July, 27% in December, and 19% in April. These graphics clearly demonstrate that only moderate amounts of insulation are necessary to respectively reduce load throughout the year.

Oddly enough, these findings do not conclude the investigation, but spur further study to fulfill the goal of

the project. In hope of additional benefits, attention is turned from the expanded view inwardly to the interrelations of the insulated components themselves. The essential probe in this direction is not to determine the effectiveness of overall amounts, but the relative importance of its location within the structure. Encouragement for this investigation sprang from a review of the twelve-month period load calculations which suggested an interesting possibility for insulation design. It occurred that cooling and heating loads could be shaved by actually reducing insulation amounts in specific walls for times during the year (Spring and Fall) when both heating and cooling modes more evenly divide between the hours of the day. Interest centers on the east wall which, if lightly insulated, could be used to "economize" the heating load by more rapidly admitting heat into the house during the early morning hours.

Conversely, the same wall, if in the shade, could be used to reduce cooling requirements throughout the later hours of the day by leaking internal heat to the outside air which is below design temperatures. Figure (19) illustrates the hourly heat behavior of each insulated component for a typical April 21. The relatively vast heat gain through the roof dominates this picture while the walls show mostly the reverse--leakage of heat to the outside. All the components could be compounded to reveal absolute amounts for each mode. It is interesting to observe the east wall which sustains an early morning heat impact between 7:45 a.m. and 10:30 a.m. to offset the combined heat leak of the other wall components. If the heat impact of the roof could be delayed and the east windows made bare to introduce morning sun, a portion of the heating load could be theoretically offset in the morning at certain times in the Spring and Fall. The same east wall arrangement could dump some internal heat to the atmosphere

DECEMBER 21 - REGULAR INSULATION
TOTAL BILL = \$9,000

(17) Daily Energy Usage

APRIL 21 - REGULAR INSULATION
TOTAL BILL = \$9,000

(18) Daily Energy Usage

(19) Hourly Energy Consumption

in the afternoon to offset gains through the west wall.

It can be seen then that the popular notion of "the more insulation, the better", which may seem more appropriate in more extreme climates, does not operate in Mission Viejo, California. The moderate climate there reduces the relative need for insulation amounts while at the same time requires a greater design commitment to further minimize energy consumption with insulation.

The significance of custom-fitting a house with insulation is the implication of using the same customizing idea with other energy conserving techniques. For instance, movable shading devices are implied for admitting the sun when appropriate, but deflecting it when total protection is needed. Delaying the great heat impact transferred through the roof to allow the insulated wall to "economize" heating and cooling modes as described is a combined problem for insulation and the heat storing capabilities of a massive roof. If the influx of heat could be delayed to cooler evening or nighttime hours, the economizer cycle within the mechanical system could efficiently remove the heat.

These possibilities reveal only a small range of the entire investigation needed to produce a Minimum Energy Dwelling. Nevertheless, applying comprehensive energy-reducing techniques as illustrated herein demonstrates an involvement in the total energy system. The willingness to commit oneself to that involvement arises from a respect for the synergistic behavior of inter-related variables, while the possibility of managing that complexity further encourages comprehensive analysis and design.

The philosophy in insulating the Minimum Energy Dwelling was to keep the amount of insulation in the four orientations the same while utilizing an increased amount in the ceiling. The walls incorporate a 6" batt of R-19

insulation within a 2" x 6" construction. The advantages of varying the insulation levels on various orientations was not thought to be appropriate in mass-production housing where the orientation of the homes change continuously throughout a subdivision. In the ceiling, a R-26 batt of fiberglass was used. The increased amount of insulation in the ceiling reflects the need to deflect the hot summer sun and to resist the natural upward flow of heat during the winter.

(20) Recent studies have indicated that the most economical amount of insulation in the Southern California coastal climate would be R-19 (6") in the ceiling and R-11 (3.5") in the walls. This may in fact be the case, but because of the experimental nature of the MED home, an increased amount was used. An important correlation to the most economical thickness of insulation is the size of the mechanical equipment required. At Mission Viejo, it appears to be possible to build a home without a traditional mechanical system. If by increasing the amount of insulation a mechanical system is not required, the added cost of insulation is justified. Actual testing of the MED home will substantiate this hypothesis.

The wall construction used for MED consisted of an exterior Stucco applied to a polyethylene barrier attached to a 2" x 6" construction spaced 24" on center. The interior finish was 5/8" drywall. The wall cavity was filled with R-19 (6") fiberglass insulation face stapled to the studs. The only increase in cost between the standard 2" x 4" construction and the 2" x 6" construction is the increased amount of insulation. The 2" x 6" construction does not substantially increase the cost of wood because they can be spaced 24" instead of 16".

When R-19 (6") insulation is used in a 2" x 6" wall, it must be squeezed in order to fit within the 5-1/2" actual width of the stud. When compressed, the density increases and the resistance to the flow of heat is decreased.

KEY : RESISTANCE (R) - ROOF / WALLS / FLOOR

R - 33 / 19 / 22		R - 26 / 19 / 13
R - 30 / 19 / 19		R - 26 / 13 / 11
R - 19 / 11 / 11		R - 38 / 19 / 22

(20) Recommended Insulation Thickness

SOURCE: Owens Corning Fiberglas Corporation

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.
POOR GOOD EXCELLENT
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.	

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

(21) Key For Insulation Matrix

Physical Structure

The physical structure description explains the process of fabrication and the method of preventing heat flow of each insulation type. Most types provide a dead air space or cell while others have a reflective surface.

Moisture Transmission

Insulation must resist the infiltration of moisture because encased water transmits heat faster than an enclosed air space. If insulation becomes saturated, the insulative value may degrade beyond a point of recovery.

Fire Resistance

The fire resistance of an insulation can help contain the spread of the fire and preserve the integrity of the building structure. The flame spread rating of a material is the distance a fire will move across a surface within a given time. The higher the number, the faster the fire will spread. In the same manner, higher fuel contribution and smoke development values indicate a greater fire hazard. If exposure to high temperatures or any Code restrictions are expected, the selection of an insulation material should be a major priority.

Installation

When selecting an insulation, the degree of labor skill or special machinery required for its installation should be considered. A labor intensive material may provide better insulation resistance for the available space.

Range of Use

For each insulating problem there may be a number of insulating materials that may be adequate. While some forms of insulation may not be appropriate for a particular construction type, the ingenuity of the design may allow for uses other than those listed.

Durability

The durability of an insulation will be important if it must be exposed to one or more of the elements of degradation. If additional construction materials are required to protect the insulation, it may be an added cost that would make another insulation a better choice.

Substrate

If the insulation lacks durability and must have surface protection, it becomes an important design consideration. Some insulations accept finish materials more easily than others. This allows for a wider choice of surface finishes and may also accelerate the construction schedule. Both can be cost considerations. Adaptation of the buildings' design may permit uses other than those which are listed.

Available Sizes

Sizes listed are general examples which also reflect the adaptability and range of use of each insulation material. All sizes listed may not be available from all the designated manufacturers. Space does not permit the listing of all shapes and sizes of some of the more versatile types of insulation.

Brand Names

The list of brand names is given to assist in locating information about a particular insulation application. Some products are easily available from local lumber or hardware outlets, while others are only sold through regional distributors or franchised contractors. It should not be presumed that the listed brands are the only available products. Local telephone directory yellow pages should be helpful in obtaining additional information.

To develop cost comparisons in the fairest possible manner, R-Values of 30 for ceilings, 19 for walls, and 19 for crawl spaces and perimeter were used as the design criteria. Using the known R-Value for an insulation, the required number of inches of that material could be established for achieving the R-Value of the design criteria. The cost of the total number of inches of insulation is divided by the number of inches required to obtain the desired resistance. This gives the material and total cost (including installation) per inch. As an example, a given insulation may have an R-Value of 3.0 for a one inch thickness. For a ceiling installation, it would require 10.0 inches of insulation to provide an R of 30. One square foot of the given insulation, 10 inches thick, costs 60 cents; therefore, dividing 60 cents by 10 inches gives a cost per inch of 6¢/sq.ft. Ten inches of insulation, installed, costs 20¢/sq.ft., or an additional 2¢/inch (sq.ft.). A total of 8¢/(sq.ft.)(inch) would be required for the material and installation.

Costs not available from manufacturers were based on the 35th Annual Edition of Means Building Construction Cost Data, 1977.

Factors which affect costs are weather conditions, the season of the year, contractor management, local Union restrictions, Building Code Requirements, availability of adequate energy, manpower and building materials, as well as general business conditions which can influence the "in place" costs of all building items.

Some insulation materials are combinations of two or more types of insulation. Due to the variety of possible combinations, they are not shown in the Insulation Matrix. These combinations may improve one or more characteristics, such as moisture resistance or durability, and can also permit a material to be used in other applications. Some innovative wall panel systems are not only good combinations of insulation, but also allow for faster installation.

Although an insulation material is shown as being used in walls or ceilings, the thickness required to achieve the desirable R-Value may exceed the space that can be allowed within the construction. A more efficient insulator may suit the situation without changing the building construction system. This type of problem will be avoided if the insulation is a consideration during the early design stages. In the selection process for a particular insulation, the cost effectiveness ratio (T/R) does not consider the additional cost of the structure or enclosure. This additional cost must be considered to obtain the total cost for selection of a particular insulation.

(22) Section Description For Insulation Matrix

The actual resistance of the insulation in this case is R-18.

The reason to use fiberglass was made on a variety of grounds.

- The use of fiberglass is widely accepted in California. Thus, no learning curve is needed for workmen learning a new process.
- The insulation is a one-time process requiring only one visit to the job site. The use of 2" x 4" construction with an insulating sheathing would have required two job visits. The elimination of additional visits is extremely important in mass-produced housing for minimal cost.
- At the time of construction, many of the foam types of insulation did not have widespread distribution in Southern California.
- Finally, and possibly the most important reason, is the cost of many of the various other techniques of insulation when compared to fiberglass.

The vapor barrier selected for the MED home consisted of externally wrapping the home with an 8' polyethylene vapor barrier attached from floor to ceiling. An exterior vapor barrier is used because of the dominant cooling load and the natural tendency for moisture to flow from the outside to inside when a home is air conditioned and dehumidified. The fiberglass insulation has an integrated vapor barrier. The vapor barrier was probably unnecessary, but was installed because it is integral with the insulation. The ceiling was installed without an exterior vapor barrier because of the difficulty to include it during the construction of the home. Instruments have been installed to determine if any moisture is trapped between the plastic film on the outside surface of the stud walls and the integrated vapor barrier with the insulation on the inside surface of the stud walls.

ALUMINUM FOIL	PERM. R. 1/2"	PERM. R. 1/4"	PERM. R. 1/8"	PERM. R. 1/16"	PERM. R. 1/32"	PERM. R. 1/64"	PERM. R. 1/128"	PERM. R. 1/256"	PERM. R. 1/512"	PERM. R. 1/1024"	PERM. R. 1/2048"	PERM. R. 1/4096"	PERM. R. 1/8192"	PERM. R. 1/16384"	PERM. R. 1/32768"	PERM. R. 1/65536"	PERM. R. 1/131072"	PERM. R. 1/262144"	PERM. R. 1/524288"	PERM. R. 1/1048576"	PERM. R. 1/2097152"	PERM. R. 1/4194304"	PERM. R. 1/8388608"	PERM. R. 1/16777216"	PERM. R. 1/33554432"	PERM. R. 1/67108864"	PERM. R. 1/134217728"	PERM. R. 1/268435456"	PERM. R. 1/536870912"	PERM. R. 1/1073741824"	PERM. R. 1/2147483648"	PERM. R. 1/4294967296"	PERM. R. 1/8589934592"	PERM. R. 1/17179869184"	PERM. R. 1/34359738368"	PERM. R. 1/68719476736"	PERM. R. 1/137438953472"	PERM. R. 1/274877906944"	PERM. R. 1/549755813888"	PERM. R. 1/1099511627776"	PERM. R. 1/2199023255552"	PERM. R. 1/4398046511104"	PERM. R. 1/8796093022208"	PERM. R. 1/17592186044416"	PERM. R. 1/35184372088832"	PERM. R. 1/70368744177664"	PERM. R. 1/140737488355328"	PERM. R. 1/281474976710656"	PERM. R. 1/562949953421312"	PERM. R. 1/1125899906842624"	PERM. R. 1/2251799813685248"	PERM. R. 1/4503599627370496"	PERM. R. 1/9007199254740992"	PERM. R. 1/18014398509481984"	PERM. R. 1/36028797018963968"	PERM. R. 1/72057594037927936"	PERM. R. 1/144115188075855872"	PERM. R. 1/288230376151711744"	PERM. R. 1/576460752303423488"	PERM. R. 1/1152921504606846976"	PERM. R. 1/2305843009213693952"	PERM. R. 1/4611686018427387904"	PERM. R. 1/9223372036854775808"	PERM. R. 1/18446744073709551616"	PERM. R. 1/36893488147419103232"	PERM. R. 1/73786976294838206464"	PERM. R. 1/147573952589676412928"	PERM. R. 1/295147905179352825856"	PERM. R. 1/590295810358705651712"	PERM. R. 1/1180591620717411303424"	PERM. R. 1/2361183241434822606848"	PERM. R. 1/4722366482869645213696"	PERM. R. 1/9444732965739290427392"	PERM. R. 1/18889465931478580854784"	PERM. R. 1/37778931862957161709568"	PERM. R. 1/75557863725914323419136"	PERM. R. 1/151115727451828646838272"	PERM. R. 1/302231454903657293676544"	PERM. R. 1/604462909807314587353088"	PERM. R. 1/1208925819614629174706176"	PERM. R. 1/2417851639229258349412352"	PERM. R. 1/4835703278458516698824704"	PERM. R. 1/9671406556917033397649408"	PERM. R. 1/19342813113834066795298816"	PERM. R. 1/38685626227668133590597632"	PERM. R. 1/77371252455336267181195264"	PERM. R. 1/154742504910672534362390528"	PERM. R. 1/309485009821345068724781056"	PERM. R. 1/618970019642690137449562112"	PERM. R. 1/1237940039285380274899124224"	PERM. R. 1/2475880078570760549798248448"	PERM. R. 1/4951760157141521099596496896"	PERM. R. 1/9903520314283042199192993792"	PERM. R. 1/19807040628566084398385987584"	PERM. R. 1/39614081257132168796771975168"	PERM. R. 1/79228162514264337593543950336"	PERM. R. 1/158456325028528675187087900672"	PERM. R. 1/316912650057057350374175801344"	PERM. R. 1/633825300114114700748351602688"	PERM. R. 1/1267650600228229401496703205376"	PERM. R. 1/2535301200456458802993406410752"	PERM. R. 1/5070602400912917605986812821504"	PERM. R. 1/10141204801825835211973625643008"	PERM. R. 1/20282409603651670423947251286016"	PERM. R. 1/40564819207303340847894502572032"	PERM. R. 1/81129638414606681695789005144064"	PERM. R. 1/162259276829213363391578010288128"	PERM. R. 1/324518553658426726783156020576256"	PERM. R. 1/649037107316853453566312041152512"	PERM. R. 1/1298074214633706907132624082305024"	PERM. R. 1/2596148429267413814265248164610048"	PERM. R. 1/5192296858534827628530496329220096"	PERM. R. 1/10384593717069655257060992658440192"	PERM. R. 1/20769187434139310514121985316880384"	PERM. R. 1/41538374868278621028243970633760768"	PERM. R. 1/83076749736557242056487941267521536"	PERM. R. 1/166153499473114484112975882535043072"	PERM. R. 1/332306998946228968225951765070086144"	PERM. R. 1/664613997892457936451903530140172288"	PERM. R. 1/1329227995784915872903807060280344576"	PERM. R. 1/2658455991569831745807614120560689152"	PERM. R. 1/5316911983139663491615228241121378304"	PERM. R. 1/10633823966279326983230456482242756608"	PERM. R. 1/21267647932558653966460912964485513216"	PERM. R. 1/42535295865117307932921825928971026432"	PERM. R. 1/85070591730234615865843651857942052864"	PERM. R. 1/170141183460469231731687303715884105728"	PERM. R. 1/340282366920938463463374607431768211456"	PERM. R. 1/680564733841876926926749214863536422912"	PERM. R. 1/1361129467683753853853498429727072845824"	PERM. R. 1/2722258935367507707706996859454145691648"	PERM. R. 1/5444517870735015415413993718908291383296"	PERM. R. 1/10889035741470030830827987437816582766592"	PERM. R. 1/21778071482940061661655974875633165533184"	PERM. R. 1/43556142965880123323311949751266331066368"	PERM. R. 1/87112285931760246646623899502532662132736"	PERM. R. 1/174224571863520493293247799005065244265472"	PERM. R. 1/348449143727040986586495598010130488530944"	PERM. R. 1/696898287454081973172991196020260977061888"	PERM. R. 1/1393796574908163946345982392040521954123776"	PERM. 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(23) Insulation Matrix

RANGE OF USE	DURABILITY	SUBSTRATE	AVAILABLE SIZES	BRAND NAMES
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 confined within an envelope of building materials.	4 cu. ft. bags or 1" and 2" rigid board.	SILICO-JS VULCANIC ROCK
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 confined within an envelope of building materials	4 cu. ft. bags.	VERTICULITE
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 it cannot be used as a finish surface. It must be sheathed over 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.	MINERAL WOOL Thermax Mineral Fiber Soydon Sprayed Premium Brand (Rockwool Indus.)
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	CELLULOSE Cellin Mon-Therm K-13 Celotex
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.	UREA Ropco-Foam Tripolymer
In ceilings and walls. In frame construction, attic floor and roof, still sealer between top of masonry foundation wall and wood framing plate. Used between wood framing strips on masonry walls.	Long lasting if protected from moisture. Moisture will not damage the glass fibers but will age the glass fibers over time. 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.	FIBER GLASS Owens-Corning Johns-Manville
Can be used as construction material as part of slabs, in built-up roof construction as well as in combination with 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 light weight (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 tapered top of 1/16", 1/8", or 1/4".	CELLULAR GLASS Foamglass (Pittsburgh Corning)
In masonry cavity walls, foundations, grooves 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. Fiberglass mesh for exterior finish.	8" boards, 24" wide; 3/4", 1", 1-1/2", 2" and 3" thick. Boards 24"x48", 1", 1-1/2", 2" and 3" thick.	EXTRUDED POLYSTYRENE Zonolite Thermo-Stud Syrfoam TG (Dow)
Walls, in built-up roofs, in well construction and under floor decking.	Must be protected from direct sunlight which degrades the material 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. Fiberglass mesh for exterior finish.	Boards in lengths of 4', 6', & 8' with thickness of 1/2", 1", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", 22", 24", 26", 28", 30", 32", 34", 36", 38", 40", 42", 44", 46", 48", 50", 52", 54", 56", 58", 60", 62", 64", 66", 68", 70", 72", 74", 76", 78", 80", 82", 84", 86", 88", 90", 92", 94", 96", 98", 100".	EXPANDED POLYSTYRENE Styrofoam Benoite Raylite Foam-Form
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.	Good surface for plaster base. Drywall for interior finish. Fiberglass mesh for exterior finish.	Foam expands to fit any shape or size space. Tapered roofing sections usually of 2"x4" or 3"x4" sections. Can also be a pre-expanded foam. Can also be a pre-expanded foam.	URETHANE Rubicon, Unirex North Carolina Foam Industries Upjohn Owens-Corning Chemicals Systems Inc.
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 inner board dividers and stapling flanges assure parallel air spaces. Loss of air space diminishes value of insulation.	Must have drywall or both and finish material in its own right. plaster type finish. It is not a finish material.	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.	ALUMINUM FOIL Meta-Foil

MASS

On top of the Minimum Energy Dwelling is installed a heavy red tile roof. The use of heavy construction has been reduced continuously over the past two hundred years in both residential and commercial buildings. Older buildings, especially in the arid Southwest, were constructed of heavy masonry materials with deep overhangs to prevent penetration of the hot summer sun. The heavy materials reduced and delayed the heat flow to the point where comfort could be maintained. The challenge of the future demands cheap and innovative methods to add mass to the building shell.

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.

Mass has the ability to store heat energy and the concept is simple to illustrate. Imagine the start of a day in late spring. Upon awakening, the outside is bright and sunny, and there is still a night chill to 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 to 85-90°F. and becomes a bit uncomfortable. Returning home about 6:00 p.m., the home 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.

Because lightweight construction can do little to delay heat flow, it has been the practice to restrict the flow of energy with insulation. By adding enough insulation, the energy flow can be reduced to the point where very little heat can get in or out.

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 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 no 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 would still require heating and cooling albeit in lesser quanti-

ties. With mass and a 12-hour time lag, the home may not require any heating or cooling.

Imagine a home that is modeled from sponges, wrapped in paper and submerged in a tub of water. The sponges represent its mass, and the paper, its insulation. The water in this case behaves much the same way heat would when it surrounds a normal house. The paper restricts the amount of water which can enter the home but does permit some to seep through. The sponges have an ability to absorb a quantity of water before they become saturated and allow water to penetrate the house.

Every building material has the ability to both resist and delay the flow of energy. Some materials are better in one characteristic than another. Brick and concrete can absorb large quantities of heat, but do little to resist flow. Conversely, fiberglass insulation will not conduct heat well because of its high resistance, but cannot absorb or delay the passage of energy.

Resistance can be defined as the BTUs which will be transferred through a thickness of material in a given amount of time. Or more accurately, the number of BTUs which will be transferred through one inch of material, one square foot in area in one hour when the driving force is 1°F. temperature differential, BTU/(In.) (Sq.Ft.) (Hr.) (°F).

The ability to absorb energy is defined by the energy capacity of a material or the number of BTUs it takes to raise a one inch by one foot square of a given material 1°F., BTU/144 (in³) (°F.). Figure 1 gives the resistance and energy capacity of some common building materials.

The common approach to building design in recent years has been to use large

	Energy Resistance btu/(in)(hr)(sq.ft.)(°F)	Energy Capacity btu/144(in ³)(°F)
Acous. Ceiling Tile	2.703	.298
Air Space	.909	0
Aluminum	.0007	3.089
Asbestos Cement Board	.250	2.500
Brick Common 4 Inch	.200	2.200
Brick Face 4 Inch	.111	2.383
Bronze Plate	1.640	2.600
Carpet (Fibrous Pad)	4.167	.333
Carpet (Rubber Pad)	2.440	.283
Ceramic	2.222	.306
Celotex	3.450	.213
Concrete Blk-LW 4 Inch	.373	.817
Concrete Blk-LW 6 Inch	.298	.817
Concrete Blk-LW 8 Inch	.250	.817
Concrete Blk-LW 12 Inch	.189	.817
Concrete Blk 4 Inch		
(Sand & Gravel Aggregate)	.179	1.833
Concrete Blk 6 Inch		
(Sand & Gravel Aggregate)	.145	1.833
Concrete Blk 8 Inch		
(Sand & Gravel Aggregate)	.139	1.833
Concrete Blk 12 Inch		
(Sand & Gravel Aggregate)	.107	1.833
Concrete Blk 3 Inch		
(Cinder Aggregate)	.287	1.833
Concrete Blk 4 Inch		
(Cinder Aggregate)	.278	1.833
Concrete Blk 8 Inch		
(Cinder Aggregate)	.216	1.833
Concrete Blk 12 Inch		
(Cinder Aggregate)	.157	1.833
Concrete Standard	.083	3.267
Copper	.0004	4.301
Corral Rock	.083	1.367
Door Core	2.381	.975
Dry Wall	.303	.750
Earth	.154	1.833
Expanded Polystyrene, Extruded Plain	4.000	.044
Expanded Polystyrene Extruded (R-12 EXP)	5.000	.053
Expanded Polystyrene Extruded (R-12 EXP) (Thickness 1 In. & Greater)	5.263	.085
Expanded Polystyrene, Molded Beads	3.571	.024
Expanded Polyurethane (R-11 EXP)	6.250	.048
(Thickness 1 In. or Greater)	6.250	.079
Felt	.752	2.333
Glass, Cellular	2.500	.180
Glass Block (Wall)	2.500	1.167
Glass Fiber, Organic Bonded	4.000	.063 - .143
Glass Plate (Door)	.060	1.610
Glass (Painted)	.400	2.690
Glass Spand Solarbrnz	.060	1.610
Granite	.078	2.694
Gypsum Deck	.602	.850
Gypsum Lath (Plasterboard)	.870	1.083
Hard Board	1.220	1.153
Haydite Block (Insulation)	.250	.817
Insulation Min. W Bat	3.125	.045
Insulation Roof Deck	2.778	.208
Insulation - CAPCO	3.846	1.670
Insulrock	1.960	.780
Kawneer	3.226	.160
Linoleum	.637	2.000
Maibite	.049	2.835
Mineral Fiber (Resin Binder)	3.448	.213
Paper, Regular	1.111	1.813
Perlite	1.075	.667
Plaster	.172	2.320
Plaster, Metal Lath	.172	1.750
Plaster, Cement	.200	2.767
Plaster, GYP LW AGG	.667	.638
Plaster, GYP SAND AGG	.179	1.750
Plywood	1.250	.827
Porcelain	.003	4.900
Rockwool Batt	3.704	.060
Roofing Asphalt Roll	.154	1.925
Roofing Built Up	.885	2.217
Sand	.182	1.063
Sheathing Fiber Resin	2.632	.412
Shingles Asphalt	3.333	2.742
Shingles Wood	2.500	1.240
Slate	.100	2.000
Steel	.003	4.789
Stone 4 Inch	.080	2.333
Stucco	.200	2.710
Tectum Deck	1.818	.367
Terrazo	.080	2.500
Tile, Asphalt	.400	3.000
Tile Floor (Vinyl)	.400	3.000
Varmiculite-Loose	2.273	.067
White Quartz	.083	2.500
Wood, Hard	.909	1.125
Wood, Soft	1.250	.880
Zanolite (Loose)	2.564	.0583

* 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).

(1) Material Characteristics

SOURCE: Westinghouse Electric Corporation

"For the style ought manifestly to be different in Egypt and Spain, in Pontus and Rome and in countries and regions of various characteristics. For in one part the earth is oppressed by the sun in its course; in another part the earth is far removed from it; in another it is affected by it at a moderate distance."

Le Corbusier

quantities of insulation. It's common to hear: "Let's insulate the hell out of it" or "This building is like a thermos bottle" or "It will only take a candle to heat this place". These kinds of comments are reactions to the energy crisis and the perceived need for more insulation in most building types. As in most other areas of life, there are exceptions to the rule with the rule in this case being "the more insulation, the better". Both insulation and mass have situations in which they excel in the conservation of energy. But if used improperly or excessively, both can actually increase energy consumption. The value of insulation is its ability to restrict the flow of energy and of mass to delay the flow.

Insulation is very important in climates with extremes in yearly temperatures. A good example is the north-central United States. In the winter, it can become extremely cold and the summer can be extremely hot. A house in such a climate needs large amounts of insulation to restrict flow of heat from the house in the winter and into the house in the summer. But in a moderate climate such as San Francisco, excessive insulation in an office building may actually be detrimental. Because of all the heat-producing items in an office building--lights, mechanical equipment and people--the building may actually require cooling even though the temperature outside may be 45-50°F. Insulation retains internal heat rather than letting it leak out. Therefore, more cooling will be required using more energy. It is important to determine in which direction heat flow will occur, for what periods of time that flow will occur, and whether the flow is detrimental or beneficial before determining the amount of insulation which should be used.

The best use of mass is in buildings which have large daily swings in energy consumption. The best possible situations are buildings which require equal amounts of heating and cooling

over a 24-hour cycle. By delaying the heat buildup during the day, the heat can be used to heat the building at night. But even buildings which only require heating or cooling may find mass worthwhile.

Consider a nursing home in the Southwest. During the summer, the building may require cooling 24 hours a day. The maximum cooling required occurs a little after 6:00 p.m. when all of the cooking has just finished and the sun has been heating the nursing home all day long. The temperature outside is still fairly high. The energy required for cooling at this time may be eight times the cooling needed early in the morning when the occupants are asleep and the sun is still low in the morning sky.

The operating efficiency for a piece of equipment can vary significantly when the cooling requirements change so drastically. 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. (2) Manufacturers understanding this principle have designed their equipment to run most efficiently at part-load requirements. The part-load efficiencies of equipment change depending on the specific type of equipment being investigated. The performance curve shown in Figure (2) is for a centrifugal chiller. As an example, a boiler, an absorption chiller, or a unitary heat pump all operate at different efficiencies depending upon the percentage of load. The part-load characteristics can usually be obtained from the equipment manufacturer. Even so, at lower percentages of the load, the system's efficiency drops off significantly. If the mechanical equipment could run continuously at high operating efficiencies, greater fuel savings would occur although the building requirements remain the same. Consider the same nursing home where enough mass has been added to dampen the daily cycle

(2) Equipment Efficiency For A Centrifugal Chiller

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0

(3) Effect of Thermal Damping Upon Equipment Size

of cooling to a constant level throughout the day.

Rather than run at a partial load between 10% and 60% of system capacity at a system efficiency near 80%, the system could run consistently near 98% efficiency for a fuel savings of over 20% per day.

Additional savings can be obtained with a smaller but more consistent load. (3) The mechanical 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 both be lower.

These design philosophies can be compared to two bicycle riders. They both decide to take a trip from Osgosh to Tipperay, but decide on different routes of getting there. Hank takes what appears to be the quickest route on the map, a straight line between the two points. He starts out only to be confronted by a steep hill. Climbing to the top, he finds a beautiful view and great downhill run, but also another steep hill. This continues for the rest of the day, and he arrives at Osgosh exhausted. The up hills were murder. Tim, on the other hand, had taken a meandering route on a road that followed the side of a stream in a beautiful valley. Although he never got to go downhill, he didn't arrive in Osgosh nearly so tired because of the gradual uphill grade.

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

In design of a building, care should be taken to determine the proper amounts of insulation and mass. Two factors must be analyzed closely:

- Climate
- Building Type

The most important factor to determine from the climatic data is the yearly temperature pattern. The following is a list of important information.

• Outdoor Design Conditions--The outdoor conditions are the maximum and minimum outdoor temperatures that can be expected during a year. The American Society of Heating, Refrigerating and Air-Conditioning Engineers have defined design conditions as weather conditions occurring less than 2-1/2% of the time. The greater the difference between indoor and outdoor temperatures, the greater the capacity of the mechanical equipment. The outdoor design conditions for summer are given with two variables; the dry-bulb temperature and wet-bulb temperature. Wet-bulb temperature is an indication of relative humidity or moisture in the air. The outdoor design conditions for Mission Viejo, California are 34°F. in the winter and 90°F. dry bulb and 70°F. wet bulb in the summer.

• Monthly Average Temperature--The monthly average temperature includes the average daily high, mean, and low which occur in a day. In design, the above information can give an indication of the normal conditions which can be expected. In practice, these values are more important than the

"The development of a nearly thermostatic state in our buildings should be regarded as one of the most valuable advances in the evolution of buildings."

Dr. Walter B. Cannon

design weather conditions because the home will operate for more hours in the average temperature regions than at the maximum and minimum temperatures and should be designed accordingly. The difference between the high and low temperature gives an early indication of the effectiveness of mass in damping out the hourly daily energy requirements. The greater the temperature difference, the greater the possibilities.

• Percentage of Weather Conditions--In the "Comfort and Climate" Chapter appears a graphical representation of the average weather conditions occurring over the year. The graph (Figure 29) labeled "Yearly Percentage Frequency of Occurrence for El Toro, California" consists of graphing the average ambient air temperatures and relative humidities over a year on a psychrometric chart. Each dot is graphed for one specific ambient air temperature and relative humidity and represents one tenth of one percent of the total time in a thirty-year period that the designated conditions occurred. The graph illustrates the weather conditions of the greatest frequency which must be handled by the design of the building.

• Solar Radiation--The solar radiation values for different months of the year can be of value. The radiation levels change constantly on each building surface as the sun moves across the sky. A south-facing wall has low solar radiation at sunrise reaching the maximum in solar intensity at noon and receding to zero again by sunset. An east-facing wall, however, reaches its greatest intensity by nine. Tables giving solar position and intensity are widely available for different latitudes of the country and different orientations of wall surfaces. The values obtained can be used in determining the effectiveness of mass, window construction or solar collectors. Also needed are the ranges of solar position in altitude and azimuth.

• Micro-Climate--The characteristics of a site will have an effect upon the design. A forested site differs in possible solutions from that of a clear field. Possible changes in the amount of solar radiation or wind direction should be noted. As an example, the temperature of a wooded site can be lower by ten degrees or more than the same area without trees. A home placed on the wooded site would have a corresponding reduction in energy consumption.

A summary of the above information for Mission Viejo, California is given in the "Comfort and Climate" Chapter. The building type requires the following information:

• People Load Profile--People generate heat and should be included in any energy analysis. Times of occupancy and types of activity should be noted.

• Lighting and Mechanical Equipment Profile--Lighting and mechanical equipment heat can be one of the most dominant air conditioning loads in commercial structures. Even in the Minimum Energy Dwelling, this load accounts for over 20% of the air conditioning requirements. Like people, times of operation and heat generated should be used. An excellent example is shown in the "Internal Energy Sources" Chapter.

• Design Philosophy--Thoughts behind the design should be noted. A requirement for a large south-facing window can increase energy consumption. A building with a large amount of surface area in relation to internal volume and its orientation on the site can have an effect on possible energy techniques. Guides or punch lists of what to look for have been prepared by a variety of organizations.^{1,2} Care must be taken when using the "punch

¹Energy Conservation Design Guidelines For New Office Buildings, General Services Administration, Washington, D.C., 1975.

²Energy, AIA Energy Notebook, The American Institute of Architects, Washington, D.C., 1975.

"Enclosure: the building shell has become a filter between exterior and interior environments rather than a simple barrier."

Architectural Forum

(4) Ideal Building Skin

lists" as no single design technique behaves independently. Many "punch list" items can be counter-productive.

Once the information on climate and building type has been assembled, a basis for rational design decisions can be developed. Climate and building type can be thought of as two energy forces pushing and pulling the occupant from one side to the other of the comfort zone. Only the building skin and mechanical system can modify the forces to maintain a feeling of comfort. The design of an energy conserving building can be done intuitively, roughly with manual calculation methods, or with varying degrees of computer sophistication. The important concept to understand is to attempt to eliminate the need for expensive mechanical HVAC equipment. The two important tools which have been discussed in this chapter are mass and insulation. By delaying or resisting the energy flow through the building, the climate and the building type should complement each other in such a way as to minimize the mechanical energy requirement. (4) The ideal building skin has the ability to admit heat from the outside when heating is required and retain heat that is internally generated. When the inside of a dwelling requires cooling, the ideal building skin can let heat generated in the interior out and deflect the heat of the outdoors.

An example of this design approach is shown in Figures (5-9). The method of analysis in this case was a small desktop programmable calculator using accepted analytical techniques. The building type is a small residence designed for a family of four very similar to the Minimum Energy Dwelling. The original design assumed a square floor plan built in a conventional but well insulated manner. The climate is the other important consideration. The home is built in Southern California at Mission Viejo. Since the home will most often be in an air conditioning mode, it was decided to study the home during a typical cooling season month.

(5) Standard Well Insulated Home

Figure (5) shows the energy consumption during each hour of a sunny July day. As can be seen, the home is in a heating mode for only a brief period of time in the morning. The amount of cooling required reaches a peak late in the afternoon when it is still hot and sunny outside and the family is home preparing for dinner. The dotted line through the middle of the curve represents the average hourly consumption of energy if the total daily requirement were divided by the number of hours in a day.

As mentioned earlier, the design concept should be to eliminate the need for mechanical HVAC equipment. The first step has been taken by insulating the home well, but as can be seen, the energy requirement throughout the day varies greatly. The use of various other design techniques, such as mass, can be used to try to level out the energy curve. At the same time, the daily requirement should ideally approach zero.

Figure (5) assumed a time lag in all the wall constructions of one hour. In Figure (6), the time lag of the west wall is four hours and the roof, nine hours. On analyzing the peak hour in the first graph, it was determined that the west wall and roof were contributing a large portion to the cooling load. By adding the additional time lag, we can delay the heat effect so it occurs during the night. The effect of the design changes is evident by the reduction of the peak hour energy requirements. Also the average has been lowered slightly.

The energy curve has been damped, but was analyzed again to see if any further improvements can be made. Along with other design changes, the time lag on the north, south and west walls was increased 11 hours. Figure (7) shows the change in the use of energy throughout the day. The hourly load approaches a constant value.

(6) Modified Home

(7) Heavy Building Construction

Figure (8) was an attempt to shift the cooling load to an early time of the day. This was accomplished through the use of an 18-hour time lag on the east wall and a 15-hour time lag on the roof. The energy usage per hour now closely approaches a constant, although cooling is still required throughout the day.

Figure (9) shows the change by increasing the cooling thermostat setting to 80°F., the upper limit of the comfort zone rather than the original 72.5°F. The magnitude of heat and cooling required varies little from zero. If the climate control center is set with a normal comfort zone setting on the thermostat of 70°F. to 78°F, the thermal requirement of the home would probably be nil.

This study illustrates one possible technique for design. The example carried to the extreme, as far as possible design changes, shows how the changing of the design variables can have a positive effect on the diurnal cycle and energy consumption. In this particular case, the peak load was lowered from 15 thousand BTU to a little under 2 thousand, a reduction of 86%. This example was only for a typical day in July but shows the validity of the concept.

The resistance and absorption characteristics change depending on the type and placement of various building materials of the building construction. The calculation of the thermal conductivity was discussed in detail in the "Insulation" Chapter. The determination of time lag is a little more complicated.

Consider two materials, 2" of rigid insulation and 8" of concrete block. Separately, (10) the insulation has a thermal conductivity or "U" value of .18 and a time lag of .75 hours. (11) The concrete block has a "U" value of 5 BTU/In(Sq.Ft.)(°F.) and a time lag of four hours.

(8) Windowless Building Construction

(9) Higher Indoor Temperature

The challenge begins when the two materials are combined. (12) First, consider putting the insulation on the inside of the dwelling and the concrete to 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 8 hours.

The placement of insulation can have a great effect on the time lag of the composite wall. (13) If, for instance, the insulation is placed in the middle with a 4" concrete block on both sides, the time lag becomes 10 hours. (14) But if the insulation is placed on the outside, the time lag becomes 13 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, the heat flow into and out is of an equal magnitude. But within a wall with an exterior insulation layer, the properties of heat flow become more selective. 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. The increase of time lag due to changing the insulation placement is five hours. The "U" value of the wall remains the same at .15.

The method developed for the calculation of time lag was developed during and shortly after World War II by Mackey and Wright of Cornell University.³ The need to consider time lag did not occur until the beginning of the widespread use of air conditioning. But with the use of traditional methods, the cooling load was consistently over-estimated. The reason for the discrepancy was determined to be due to the absorption of heat by the

(10) Insulation

(11) Mass

(12) Insulation On The Inside

³Mackey, C. O. and Wright, L. T., "Periodic Heat Flow-Homogeneous Walls or Roofs," Heating, Piping and Air Conditioning, September 1944.

(13) Insulation In The Middle

(14) Insulation On The Outside

building mass. Since the introduction of the time lag method, other methods have been developed. Although the time lag method isn't truly accurate, it is the most useful for the designer. The time lag method allows the designer to compare various wall constructions and the effect on time lag, a concept easily understood.

The thermal response method is similar to the time lag method, but is more burdensome to use by hand. It is, however, more accurate and is used extensively in large scale computer calculated heat gain and heat loss calculations. The thermal response method does not give an easy indication of the time lag of the material which can be of importance for the designer. The need to understand or calculate thermal response factors is not necessary for most designers, but the reader should be aware of their existence. A comparison of the values computed by the two methods maybe necessary, and the reader should be aware of the differences. The difference in the predicted energy consumption between the two methods of time lag and thermal response factors is less than 5%.

In order to predict the performance of a wall, Mackey and Wright determined the need for three important pieces of information:

Concept	Methodology
• energy resistance	"U" Value
• energy capacity	Time Lag
• energy diffusion	Decrement Factor

To help explain the concepts, imagine the temperature cycle of an exterior wall through a day. (15a) During the day, the wall is heated up by the sun and cools at night cycling around an average daily wall temperature. If the energy resistance, energy capacity and energy diffusion had no effect, the temperature cycle of the inside wall surface would be identical to the exterior.

(15b) Assume first only the addition of energy resistance or "U" value. The temperature cycle of the inside wall surface would respond with reduced amplitude. The change of amplitude is directly related to "U" value. The lower the "U" value, the less the amplitude. No change has occurred to the time interval of the cycle.

(15c) Considering time lag alone shifts the temperature cycle of the indoor wall by a calculated number of hours but with no change in the amplitude of the cycle. The greater the time lag, the greater shift in time.

(15d) Energy diffusion or decrement factor can be explained as a change of amplitude directly related to time lag. During the day, the wall has an average temperature which is cooler than the exterior surface and, therefore, absorbs thermal energy. At night because the wall temperature is warmer than the outdoor air temperature, some of the heat is re-radiated to the exterior and never affects the indoor wall temperature. The decrement factor then changes the amplitude.

(15e) A composite of all three concepts relates time lag to a shift of the cycle and decrement factor and "U" value as a subtractive change in amplitude.

To explain the calculation of time lag, assume a simple homogeneous wall construction such as a regular weight 8" concrete block. Determine the energy resistance and energy capacity values given earlier in the chapter. The values are .139 (Hr) (Sq.Ft.) ($^{\circ}\text{F.}$) (BTU/In) and 1.833 BTU/(144 In³) ($^{\circ}\text{F.}$) respectively. Multiplying these values by the thickness of the wall modifies wall characteristics for a given thickness of the wall. In this case, (.139) (8) = 1.112 (BTU/In) (Hr) (Sq.Ft.) ($^{\circ}\text{F.}$) and (1.833) (8) = 14.664 (BTU/144) (In³) ($^{\circ}\text{F.}$).

(15) Graphic Representation Of "U" Value, Time Lag, And Decrement Factor

(16) Time Lag

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Concrete Block Characteristics

	Symbol	Material
Energy Resistance/Inch		.14
Energy Capacity/Inch		1.83
Thickness In Inches		8.00
Energy Resistance For Given Thickness	R	1.10
Energy Capacity For Given Thickness	C	14.70

The "U" value of the wall is the reciprocal of the resistance (R) or

$$1/1.112 = .899.$$

The time lag can be determined with the use of the first of the following charts. (16) The chart is constructed with "U" value or thermal conductance as the ordinate or horizontal axis and Time Lag as the abscissa or the vertical axis. The sloping lines across the graph are values of Energy Capacity. Reading the Energy Capacity line of 14.7 and intersection with a "U" value of .899, a Time Lag of five hours can be read in a similar manner on Figure (17). A value of .19 can be read on the vertical axis. A summary of the results are as follows:

(17) Decrement Factor

Characteristics of Wall

"U" Value	.899 BTU/(In) (Ft ²) (°F.) (Hr)
Time Lag	5 Hours
Decrement Factor	.19

The value of the technique is in the easy calculation of time lag of different building materials, allowing for easy comparison of their relative performance.

The characteristics of a composite wall are harder to determine. Mackay and Wright developed a method to convert the characteristics of the different components of a composite wall into an equivalent homogeneous wall. The calculated values can then be used on the previously explained charts. As an example, assume an 8" concrete block with 2" of rigid insulation on the inside.

Insulated Concrete Block Wall Characteristics

		Outside Conc. Block	Inside Rigid Insul.
Energy Resistance/ Inch		.14	2.778
Energy Capacity/ Inch		1.83	.347
Thickness In Inches		8.00	2.000
Energy Resistance For Given Thickness	R	1.12	5.556
Energy Capacity For Given Thickness	C	14.70	.694
Energy Capacity/ Energy Resistance	A	13.19	.125

The resistance of the composite wall is the addition of the resistance of the individual components.

Energy resistance of the composite wall:

$$R_c = 1.12 + 5.556 = 6.676$$

The calculation of an equivalent energy capacity for a composite wall required the following formula developed by Mackey and Wright using the given information.

Energy capacity of the composite wall, where:

C_o = Energy capacity of the exterior layer

A_o = The ratio of the energy capacity to the energy resistance of the exterior layer

R_o = Energy resistance of the exterior layer

R_i = Energy resistance of the interior layer

R_c = Energy resistance of the composite wall

$$\begin{aligned} C_c &= \frac{1.1 (C_o) + A_o (R_o - .1 (R_i))}{R_c} \\ &= \frac{1.1 (14.7) + 13.19(1.12 - .1(5.556))}{6.676} \\ &= \frac{16.17 + 7.44}{6.676} = 3.54 \text{ BTU/}^\circ\text{F(Sq.Ft)} \end{aligned}$$

Using the value of 6.676 for the resistance or a "U" value of .15 for the composite wall and 3.54 for the Energy Capacity of the composite wall, the following characteristics can be determined.

Insulated Concrete Block
Wall Characteristics

"U" Value	.15 BTU/In(Hr) (Sq.Ft) ($^\circ$ F.)
Time Lag	16 Hours
Decrement Factor	.008

One further example should be of use. Assume a wall construction from outside to inside of the following material: 4" concrete block, 4" rigid insulation, 8" concrete block, and 1" stucco.

Material Characteristics
Energy Resistance/Inch
Energy Capacity/Inch
Thickness in Inches
Energy Res. for Given Thickness
Energy Cap. for Given Thickness
Energy Capacity/Energy Resistance

Wall Component Characteristics

Symbol	Out- side	M ₁	M ₂	Inside
	Conc. Block	Rigid Insul.	Conc. Block	Stucco
	.179	2.778	.139	.20
	1.833	.347	1.833	2.71
	4.000	4.000	8.000	1.00
R	.716	11.110	1.110	.20
C	7.332	1.388	14.664	2.71
A	10.240	.125	13.200	13.55

Energy resistance of a composite wall:

$$R_c = R_o + R_{m1} + R_{m2} + \dots + R_i$$

$$= .716 + 11.11 + 1.11 + .2 = 13.136$$

The equation for energy capacity for a composite wall given in the previous example can be modified for any number of layers.

Energy capacity of a composite wall:

$$C_c = \frac{1.1(C_o + C_{m1} + C_{m2} + \dots + C_i - 1)}{R_c}$$

$$+ \frac{A_o(R_o - .1(R_{m1} + R_{m2} + \dots + R_i))}{R_c}$$

$$= \frac{1.1(7.332 + 1.388 + 14.664)}{13.136}$$

$$+ \frac{10.24 (.716 - .1(11.11 + 1.11 + .2))}{13.136}$$

$$+ \frac{25.72 + (-5.39)}{13.136}$$

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

$$C_c = \frac{25.72 + 0}{13.136} = 1.96 \text{ BTU/}^\circ\text{F. (Sq.Ft)}$$

Again, using the composite value for the energy resistance and energy capacity of the composite wall.

Component Wall Characteristics

"U" Value	.076
Time Lag	23 Hours
Decrement Factor	.001

With the ability to calculate time lag comes the ability to compare the time lag of different wall constructions. This can be of importance to a designer having decided on an optimum time lag during preliminary design and the optimization of the most economical wall section. By the variation of building materials, a given time lag can be incorporated within the building structure at the least cost.

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 diurnal cycling of the outside air temperature. The dwelling remains at a constant ground temperature throughout the day. In practical terms, the ultimate is difficult 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 that providing a time lag of less than 24 hours. It takes relatively small amounts of heavy materials in conjunction with an external insulation to obtain a reasonable time lag. Assuming a typical home, the time lag should vary depending on the orientation of the walls. The motion of the sun on different orientations and the timing of the energy impact is of importance in determining the impact on the mechanical air conditioning load and, hence, the appropriate time lag.

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 asleep; outside 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

(18) Suggested Time Lags For Orientations

	N	NE	E	SE	S	SW	W	NW
BEDROOMS	●	●	●	●	●	●		
LIVING				●	●	●	●	
DINING			●	●	●	●	●	
KITCHEN			●	●	●	●		
LIBRARY	●	●						●
LAUNDRY	●	●						●
PLAY				●	●	●	●	
DRYING YD				●	●	●	●	
BATHROOMS	●	●	●	●	●	●	●	●
UTILITY	●	●						●
GARAGE	●	●	●	●	●	●	●	●
WORKSHOP	●	●						●
TERRACES			●	●	●	●	●	
SUN PORCH			●	●	●	●		

(19) Suggested Sun Orientations For Rooms

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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 cooling season, 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.

(18) The recommended 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 the home while the home is still relatively cool. To have a time lag greater than 18 hours could be useful but would probably prove to be uneconomical. 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 cooling load impact into the late evening hours. The system may be able to use cool evening air in an economizer mode at this time, thus avoiding the need to remove the afternoon's heat by mechanical cooling.

Recommendations for other orientations are shown in Figure (19). Along with time lag, the home can have its rooms oriented in a manner described in the accompanying matrix. Although hard to predict and quantify in saving energy, the matching of time lag and room orientations should be considered. The psychological importance of the sun pouring in a window while eating breakfast should not be overlooked. It can have an impact on where the thermostat is set in the room.

During recent years, more attention has been placed on techniques by which a home is designed to respond to the climate. The term passive is used to describe these techniques. Much of what has been discussed in this chapter would be characterized as using

passive techniques. Some recent designs have taken advantage of these simple concepts of mass and insulation and adapted them by innovation.

Imagine the inside temperature cycle for a wall with no time lag. It rises steadily throughout the day and back down at night. (20a) If a heavy masonry material is assumed, the temperature cycle is shifted in time and occurs later. (20b) The addition of insulation to the masonry will add to the time lag and change the amplitude of the temperature cycle. Although the amplitude and the time of occurrence change, they continue to average around the same point. If the average temperature is 45°F., then continual heating may be required.

Designers in colder climates have tried to move the average temperature up by the use of various interesting techniques. (20c) The first involves placing glass in front of the mass with an air space in between. The advantage of this method is that most of the solar energy can pass through the glass and be absorbed by the massive wall, therefore, the amplitude of the warm part of the cycle remains as if there were no glass. The cool side of the cycle reacts as if there is insulation on the outside and has a reduced amplitude. The net effect of the glazing is to raise the average daily temperature of the wall. The problem with this particular technique is that the air between the glass is not the best insulation, providing only the equivalent of 3/4" of air for insulation no matter how deep the air space is past 3/4".

An improved solution would incorporate the same principle only with increased insulation. (20d) One possibility involves movable insulation. Remove it during the day and replace it at night. The effect upon the cycle is the same except the cooler part of the cycle is further reduced in amplitude and the average wall temperature is further increased. In addition to being able to increase the average

(20) Comparison Of Different Passive Techniques

"The designer must consider each face of the building separately because each experiences different climatic conditions."

Energy Conservation in Building Design

wall temperature, movable insulation can be used to lower the average wall temperature at times during the year that a building required cooling. This can be done by placing the insulation over the mass during the day and removing it at night. In this manner, the warm daytime cycle amplitude can be reduced with little change in the nighttime amplitude.

In both of the last three systems, the time lag characteristics should be calculated only for the part of the wall which is inside of the glazing or inside of the movable insulation.

Steve Baer, an innovative environmental designer, has a simple way of explaining the concept of movable insulation. Imagine a styrofoam ice chest filled with water. During the day, take the lid off and let the sunshine in. The sun will warm the temperature of the water and the insulation lid can be replaced at night to retard the heat from getting out. The opposite can be done if a temperature lower than average is desired.

One of the best uses of mass is in combination with cool outside nighttime air during the cooling season. The possibilities have just begun to be explored. The cost of operating cooling equipment is expensive, especially when compared to the cost of bringing in cool outside air as an alternative.

In the past a balance point between heating and cooling has been assumed to be approximately 65°F. outside air temperature for homes. With better insulated and weatherstripped homes, cooling may now be required for a home until the outside temperature is 55°F. or lower. The heat buildup from internal energy sources cannot get out. During the cooling season, a home can require cooling, but because the maximum cooling occurs at the same approximate time as the maximum outdoor temperature, there is little probability of using outside air and air conditioning must be supplied.

With mass in the building, the heat can be delayed before entering the interior of the building until late at night when the outside temperature is lower. The cool night air can be drawn into home for natural cooling. The same cycle can be used again the following day.

There are a variety of methods to bring in the cool nighttime air. The simplest method involves just opening the windows, but can be rather unpredictable in its performance. Several commercial companies have begun marketing what is called an economizer unit. This method involves the use of mechanical equipment to bring in outside air. It is controlled by sensors which can determine the indoor and outdoor temperatures and the relative humidity. If the dwelling requires cooling and the outdoor air is at the proper temperature, the blower is turned on. The system also determines the amount of air required and will not operate if the air is too humid. An in-depth explanation of the economizer cycle is included in the "Mechanical System" Chapter. Another approach to the introduction of outside air is by a disciplined design solution of the orientation of ventilation openings. By understanding the movement and intensity of the winds, the effect of natural ventilation can be predicted. Further, natural air currents can be created within a house by heating a high heat absorbing wall with solar energy and creating a chimney effect. (21) The chimney effect can be used to draw hot air out and replace it with cool outside air.

In the design of the Minimum Energy Dwelling, all of the topics discussed and information presented thus far were used in the early schematic phases. The problem of trying to construct a building with heavy and massive construction is cost. The particular building type which had to be addressed in this project was the lowest cost end of the housing market.

(21) The Solar Chimney

Methods of adding mass to a house at a low cost have not been adequately studied. Most buildings are presently designed to reduce the amount of mass incorporated within a structure. Increased mass usually implies an increase in the amount of structuring required to support it, thus increasing cost. This is especially important in the addition of mass in the roof. The roof is the important area to maintain a high time lag. The high intensity of the sun throughout the day beating down on an unshaded roof is twice the amount striking any other wall surface. Since the roof is often the largest building surface, it adds considerably to the cooling load. The structural penalty for mass on the roof is also considerable.

The incorporation of mass in the final design of the Minimum Energy Dwelling is minimal. No cost effective means of incorporating mass was discovered that is of the same cost or lower than the conventional wood frame construction. Possibly the greatest deterrent to its incorporation was the existing Cordova model home line. The Minimum Energy Dwelling is a modification of the Cordova home, and as such, remains steeped in a traditional design philosophy. Any drastic change in the construction to include significant mass would have required change in traditional methods of construction or a deviation from the Cordova standard.

Mass and its incorporation in the construction of low-cost homes must, therefore, be approached at the beginning of design of a new model line and not after the plan and its construction have been fixed. At such a time, cost effective means of adding mass to the building can be investigated.

One of the earliest proposals to add mass to the Minimum Energy Dwelling was the use of an earth berm around the base of the house. The building in principle would be half underground. The additional mass would add considerably to the thermal inertia of

the building. The effect of berming is minimal in this particular case because of the location of floor-height openings required by the present plan. The plan restricts the amount of continuous berm that can be added. A future design of the floor plan could more easily accommodate the berm concept. Asthetically, one positive attribute would be a larger, more horizontal profile. The berming shortens the distance between the roof and the ground, accenting the horizontal expression of the house. The construction of a bermed wall could be accomplished with ease by using the all-weather wood foundation system. The wood foundation is a pressure-treated plywood sheathed stud wall located below grade. It can be built using conventional framing techniques eliminating the need for a more conventional concrete or concrete block foundation system. A foundation built of wood rather than concrete has the additional advantage of being a warmer more pleasant space due to the low rate of thermal conductivity. The walls can be insulated in a standard manner eliminating the more expensive foundation insulation systems. If an entire development was based on the wood foundation system, saving in construction and energy appear possible.

A second alternative considered as a possible energy conserving wall construction was styrofoam building insulation block (Foam Form). As earlier discussed, the best position for insulation is on the exterior of a massive construction. In that position, the time lag is the greatest. Almost all of the present building techniques do not employ that concept. Usually the insulation, being a more delicate material, is placed on the interior where it is offered some protection. (22) Foam form, on the other hand, is an expanded polystyrene in the form of modular core units. The units look very similar to concrete block and are stacked in a similar manner. The method of building is similar to concrete block and

(22) Foam Form

(23) Exterior Insulation System

when stacked, the cores are tied with steel reinforcing rods and filled with concrete.

The construction offers the best relationship for time lag and insulation with mass wrapped with insulation. As a wall, foam form is an in-place form for concrete providing a load bearing wall which is lightweight to handle and costs less than form work alone, eliminating preparatory site work, cleanup, storage and completion time. The "U" value is an excellent .0425 to .0607 depending on thickness and finishes. Foam form is still a relatively new product and not commonly available. Consideration should be given for its use if a large volume could be generated to solve problems inherent in using a new construction technique.

Another possibility for adding mass to the wall involves the use of an exterior wall insulation system. This system can be added to either conventional frame or masonry construction. (23) Exterior insulation is applied with a four-layer process which is a complete exterior wall and finish system:

- Insulation Board--An expanded polystyrene varying in thickness according to needs;
- Reinforcing Fabric--Treated fiberglass is next added and is affixed to the insulation board using,
- Adhesive--Used to adhere fiberglass, it can also be used to adhere the insulation to the backup wall.
- Exterior Finish--The finish similar in texture to Stucco is trowel applied giving a finished surface. The finish provides a high bond strength, permanent color and a jointless weatherproof exterior surface.

The incorporation of the exterior insulation system with masonry construction provides the excellent

combination of exterior insulation and a heavy masonry material. In the Minimum Energy Dwelling, as in most residential construction, the standard building technique is wood frame construction.

Methods were investigated to incorporate the exterior insulation system with a cheap, high density construction material such as water or sand. The method involved the construction of a typical framing plan and applying insulation to the exterior. The core space between stud spaces could be filled with sand or water in a heavy duty watertight bag. The use of water offers a number of advantages as a building material.

- On a volume basis, water offers the greatest energy capacity of any other material and compared to stone, water can absorb three times the amount of energy.
- The cost of water is also very favorable, less than \$2.00 for a hundred cubic feet. Considering that the standard home weighs in the neighborhood of 50,000 lbs., an entire home could be build for \$160.00 if it could be based on the material cost of water.

The problem with using water is containment. Leaks must be prevented to eliminate possible damage to the building structure. One possible solution is the use of a technology similar to the construction of a water bed. The walls could be built in the usual manner with additional bracing to accommodate the hydrostatic head of the water and an inlet provided to a water bag. The bags could then be filled using the wall construction for support. Antifreeze may have to be added in freezing climates.

Inexpensive methods for adding the right combination of exterior insulation and mass appear attainable in wall construction, but the greatest cooling load stress is often the roof.

(24) Built-Up Gravel Roof On Sloped Wood Roof

It is here that most problems of adding mass are encountered.

One possible solution of adding mass cheaply is a modified builtup roof. (24) After a roof has been raftered and sheathed, a waterproofing membrane such as roll roofing is applied. Three to four inches of pea gravel are then distributed over the roof. On top of the pea gravel, two inches of rigid insulation are laid and covered with a one-inch layer of stone providing weight and protecting the insulation from deterioration. The insulation is placed in the proper relationship of being to the exterior and the mass to the interior permitting the maximum time lag with the least amount of mass. This relationship allows a minimum of additional structural support.

The method described works best in cathedral ceilingss where no attic space exists. In a vented attic, the use of mass using this particular design will not work effectively because the ventilation of the back-side of the mass prevents it from affecting the roomside temperature. A ceiling with an attic above, therefore, should incorpoate mass above the ceiling in the area of the joists below the ventilation path. A house incorporating both a vented attic and insulated ceiling should get the best possible cooling load performance.

A future possibility in building may involve the use of heat of fusion storage materials. The heat of fusion is the amount of energy required to change the state of a material. An example is the changing of water to ice. The amount of energy necessary to change the state of a material is considerably greater than the energy required to increase its temperature. The amount of energy required to heat a gallon of water one degree is approximately 8 BTUs. But if water is frozen at 32°F., it required 143 BTUs to raise it one degree or 18 times the amount of energy. Essentially, mass is a heat storage material and the

heat-of-fusion concept allows the use of much smaller amounts of material to store an equivalent amount of energy in the conventional manner.

A recent development uses a heat-of-fusion material which has a melting point of 74°F. The concept is a solar tile. The heat-of-fusion material consists of a 2' x 8' panel, 1/2" thick subdivided into 1/4" segments by a fiberglass membrane. Two panels are then wrapped in a polyester concrete to produce a 4' x 8' building panel. The total building material is less than 2" thick, but it has a tremendous heat capacity potential in the order of a 10" masonry wall. Present development is progressing, but commercial application is still years away.

The Minimum Energy Dwelling, while not having a large amount of mass incorporated in the structure, still maintains respectable time lag in the wall and roof constructions.

The walls are built with 2" x 6" wood studs spaced 2'-0" on center and finished on the exterior with a vapor barrier and 1/2" sprayed Stucco. The interior wall consists of 5/8" drywall and is finished with paint. The wall cavity contains a 6" batt of fiberglass insulation. When the fiberglass batt is compressed into a 5-1/2" space, the R-19 batt has a reduced resistance of 18. The wall has a "U" value of the composite materials of .052 and a time lag of 6 hours.

The "U" value and time lag for all wall orientations for the MED home are the same. As mentioned earlier in the chapter, changing the time lag for the different orientations is preferable but was not considered for the Minimum Energy Dwelling due to its incorporation into a tract development. If the MED home was built as a production home, it would be placed in an infinite amount of orientations, each requiring an optimization of amounts of insulation and mass. To simplify the concept, an equal amount of insu-

lation and mass was placed on all sides of the home.

The ceiling and roof of the MED home has two different configurations-- vaulted and unvaulted (ceiling with attic above). The vaulted roof consists of a $3/4$ " clay tile over $1/2$ " of plywood sheathing. Underneath the sheathing is $8-1/2$ " of fiberglass having a resistance of 26. The interior is finished with $5/8$ " drywall. The combination of materials gives a "U" value of .035 and a time lag of 13 hours. The ideal time lag, as shown earlier in the chapter (18), is 12 hours. The needed time lag was obtained with the use of very little mass and is primarily due to the amount of insulation in the house. An equal time lag can be obtained by having a large quantity of mass and little insulation or as in this case, a large amount of insulation and little in the way of mass. The actual amount of each is not as important as the relationship to each other.

The tile roof has an effect on the time lag in the vaulted ceiling areas of the house. Replacing the tile roof with an asphalt shingle roof would decrease the time lag by 3.5 hours to 9.5 hours. The reduction in time lag is due to the decreased density and thickness of the asphalt tile roof. The mass in the form of the tile roof is not positioned to obtain maximum benefit. However, the ideal placement would be to install the insulation on the exterior with the mass on the interior. This, however, was not possible in standard residential construction used in MED and the tile roof was felt to be the best compromise.

In the unvaulted roof areas, the tile roof has no effect upon the time lag. The unvaulted roof areas have a vented attic separating the tile roof from the conditioned space. The natural ventilation created by the ridge and soffit vents prevents any noticeable change in the time lag. Therefore, the time lag is calculated only from the

materials of the attic floor down to the conditioned space. The ceiling below the attic contains an R-26 fiberglass batt 8-1/2" and is finished on the interior with 5/8" drywall. The finished insulation and drywall configuration has a "U" value of .037 and a time lag of 11 hours. Although less than the 13 hours was obtained in the unvented (vaulted roof) areas, the time lag is still quite adequate.

Just as ventilation in the attic reduced the time lag, care must be taken to assure that the MED home has a reduced infiltration rate. Infiltration or ventilation can negate the effectiveness of any calculated time lag values. The moving air transfers heat from the building surfaces, which when carried from the conditioned spaces, takes away some of the stored energy in the building materials. If the amount of air movement out of the house becomes excessive, the time lag can be reduced to zero. The Minimum Energy Dwelling, as designed, has an infiltration rate one-third the normal construction in Southern California and, therefore, is not felt to be a problem.

Some of the most exciting developments will occur in the walls by the methods that mass and insulation are combined in the building industry. Most of the future developed ideas will be based on concepts in this chapter.

■

SUN & WINDOWS

A high quality double insulating glass was used in the Minimum Energy Dwelling. The window included an integral venetian-type blind which fits between the two panes of glass. The blind is easily adjustable from the interior living space. To the side of the windows is a vertical shading device, protecting the window from the sun during the day. Windows and the method of controlling the sun are of critical importance in the arid Southwest.

When calculating the thermal behavior of a building's enclosure system, the window components are considered separately from the regular wall construction. Because windows behave as "holes" in the wall, rapidly leaking or transmitting many more times the amount of heat than the adjacent opaque wall surrounding it, their relative influence over the entire thermal comfort problem is far reaching and requires a greater amount of concern in controlling its effect. One might immediately suggest the elimination of all glass areas to save energy; but 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 affect the well being of the people

occupying the building. A good designer may include glass areas and still save energy without having to resort to such extremes and show that at certain times and places the window areas can actually be used to positively supplement heating or cooling, rather than always being assumed to have a negative effect.

Glass

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 BTUH and will conduct heat at a rate 13-1/2 times that of a surrounding conventional wall of "U" value (.08). Even though double-pane insulating glass, rated at .56 BTUH, will reduce heat flow considerably, the rate is still seven times as great.

Regardless of its comparatively poor resistance to heat flow, its ability to instantaneously 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. (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 small. At incidence angles beyond 60° , the reflected component increases greatly and the transmitted portion that influences the thermal conditions of the interior space.

The characterizing property of glass that allows it to transmit 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 magnitude of 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

(1) Window Transmission

(2) Heat Transmission Of A Wood Constructed Wall

(3) Heat Transmission Of A Glass Plane

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, for shading with its logical benefits is readily apparent. 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 this passive technique of energy conservation. Given enough information about the movement of the sun, periods of overheating, and the ways to secure shade, 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 positions 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.

One method for charting the overheated period is to secure accurate weather data and plot all the times during the year when the ambient air temperature rises above the comfortable levels. This method uses outside air temperature and pertains to no specific building. The true overheated period is the time when a cooling load exists

in a building and may be independent of the ambient air temperature, which may be below the comfort range during a period when cooling is required. The action of internal heat sources or radiation through the windows are responsible for this condition. The difficulty in calculating the true overheated period during a design process is that certain essential facts about a building such as the glass areas, the number of people, and types of equipment that generate heat must be known. Unfortunately, it is the early stages in the design process when these facts are needed to make quality decisions concerning energy consumption. At this point, the building's design may be highly schematic.

This problem can be solved either intuitively or with more refined computer techniques. The more detailed the technique, the more accurate the results. The overheated period for the MED house was calculated using a small desk-top micro-computer. The results are shown in Figure (4) which illustrates that a cooling load is generated in the building for nearly every hour of sunshine during the year. To reduce the magnitude of this load, an attempt must be made to shield the windows from the sun at nearly all times.

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 characteristic 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 will still be valid for application in more balanced heating and cooling areas.

After the times of overheating have been determined, they must be cor-

(4) Hours Of Sunshine Vs. Period Of Cooling
Mission Viejo - No Shading

SOURCE: Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (copyright (c) 1963 by Princeton University Press) Reprinted by permission of Princeton University Press.

related 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. The two coordinates for the sun are its altitude and its azimuth. (5) 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 or range across the sky vault and is called the sun's bearing. In the northern hemisphere, it is measured in degrees from true south.

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 Charts¹ and according to a particular 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 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 at different times during the year. This can

(5) Altitude and Azimuth

¹Sun Charts of the sun angle calculator are available from Libbey-Owens-Ford, Toledo, Ohio, for \$5.00. They also appear in Architectural Graphic Standards, John Wiley & Sons, Inc., New York.

32° SUN CHART (32° N. Lat.)

(6) The Sun Angle Calculator

SOURCE: Libbey-Owens-Ford Glass Company, Sun Angle Calculator, 1974.

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 in 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 uncomfortably heat it. 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 by its corresponding altitude and azimuth. These can be read with the help of a movable cursor. By aligning the cursor "A" with the intersection of lines "D" and "C", the sun's altitude of 48° can be read from the cursor and the azimuth of 70°E can be read from the scale labeled "B". The altitude and azimuth for other months and times can be read in a similar manner. Using the Sun-Angle calculator the shading device for a building can be determined.

Shading Devices

Shading devices can be separated into three categories:

- Fixed Devices, such 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. The final category is the
- Organic means available for shading--the various trees, shrubs, and vines that can be strategically planted to offer shade at the appropriate time.

Fixed Devices

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.² The in-

²Olgay, Victor, Design With Climate: Bioclimatic Approach to Architectural Regionalism, Princeton University Press, New Jersey, 1963.

32° SUN CHART (32° N. Lat.)

(7) Shading Requirement Based Upon Cooling Requirement

formation 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-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-dimensional object that would intersect those lines would be the properly shaped device.

Shading Masks

The three essential geometrical configurations for shading are a horizontal plane (overhang), a vertical

HORIZONTAL

DEVICES OBSTRUCTING AREAS
OF THE SKY VAULT

SEGMENTAL MASK

(8) Horizontal Shading Device

SOURCE: Victor Olgay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (copyright (c) 1963 by Princeton University Press) Reprinted by permission of Princeton University Press.

plan (thin), and their combination (egg crate). The technique that relates shape to overheated sun time transforms the basic geometrics from three dimensional projections to their respective two-dimensional shading masks.

(8) (9) (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.

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:

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

Using the formula for the overhang, the effective altitude can be calculated.

$$\begin{aligned} \text{effective altitude} &= \arctan \frac{(4 \text{ feet})}{(3 \text{ feet})} \\ &= \arctan (1.333) \\ &= 53^\circ \end{aligned}$$

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

VERTICAL

EGGCRATE

DEVICES OBSTRUCTING AREAS
OF THE SKY VAULT

OBSTRUCTION OF HORIZONTAL
DEVICES WILL SHOW A SEG-
MENTAL CHARACTER; THOSE
OF VERTICAL FINS WILL
HAVE A RADIAL PATTERN
AND EGGCRATE WILL HAVE
A COMBINATION OF THESE
FORMS.

RADIAL MASK

(9) Vertical Shading Device

COMPINATIVE MASK

(10) Egg Crate Shading Device

SOURCE: Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (copyright (c) 1963 by Princeton University Press) Reprinted by permission of Princeton University Press.

SOURCE: Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (copyright (c) 1963 by Princeton University Press) Reprinted by permission of Princeton University Press.

32° SUN CHART (32° N. Lat.)

(11) Shading Mask For Example Problem

$$\begin{aligned} \text{effective azimuth angle} &= \arctan \frac{(3 \text{ feet})}{(1.5 \text{ feet})} \\ &= \arctan (2.0) \\ &= 63^\circ \end{aligned}$$

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 perpen-

dicular to the tangent of the circle and are located by subtracting 63° from 90 and plotting the 27° line.

The previous illustration is for a south-facing window and can be shifted for any other orientation.

It must be remembered that the scale of the device is not important, but the ratio of its projection to the proper dimension of the wall is the factor determining its area of influence. This is expressed by the

angle which shows this ratio in a plane normal to the wall. For this reason, a vertically hung device with many small slats would have the same effectiveness of a large extended horizontal overhang.

The Effectiveness of Shading

Custom designing overhangs and louvers with the foregoing method for specific applications is a way to give proper dimensions to a device that will be able to block the sun's radiation. A method to actually determine the value of effectiveness of overhangs, marketed shading devices, interior curtains, venetian blinds, reflective glass, or vegetation has been developed and relates the amount of shading to the BTUH heat gain. This technique provides an index of percentage points called Shading Coefficients which are assigned to laboratory tested shading methods according to their effectiveness. This coefficient is the ratio of the total solar heat gain from transmitted, absorbed, and re-radiated heat through a single thickness pane of unshaded common window glass. Since none of the energy passing through the common window glass is affected by a shade, the single glass is assigned a value of 100%, or 1. Since any shading device would block a portion of this total, all shading devices have coefficients of less than 1. These ratios represent the percentage of radiation that is not intercepted by a device projecting from the wall. This particular coefficient can be multiplied by the absolute amount of energy for any hour that would otherwise pass through the window. This gives the actual amount admitted to the inside space. Since a device is assigned one coefficient for all conditions and, therefore, should be considered an approximation and used accordingly. A primary advantage of shading coefficient is their use in describing the film characteristics for various kinds of glass that are not shaded.

(12) Window Configuration With Vertical Shading Planes

(13) Window Configuration With Horizontal Shading Planes

(14) Window Configuration Using Exterior Louvers
(Fixed or Operable)

Type of Glass	Nominal Thickness Ea. Light	Solar Trans. ^b		Type of Shading				
		Outer Pane	Inner Pane	Venetian Blinds		Roller Shade		
				Medium	Light	Opaque	Translucent	Light
Regular Sheet Out	3/32, 1/8	0.87	0.87					
Regular Sheet In				0.57	0.51	0.60	0.25	0.37
Regular Plate Out	1/4	0.80	0.80					
Regular Plate In								
Heat-Absorbing Plate Out	1/4	0.46	0.80					
Regular Plate In								
Grey Plate Out	1/4	0.46	0.80					
Regular Plate In				0.39	0.36	0.40	0.72	0.30

^a Refers to factory-fabricated units with 3/16, 1/4 or 1/2 in. air space, or to prime windows plus storm windows

^b Refer to manufacturer's literature for exact values.

(15) Shading Coefficients

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

To determine the amount of energy from the sun coming through a window, the shading coefficient and the solar radiation for the given hour and orientation are required. Shown in Figure (16) is the solar position and intensity for 40°N Latitude on June 21st. Values are available from ASHRAE³ for different latitudes and months. As an example, calculate the amount of radiation through a south facing 4' x 5' insulating glass window at noon on June 21st. The window is made up of two panes of 1/8" DSB sheet glass. On the interior is a light colored venetian blind for shading. Using Figures (15) and (16), the amount of energy in BTUH/sq. ft. (Hr.) can be determined.

Heat Gain to Dwelling - Clear Sky

$$\begin{aligned}
 &= (\text{Area of window}) (\text{Shading Coefficient}) (\text{Solar Radiation}) \\
 &= (4')(5') (.51) (95 \text{ BTUH/Sq.Ft.}) \\
 &= 969 \text{ BTUH/Sq.Ft.}
 \end{aligned}$$

The values given by this technique are for clear sky conditions but can be modified for average conditions by obtaining average solar radiation values from the local weather bureau. Radiation values are available at more than 80 weather stations across the United States. The value obtained will be given in average solar radiation falling on a horizontal surface during a day. It is usually given in Langleys which can be converted to BTU/Sq.Ft. by multiplying by the constant 3.69. Values for El Toro, California are given in the "Comfort and Climate" chapter in Figure (28).

To convert the clear sky radiation values to average values, determine the daily total for clear sky conditions and multiply by 1.2. This constant is necessary because the values in the table (16) assume the reduction in

³ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1972, Chapter 22, p. 390.

radiation due to transmission through a single piece of glass. Divide the value obtained into the average value. The result is an average radiation multiplier which is used to modify the radiation values in Figure (16).

For example, Columbus, Ohio has an average of 2103 BTU/Sq.Ft./Day falling on a horizontal surface. The clear sky conditions can be obtained from Figure (16) by adding the hourly values for the horizontal surface over the day. The value obtained is 2245 BTU/Sq.Ft./Day. Therefore:

$$\text{Average radiation multiplier} = \frac{2103}{2245 (1.2)} = .78$$

Using the multiplier, the average radiation transmitted through the window can be determined.

Heat Gain To Dwelling - Average Sky

$$= 969 \text{ BTU/Sq.Ft. } (.78)$$

$$= 755 \text{ BTU/Sq.Ft.}$$

Manufacturers of windows and glass have developed shading coefficients for their particular products. To obtain accurate results, these values should be used.

In Figure (17) various shades are ranked against common glass according to their effectiveness. In addition to the conventional shading devices available such as overhangs, venetian blinds, and trees and bushes, a number of brand name items are included and placed in the list according to information supplied by the manufacturer. These laboratory-determined shading coefficients become a great aid to a designer who would specify, from an energy standpoint, one device or window type over another.

In addition to the specific information supplied in Figure (17), two principles can be established about the effectiveness of general classes of shading devices. Light color will

BTUH/SQ. FT.

Solar Time (A.M.)	5:00	6:00	7:00	8:00	9:00	10:00	11:00	Noon
Solar Position								
Altitude	4	15	26	37	49	60	69	74
Azimuth	117	108	100	91	80	66	42	0
Direct Normal Irradiation Btu/Sq.Ft.	21	154	215	246	262	272	276	278
North	10	47	37	29	33	35	37	38
Northeast	21	142	172	156	113	62	40	38
East	20	151	207	215	192	145	80	41
Southeast	6	70	122	152	161	148	116	71
South	1	12	21	29	45	69	88	95
Southwest	1	12	20	26	31	36	41	71
West	1	12	20	26	31	35	37	41
Northwest	1	12	20	26	31	35	37	38
Horizontal	2	39	97	153	201	237	260	267
Solar Time (P.M.)	1:00	2:00	3:00	4:00	5:00	6:00	7:00	
Solar Position								
Altitude	69	60	49	37	26	15	4	
Azimuth	42	66	80	91	100	108	117	
Direct Normal Irradiation Btu/Sq.Ft.	276	272	262	246	215	154	21	
North	37	35	33	29	37	47	10	
Northeast	37	35	31	26	20	12	1	
East	37	35	31	26	20	12	1	
Southeast	41	36	31	26	20	12	1	
South	88	69	45	29	21	12	1	
Southwest	116	148	161	152	122	70	6	
West	80	145	192	215	207	151	20	
Northwest	40	62	113	156	172	142	21	
Horizontal	260	237	201	153	97	39	2	

(16) Solar Position And Intensity
@ 40° North Latitude And At June 21

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

perform better than dark because of a higher index of reflectivity. Exterior devices can develop shading coefficients much lower than interior blinds because the sun's radiation is intercepted before it passes through the glass. Although an interior venetian blind or curtain will reflect a portion of radiation that has penetrated the glass, the heat of the shading device can be convected throughout the space to raise its temperature.

Unfortunately, the criteria for choosing the proper device extends beyond its shading coefficient to complicated decision making. Availability, cost, maintenance, flexibility and aesthetics are all factors that must be considered. Besides their shading function, some devices provide other benefits, such as privacy or noise reduction. A number of available forms of shading were investigated during the course of this project. A discussion of the characteristics of three exterior devices from the market follows along with a description of an interior shutter custom designed specifically for possible use in the MED house.

Koolshade Solar Screen

These exterior screens are manufactured by the Koolshade Corporation located at 722 Genevieve Street, Solana Beach, California 92075. (18) The Koolshade is a miniaturized 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 warp wire of special alloy. This method of assembly ties the materials together into a very stiff composition. Their standard color is black, and gives the appearance of a fine black screen stretched across the vertical expanse of glass. Koolshades, manufactured in widths up to 72-1/2" and unlimited lengths, come in two types--the Standard Koolshade for normal applications with 17 louvers per inch, and the Low Sun Angle Koolshade. This type con-

SHADING DEVICES
GOOD 8 1 POOR
TYPE	REGULAR GLASS	MEDIUM DARK TINTED	INSIDE BLIND	CURTAIN	OVERHANG
EASE OF MAINTENANCE
SHADING COEFFICIENT
INSTALLATION LOST
MATERIAL LOST
EASE OF INSTALLATION
AVAILABILITY

(17) Shading Device Comparison

TREE	INTERNAL BLIND	SHADING SCREEN	OUTSIDE BLIND	SWISS BLIND	INSULATING SHUTTERS

tains 23 louvers per inch and is recommended for low sun angle conditions. According to the manufacturer's information, the Standard Koolshade will shut 100% of the direct radiation when the sun is at a 30° altitude. At a zero altitude, 35° of the solar radiation is deflected by the solar screen. The Low Sun Angle Koolshade is more effective showing 100% deflection at 26° altitude angle, while horizontal radiation at 0° is 50% deflected. The Standard has shading coefficients ranging from .51 down to .18; the range of the Low Sun Angle is .35 to .15. Even though Koolshades deflect the sun's direct radiation, they still allow outside visibility for the occupants of the building.

The Koolshades claim other benefits beyond shading; they slightly improve the "U" value of a window and can provide noise reduction up to 52%. The manufacturer also claims that these shades offer stiff resistance to the violent assaults of vandals bent on smashing windows with rocks and bottles.

Swiss Blinds

Richard Goder Associates, Inc. distributes the Swiss Blind. The company's location is 7064 Lyndon, Rosemont, Illinois 60018. Swiss blinds are one of the most versatile of the shading devices on the market. They are manufactured in Europe and have been used there for a number of years. The essential feature of the Swiss Blinds is that they are adjustable. (19) These devices are rolling shutters which can be lowered to fully cover the window or be completely raised for full exposure. The Swiss Blinds also come in two types. The "Lamellen" looks like an oversized venetian blind, but is sturdier and mounted on the exterior of the window. The "Rolladen" is similar to commercial rolling vertical doors and is the more popular of the two types. Both types are operated from the inside of the building. When the "Rolladen" is

WINDOW CONFIGURATION
USING VERTICAL &
HORIZONTAL SHADING PLANES
WITH KOOLSHADE® SOLAR-SCREEN

(18) Koolshade Solar Screen

WINDOW CONFIGURATION USING
SHALLOW PERIFERAL SHADING
PLANES AND EXT.

(19) Swiss Blinds

drawn upward, it winds into a roll above the window. This roll can be contained in an exterior housing attached to the building or housed internally within the wall construction. In its extended position, the "Rolladen" can block the entire area of the window. The "Rolladen" can be adjusted to admit diffuse light by applying a slight tension on the blind. Small openings appear between the slats and allow light to enter the room. The "Lamellen" blind has greater adjustability but is not as substantial as the "Rolladen" blind. As mentioned, it looks and operates similarly to a venetian blind. It can be raised or lowered to any height, and its series of slats can be tilted at various angles or completely closed. When retracted for full window exposure, the array of slats gather into a housing that is attached to the exterior of the building. When fully drawn, both types provide total shading, but even when the slats of the "Lamellen" blind are set at 45° from horizontal, it still has excellent performance, attaining a shading coefficient of .15 in combination with insulating glass.

In ordinary circumstances, the Swiss Blinds are operated manually. If desired, their operation can be motorized. In certain large-scale installations, this mode of operation may be necessary in order to gain more complete protection from the sun instead of relying on people within the building to make the proper adjustments. The motors that operate the blinds can be activated locally or by a photocell that detects increased levels of radiation. Gang shutters can be operated by one small motor that draws them when the photocell delivers its signal.

In addition to their shading function, the Swiss Blinds have other advantages. The "Rolladen" blind can be locked in place to provide security, and both types offer complete privacy and considerable noise reduction. The substantial construction of the Swiss

Blinds also resists the impact of flying debris during severe storms. Manufacturer's samples of these blinds have been examined, and they appear to be made from quality materials with durable hardware that would extend their life. Because of this commitment to quality, their cost is understandably high. At even greater cost, another quality feature is available; the "Lamellen" blind can be specially ordered with wooden slats.

Pella Window With Slimshade

The Pella window, which was finally selected for use in the MED home, combines the function of window and shade. The Slimshade option offered by the Pella Window Company is affixed to the window between two panes of glass. (20) In this position, the delicate shade, which also has the appearance of a venetian blind, is protected from the outside weather or from accidental damage from within the building. The weatherstripped inner-pane of glass can be removed for access to the Slimshade for cleaning or repair. The adjustability of this window-shade combination is limited. The angle of the slats can rotate between horizontal and vertical, but the entire array cannot be raised or lowered.

According to laboratory tests, the shading coefficients that the Pella Window can offer are available. The Pella Slimshade is rated at four positions. When the slats are horizontal, the shading coefficient is .38, at 30° from horizontal the coefficient is .34, and at 60° from horizontal the rating is .27. With the slats fully closed, this shade develops a .18 coefficient. Its construction is of good quality. Polyester cord ladders support Slimshade's narrow aluminum slats. A built-in operating dial at the bottom corner of the sash adjusts slats from completely open to fully closed. Finish of the shade part is Oyster White or Dark Bronze Baked Enamel.

PELLA CLAD® WINDOW
W/INTEGRATED SLIMSHADE

(20) - Pella Window With Slimshade

(21) Interior Insulating Shutter

Interior Insulating Shutter

Figure (21) illustrates the construction and operation of a lightweight insulating shutter that was designed specifically for the MED Project. The device was not used because the expected benefit would not justify the increased cost in a mild climate such as coastal Southern California. The use of this shading and insulating device should be re-evaluated for other climates or uses. Besides cost advantage and insulation value, it is located inside the house and protected from the weather. 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 insulating pocketed panels to fold up into a neat stack. The continuous fabric acts as soft hinges between the panels. The mats used by gymnasts are designed in a similar way. The shutter develops a tight fit around a window or 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 fabric portion of the shutters consists of two pieces, preferably white on the window side to reflect the sun and patterned or colored on the room side to match the decor of the room. These two pieces have to be carefully sewn together to provide the "alternating hinge" necessary to allow the folding action.

The particular shutter illustrated protects a sliding glass door and is hung from the ceiling by cords and operated with the use of pulleys. At the ends of each panel unit, a bit of extra fabric is sewn together to provide a flap of material. In the center of the flap an oblong metal grommet is attached. This allows the cord to freely pass through this guiding hole to keep the panels

aligned during operation much like a venetian blind. It is essential that the grommet be centrally located in the flap to promote free and easy raising and lowering of the shutter.

Minimum Energy Dwelling

The physical starting point for the application of energy-saving techniques was the "Cordova" model, Plan No. 20 and its building site. This original plan was developed by Mission Viejo Company and was chosen from the beginning as the pattern to be modified and transformed into the MED house. The particular energy characteristics of the "Cordova" will serve as a "Base Line" for comparison to future modifications. As a standard model, Plan No. 20 offers 1109 square feet plus an attached garage. The house contains sliding glass doors and windows with single thickness panes. Six windows at 130 square feet, and one sliding glass door at 80 square feet total 210 square feet of glass area, with an option for substituting a glass door for a window that would increase the total glass area to 223 square feet. In the process of transforming the "Cordova" into the Minimum Energy Dwelling, Plan No. 20 became Mission Viejo Company's Modified Plan No. 20. The entrance was re-arranged and the garage lengthened along with other small modifications.

The relative thermal influence of the glass areas in a house of this size is quite large. The strategies, then, in redesigning the windows were to reduce the window area as much as possible, group the windows in pairs to economically use single overhangs and vertical fins, and select an economical window shutter or shade to insure complete protection if necessary. In addition to the concerns with these specific physical arrangements, the computer program developed during the project enabled an iterative man-machine design process to quickly test the implication of different variables. The thrust of this specific analysis was directed in three areas:

32° SUN CHART (32° N. Lat.)

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(22) Effect Of Shading In Reducing Cooling Requirements

- Determining the extreme condition that could theoretically exist; and absolute lack of a shading benefit.
- A positive ideal--determining the benefits of the best possible window-shade combinations.
- Moderate applications--determining benefits of shading that would be most likely to occur.

The analysis began with calculating three different periods of overheating

within the house that correspond to the actual glass areas of the MED with their respective shade treatments. These are shown on the Sun Chart in Figure (22). Without shading or, in other words, an external and window shading coefficient of 10., the extremely narrow period of sun time, when the house does not revert to a cooling load, is apparent. The effect of shading devices with a lower shading coefficient is seen by the delay in cooling need to the later morning hours.

The immense importance of shading in the MED house is even more visibly illustrated in Figures (23) and (24), where the two extreme possibilities are graphed as a three-dimensional projection. The entire period of a year is represented by months and hours on the ordinate and abscissa. This is charted against a vertical axis calibrating BTU or the absolute amount of energy in the heating or cooling loads. It is shown at different times of the day and extrapolated between months. These BTU amounts include all internal heat sources such as people, lighting and cooking.

The yearly cooling load is the mountain-like bulk that rises from the horizontal plane of the graph which marks hours and months. This plane divides the cooling above it from the heating load which projects below it. The craggy peaks on both "energy mountains" reflect the internal heat generated in the course of cooking during the day. These types of heat sources are unaffected by shading and are the same for both figures. The difference in their volume is due only to the shading. The value of these pictures is obvious. Figure (23) is the worst condition--no shading at all. Figures (25) and (26) illustrate the effect shading can have during a typical July 21st day. Figure (25) records the energy usage in an unshaded MED home. It divides it into the various components of usage and shows each component's relative importance by percentage. If an ideal shading condition (shading coefficient .15) is tested on the house, the results show a dramatic reduction in energy usage. The windows now constitute only 8% of the energy usage as opposed to 44% in the unshaded house. The total percentage that can be saved during the day is 42%. Figure (27) goes one step further to illustrate the relative importance of shading during each hour of the day. The dramatic reduction totaled in the two previous figures are here partitioned to show the greatest benefit of shading in the early morning hours.

(23) Annual Energy Use
Shading Coefficient = 1.0

(24) Annual Energy Use
Shading Coefficient = .15

(25) Daily Energy Usage
Shading Coefficient = 1.0

(26) Daily Energy Usage
Shading Coefficient = .15

* GRAPH ASSUMES 1.0, (NO SHADING) AS DENOMINATOR FOR REDUCTION RATIOS

(27) Effect Of Shading Coefficient On Hourly Energy Consumption July 21

The final Minimum Energy Dwelling design uses three types of shading to block the sun's radiation:

- Fixed overhangs and vertical fins
- A shading device at the window's surface
- Carefully placed vegetation

The windows were grouped in pairs and effectively surrounded by vertical fins and extended overhang. This arrangement also occurs with the windows on the north side of the house to give the dwelling a consistent design uni-

formity. The living room window near the entrance is shaded by the deep overhang of the porch. Pella windows with Slimshade supplant the original windows of the "Cordova" to fulfill its energy conserving promises. They were finally chosen over the other devices for their elegant multi-function as window and shading device. The Pella group also conserves glass. The MED home has more than 50% less window area than the standard "Cordova". No Slimshade exists for the two sliding glass doors in the back in the MED home. These will rely heavily on drapery, and shrubs grown on or near the patio cover to shade them from the morning sun.

INTERNAL LOADS

The washer and dryer can add unwanted heat to a home, especially in the Minimum Energy Dwelling. This occurs here because of the extensive insulation which can hold the heat in and make the interior uncomfortable for the family. In this case, the washer and dryer are placed in a small alcove having weatherstripped doors which can be closed when the washer and dryer are in operation. Air required for the dryer is brought in from the outside and exhausted back to the outside. Internal loads from all appliances, people, and lights need attention in order to obtain maximum efficiency out of the thermal characteristics of the home.

The thermal environment of an enclosed space depends on three criteria:

- The influence of the microclimate
- The amount of mechanical cooling
- The effect of the building skin on each

Previous chapters have dealt with the relation of climate and building skin components to the thermal response of a structure. The mechanical system for the MED Project will be discussed in a future chapter. The purpose of this chapter is to examine the sources of internally produced heat and the impact the resultant load has on a mechanical system's energy consumption.

An internal load is any heat produced by an individual or an item inside a building, excluding that supplied by design through the mechanical system. The degree to which internal loads will affect a building's energy consumption is dependent upon three factors. Climate and building composition, listed previously, are two. The third is the heating or cooling supplied by the mechanical system. In a heating mode, internally produced heat is a benefit. If cooling is necessary, internal heat sources become a detrimental component of the total cooling load.

Climate and building composition are closely related in how they affect the magnitude of internal loads. Of primary importance is the amount of solar radiation which strikes the building surfaces and penetrates the interior. Increased interior temperatures resulting from solar gain through windows, walls and roof surfaces usually dictate cooling.

Internal heat sources compound the cooling load, resulting in increased energy consumption. Once the building skin becomes saturated with heat, surface temperatures rise. Because heat will only flow from a warm surface

to a cool surface, no heat can escape the building through the skin once the surface temperatures rise above indoor air temperatures. (See the chapter on the discussion of "Mass") This extends the time period in which cooling is required by eliminating a route for dissipating internally generated heat.

During the winter or on overcast days, the sun's intensity is diminished. Internal loads then become a larger percentage of the cooling demand. When low radiation levels and accompanying cold exterior conditions result in the need for mechanical heating, internally generated heat becomes beneficial. In areas having mild diurnal temperatures, and temperature cycles devoid of high and low extremes, infiltration and natural ventilation should be encouraged to dissipate heat produced by internal sources.

Removing heat by passive means reduces the need for energy-intensive ventilating machinery. Moderate conditions also suggest that closing building penetrations and retaining heat generated by internal sources may be sufficient to satisfy or minimize a consistently small heating demand.

As climatically induced thermal stresses become minimal, the lifestyle, habits and daily routines of the occupants become more important as they relate to internal heat production. Increased use of appliances, stereo components and televisions contribute to internal heat loads. Homes with un-insulated ductwork, domestic hot water heaters, or feed lines within the conditioned spaces may also experience unwanted heat. At the same time, moderate climates with pleasant temperatures permit more opportunities for outdoor living. This would include food preparation, work and leisure activities, and sleeping. Removing as many heat producing activities from the dwelling as possible reduces the need for energy consuming mechanical conditioning.

The amount of heat produced by internal sources is primarily a function of building type and usage patterns. How much internal heat is effectively utilized or prevented is a matter of intelligent design and the type of conditioning equipment selected. Consequently the difference in the percentage of total energy consumption ascribed to internal loads may be quite large for two different building types occupying adjacent sites.

For example, in a high rise office building, there are a number of heat producing possibilities which together comprise a very significant cooling load. Concentrations of mechanical equipment may appear at different locations in the building. Long piping and ductwork runs which radiate heat are unavoidable, but are generally insignificant.

Cafeteria kitchens, when present, contribute considerably to the cooling load. Lighting is a major source of heat in any office complex, as are the occupants themselves.

Buildings which require cooling during periods of low outside temperatures are not uncommon, nor are air conditioning equipment failures during periods of high outside temperatures. Internal loads are responsible to a large extent for both.

On a residential scale, the sources are of a much smaller magnitude and are not as varied. However, the building itself is much smaller, of course, and the building skin is of a different composition. Together these conditions dictate that the internal loads are still important in considering space conditioning requirements and the resultant energy consumption. In this chapter, internal heat sources are identified and analyzed in an effort to determine exactly what amount each source contributes to the total internal heat load.

In order to closely examine the amount of internal heat produced in the MED,

the heat sources must first be identified. The following categories were considered in analyzing the internally produced heat loads in the MED:

- People
- Lighting
- Appliances
- Bathroom Activities

All four categories were examined on a twenty-four hour basis for three different days: weekdays, Saturdays, and Sundays and Holidays. This was a deliberate effort undertaken to illustrate the impact of internal heat production on the mechanical system as a result of various day use and occupancy patterns. In doing so, the role of each item is displayed and the examination of peak loading conditions may be more easily facilitated.

It may be argued that a breakdown as detailed as that exhibited by the following tables is of little value in light of their arbitrary nature. To an extent this is true. However, the tabulations of the weekday calculations are very close to the national averages¹ found in the "Residential Energy Usage" chapter and are, therefore, worthy of consideration. The day use and occupancy patterns for Saturdays, and Sundays and Holidays are included to compare the influence of people, lighting, appliances, and bathroom activities under varying schedules. Although the totals for these days do not coincide exactly with national averages, their inclusion is nevertheless valid as they represent believable deviations from the norm.

In order to provide accurate comparisons with conventional homes, a four-member family, typical of the El Toro region, was selected. It is comprised of two parents in their late twenties and two children--one school age and

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

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.	% ^a 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

^aTabulated 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.

(1) Rates of Heat Gain From The Occupants Of Conditioned Spaces

SOURCE: Reprinted from ASHRAE handbook of Fundamentals, 1972.

one preschool age. According to Mission Viejo surveys, the mother works part-time. The statistics developed in this chapter were based on the preceeding family description. However, the family selected to live in the built MED home differs slightly in that they have only one preschool child.

The occupancy patterns will be explained in greater detail with the individual day-use description. Because of the range of activities occurring during a normal day resulting in a tremendous variation of heat production by the occupants, it was decided to increase the "sedentary" values from 300 to 350 BTUH for the adult male, and average the "active" values, deciding on 450 BTUH. This results in slightly lower values during working hours. (1) However, increasing the sedentary value takes into account periods during late evening or early morning when personal activities generate more heat than the 290-300 BTUH generally accepted for sleeping adults, but less than the 450 BTUH 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 average values given in the ASHRAE Handbook of Fundamentals². At a rate of 340 BTUH heat output, the energy generated is equivalent to a 100-watt lightbulb.

Lighting in the MED home is a major contributor to the total internal heat production averaging 28% of the total for any given day. In formulating the day use patterns, lighting was furnished and used as realistically as possible as they referred to fixture locations. The living room and bedrooms were lit with a typical assemblage of common fixtures. The number and wattage of the fixtures are listed

²ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1972, Chapter 22, p. 416.

in the appropriate tables toward the end of the chapter.

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 reclamation from the dryer in

"Americans are probably more dependent on various home appliances than people of any other nation in the world."

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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. Although it could be added to the return air duct enroute to the air handler, it would eventually have to be dehumidified before being introduced to the living spaces. Considering how infrequently the clothes dryer is used, an average of four times a week, and the fact that the MED will require only a small amount of heating which will be supplied easily by the solar system, it was decided to simply reject the heat in the conventional manner.

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 thousand cubic feet 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 SDU 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 time 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.

Customer surveys conducted by the manufacturer show that usually one load per day is done immediately after the evening meal. The 1944 BTUH heat production appears during the hour of 7:00 p.m. in keeping with this information.

Range

The MED will feature Tappan Model 30-3866 Gas Convectionaire Ranges with self-cleaning ovens. At the time of this writing, no specific information of gas consumption rates was available for the 30-3866. As a result, information from similar units was used to formulate average gas consumption rates for both range-top burners and the oven/broiler burner. A medium heat 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.

In formulating the day use patterns included in this chapter, the range-top burners, oven and broiler were used in various combinations for the different meals in order to illustrate the importance of food preparation on daily internal loads. (22) Of particular interest is the 5:00 p.m dinner hour totals which reveal a significant spread in internal heat production for the three separate days. This is a direct result of the presence of people and large cooling loads characteristic of the evening meal as compared to preparing and eating the meal outside as illustrated by the Sunday/Holiday day use pattern. Meal production during the dinner hour would account for 60% of the total appliance load if it were not for the refrigerator's ability to reject heat. (See discussion of refrigerator, this chapter)

The problem of range-generated heat was studied a number of various ways in the early stages of the MED development. (26) 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 through a ductwork and fan integral with the range appliance. In such an arrange-

ment, the heat and moisture are not allowed to saturate the air above the range top, even enroute to discharge. 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 enthalpy 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 ranges ventilating fan would also have to be taken into account under such circumstances.

A useful modification of this system would be the introduction of outside air in such a way as to be an effective substitute for conditioned outside air. That is, the locating of a duct or air passage that would supply air close enough to the proximity ventilating system's range-top discharge vent so as to effectively supply the discharge system's demand for air. In doing so, unconditioned air could be used for removing heat and odors, relieving the mechanical system from the chore of supplying conditioned air to accomplish the same thing.

Certain problems present themselves with such an approach, however.

- The integral proximity venting feature is available only on a limited number of ranges to date. These units are manufactured items which would unavoidably have to undergo a certain amount of reworking in order to accept the addition of an outside air vent.
- Special attention would have to be given to the exterior supply air vent so that it would not become an "air leak" for the rest of the home, emitting conditioned air or allowing undesirable outside air to enter the home.

- The only ranges featuring the proximity venting option were electric. This, of course, would be a more expensive choice with gas equally available in the Mission Viejo region.

In the MED there are two factors which will serve to minimize or eliminate undesirable heat buildup during "peak" hours. First, as the included day use patterns illustrate, most concentrated cooking activities occur in the early morning or early evening. (Although the peak production is at five or six, heat dissipation would occur over a one- or two-hour period.) These are prime times for using the economizer cycle. (See "Mechanical System" chapter.) Hence, a large portion of the cooling load will be satisfied with outside air, minimizing the amount of energy needed for "peak shaving" during meal hours.

The economizer relief vent serving the living spaces of the MED is located high on the kitchen wall, penetrating to the attic space. This allows a natural draft to carry heat buildup in the kitchen space out through the ridge vent in the roof.

Second, the vaulted ceiling in the kitchen acts as a heat trap, where warm air can gather without making its presence felt immediately by creating uncomfortable "close" conditions in the kitchen, or triggering room thermostats prematurely.

Hopefully, these two items together will accomplish effective, economic removal of heat generated in the kitchen without a mechanical assist from a ventilating fan.

Another item given extensive consideration was the refrigerator. The Magic Chief Model FC196H3 was selected because of its energy-conserving features. Manufacturer's literature claims a possible 45% savings in electricity as compared to similar models, depending on outside conditions and electric rates. Like most

conventional residential refrigerators, the FC196 is a closed loop design incorporating a hermetic compressor, an aluminum fin and tube condenser, an aluminum fin and tube evaporator coil where it vaporizes and picks up heat. It is returned to the compressor through the suction line of the tubing assembly. Air is driven over the condenser by a propeller fan rejecting heat in the process.

Heat rejection from the refrigerator was scrutinized for possible ways of rejecting heat from the condenser in order to minimize heat gain from refrigerator cycling in a cost effective manner. The following is a brief description of some of the alternatives examined.

Figure (2) illustrates one possible way of rejecting heat to the exterior. Very simply, interior air is drawn over the condenser coil and exhausted by the condenser fan through a duct to the outside. This approach has the same disadvantage as the proximity ventilation range mentioned previously. That is, conditioned air is exhausted to the outside necessitating make-up air from the outside. Except in situations where the economizer cycle is functioning (and perhaps not even then), this is an energy intensive net result. During exceptionally warm periods, or when high enthalpy conditions exist, it is particularly undesirable to exhaust conditioned air in this manner.

A logical alternative to the first approach would be that shown in Figure (3). In this configuration, outside air replaces conditioned interior air as the cooling source. The obvious advantage is that interior air is retained and the mechanical system does not have to satisfy the refrigerator's supply air needs. However, this arrangement also has certain inherent disadvantages.

(2) Refrigerator Heat Transfer Using Conditioned Interior Air

(3) Refrigerator Heat Transfer Using Outside Air

- The refrigerator base is subject to outside air conditions. Interfacing with interior design air conditions may result in condensation on the refrigerator cabinet if dew point conditions occur.
- Fixed ducts are required with this scheme for both supply and exhaust air routes. It is doubtful whether airtight tolerances can be maintained using sheet metal panel enclosures and friction duct fittings.
- Removing the refrigerator for cleaning or servicing would result in an unavoidable disconnection of these ducts. Re-alignment may prove difficult if the occupant or serviceman cannot see well behind the refrigerator while replacing it.
- The compressor is subject to outside air conditions. Subjecting the compressor to the adverse working environment caused by hot and humid air may result in a shortened life span for the unit.

(4) Refrigerator Heat Transfer Using Outside Condenser Location

Figure (4) was examined in an attempt to alleviate some of the problems just mentioned. By locating the condenser coil outside and keeping the compressor inside the refrigerator cabinet, a few problems are resolved. Outside air is used exclusively, eliminating the need for conditioned air. Condensation problems are eliminated as the condenser is outside and the compressor works at room design temperatures. The condenser is easily removed from the FC196 making remote location relatively simple. By housing the condenser outside, ductwork and leaking friction fittings are eliminated. By extending the suction and discharge capillary tubes and fan motor leads, the refrigerator may be moved at will.

Although this solution is close to a workable arrangement, some disadvantages are still present.

- Depending upon the size and type of materials, construction of an ex-

terior closure for the condenser may be unnecessarily expensive. The enclosure would have to be essentially weatherproof, yet constructed so that access to the condenser and fan is possible.

- Depending on its location, the condenser may be subject to accidental damage or vandalism.
- It may be undesirable aesthetically.
- In more severe climates, heat build-up in the enclosure in combination with unusually high ambient temperature may prohibit effective heat rejection.
- No method of rejecting the heat indoors is possible in climates which are not predominately in a heating mode.

The system of refrigerator heat transfer selected for the MED is that shown in Figure (5). The bottom portion of the kitchen's corner closet adjacent to the exterior wall is converted into an insulated air chamber. A horizontal plane of plywood divides the chamber into an upper and lower cavity while serving as a mount for the relocated refrigerator condenser and fan. Access may be provided through an airtight insulated access panel from the kitchen or through the ductwork openings by virtue of removable air diffusers and ductwork sections. Utilizing the bottom of the kitchen closet eliminates the need for an exterior enclosure while providing a weatherproof air chamber.

The arrangement of air intakes and exhaust openings allows for two distinct heat transfer possibilities. First, heat may be rejected to the outside during cooling modes by closing the ducts to the living area and opening those to the outside. Outside air may then be drawn across the condenser and exhausted back out by the condenser fan without disturbing the conditioned interior spaces. In heating modes, the outside vents may

(A) HERMETIC COMPRESSOR,	(I) WARM AIR EXHAUST
(TO EXTERIOR, IN COOLING MODE)
(B) CONDENSER COIL
(RELOCATED FROM REFRIGERATOR)	(J) OUTSIDE AIR INTAKE
(FROM EXTERIOR, IN COOLING MODE)
(C) DISCHARGE LINE	(K) AIR CHAMBER, DIVIDING PANEL
AND CONDENSER PLATFORM
(D) SUCTION LINE	(L) CONDENSATE PAN
(E) CONDENSER FAN	(M) 3" RIGID INSULATION
(SURROUNDS ENTIRE AIR CHAMBER)
(F) CONDENSER FAN LEADS	(N) REFRIGERATOR, BASE
(G) WARM AIR SUPPLY
(TO LIVING AREA IN HEATING MODE)	(O) KITCHEN CORNER STORAGE
(H) RETURN AIR
(FROM LIVING AREA IN HEATING MODE)	

(5) Refrigerator Condenser Heat Transfer

be closed (keeping out cold air) and the living room vents opened. Condenser heat may then be exhausted into the interior and retained. The "switch over" for refrigerator heat transfer is expected to be manual.

This solution combines all the advantages of the previous two while providing the option to exhaust or retain heat. The impact of refrigerator heat rejection on internal heat production depends on whether the mechanical system is in a heating or cooling mode.

Manufacturer's information claims the FC196 rejects a minimum 400 BTUH in a 70°F. room under normal circumstances. This is assuming that interior air which is used for cooling the condenser is re-introduced into the space. Heat that seeps through the refrigerator walls is, of course, rejected back out this way. This is what occurs when a heating mode dictates that the outside dampers be closed and the interior dampers open.

However, when outside air is drawn across the condenser coil and exhausted to the outside, another entirely different situation exists. Assuming a coefficient of performance (C.O.P.) of three, 1200 BTUH total would be rejected by the refrigerator every hour. If we maintain that 400 BTUH of the total 1200 BTUH is condenser heat and rejected heat of compression, the remaining 800 BTUH would represent that which the refrigerator absorbs from the interior space and rejects to the outside. The refrigerator is acting as an inefficient air conditioner when functioning in this manner.

As the following graphs and tables will illustrate, the 800 BTUH rejection rate is significant enough to result in a net positive cooling at times were it not for the presence of the occupants. Theoretically, if the external loads could be eliminated (solar gain, etc.), installing the refrigerator condenser in this manner

	Watts	Hrs./Month	KWHRS/Month		Watts	Hrs./Month	KWHRS/Month
blanket	190	80	15	fryer, cooker	1000-1500		5
blanket	50-200		15	fryer, deep			
blender	350	3	1	fat	1500	4	6
broiler	1436	6	8.5	frying pan	1196	12	15
clock	1-10		1-4*	furnace, fan			32**
clothes drier	4600	20	92**	garbage disposal equip-			
clothes drier, electric heat	4856	18	86**	ment	1/4-1/3 hp		1/2*
clothes drier, gas heat	325	18	6**	griddle	450-1000		5
clothes washer, automatic	250	12	3*	grill	650-1300		5
clothes washer, conventional	200	12	2**	hair drier	200-1200	5	1/2-6*
clothes washer, automatic	512	17.3	9*	hair drier	400		2*
clothes washer, wringer	275	15	4**	heat lamp	125-250	30	40
coffee maker	800	15	12	heater, aux.	1320		
coffee maker, twice a day			8	heater, portable	660-2000		15-30
coffee perco-	300-600		3-10	heat lamp	250	10	3
lator	894	10	9	hi-fi stereo	500-1650		9*
coffee pot	460-650		1	hot plate	500		7-30
corn popper	10-20		1/2	humidifier	1100	12	5-15*
curling iron	300-500		50*	iron			13
dehumidifier	1200	30	36*	iron, 16 hrs/month	1500	12	18
dishwasher	1200	25	30*	ironer	125		1/2*
dishwasher	375	2	1*	knife sharp-	125	6	1
disposal	445	6	3*	ener	50-200		1
drill, electric, 1/2"	250	2	5	mixer	300-1000		
electrocuter, insect	5-250		1*	mixer, food			
electronic oven	3000-7000		100*	movie pro-			
footwarmer	50-100		1	jector			
freezer, food, 5-30 cu.ft.	300-800		30-125*	pasteurizer,			
freezer, ice cream	50-300		1/2	1/2 gal.	1500		10-40
freezer, 15 cu.ft.	350	90	32*	polisher	350	6	2
freezer, 14 cu.ft.	440	330	145*	power tools	500	4	3
freezer, frost free	440	180	57*	projector			2*
refrigerator-freezer	200	150	30*	radio	100-300		8
refrigerator-freezer, 14 cu.ft.	326	290	95*	radio, console	40-100		5-15*
refrigerator-freezer, frost free	360	500	180*	radio, table	8500-1600		5-10*
roaster	1320	30	40	range	75-100		100-150
rotisserie	1400	30	42*	record player			1-5
sauce pan	300-1400		2-10	record player, transistor	60	50	3*
sewing machine	30-100		1/2-2	record player, tube	150	50	7.5*
sewing machine	100	10	1	recorder, tape	100	10	1*
shaver	12		1/10	refrigerator	200-300		25-30*
skillet	1000-1350		5-20	refrigerator, conventional			83*
skill saw	1000	6	6	water heater	4474	89	400
sunlamp	400	10	4	water heater	1200-7000		200-300
sunlamp	279	5.4	1.5	water pump (shallow)	1/2 hp		5-20**
television	200-315		15-30*	water pump (deep)	1/3-1 hp		10-60**
TV, BW	200	120	24*				
TV, BW	237	110	25*	Symbol Explanation:			
TV, color	350	120	42*	*AC power required			
toaster	1150	4	5	**Normally AC, but convertible to DC			
typewriter	30	15	.5*	Notes: Lighting in this table is assumed to be incandescent--if fluorescent, the watt-			
vacuum cleaner	600	10	6	age bulbs consume the same power but de-			
vacuum cleaner, 1 hr/week			4	liver 3 times as much light--fluorescent			
vaporizer	200-500		2-5	bulbs also require AC, but can be converted			
waffle iron	550-1300		1-2	to DC.			
washing machine, 12 hrs/month			9*	These figures can be cut by 50% with con-			
washer, auto.	300-700		3-8*	servation of electricity.			
washer, conventional	100-400		2-4*	1) Sources for this table represent a con-			

(6) Energy Use Ratings For Various Appliances

SOURCE: Energy Primer, (c) 1974, Portola Institute, Menlo Park, California.

would almost eliminate the need for mechanical conditioning during the evening hours, or during periods of vacancy.

The day use patterns were tabulated assuming the MED was in a cooling mode; the resultant 19,200 BTUH/day is a result of that assumption and represents the heat rejection accomplished by the refrigerator.

The additional appliances are included for interest and authenticity. (6) Although they do not contribute significantly to daily totals, they do serve to modulate the hourly totals somewhat. Ratings and hours of use for the various miscellaneous appliances were obtained from the Energy Primer.³ Included in the appliance totals is the heat generated by showering. Again, although they are not a significant part of daily totals, heat produced by showering is responsible for a quick, concentrated heat load for which the mechanical system must compensate.

Day Use Patterns-Internal Heat Sources

The following tables are included as a detailed examination of various internal heat sources. Daily schedules were formulated as accurately as possible to simulate activities and conditions for a typical weekday, Saturday, and a Sunday or Holiday in order to illustrate the individual role of people, lighting, and appliances as they relate to total daily internal heat production.

Weekday. (7) (8) (9) (10) (11)

During the week, it was assumed that the family would rise together, perform morning toilet duties, and have a light breakfast before leaving for work, school and play. The mother then does some house cleaning before leaving for her part-time job at noon. The children arrive home from school

³Energy Primer, Portola Institute, California, 1974.

SOURCE	TIME																								BTU/DAY TOTALS
	(M)	1	2	3	4	5	6	7	8	9	10	11	(N)	1	2	3	4	5	6	7	8	9	10	11	(M)
MOTHERS																									
SEVENTHARY																									2184
MOD. ACTIVE																									4920
FATHERS																									
SEVENTHARY																									2928
MOD. ACTIVE																									3576
1 st CHILD																									
SEVENTHARY																									2928
MOD. ACTIVE																									2194
2 nd CHILD																									
SEVENTHARY																									2928
MOD. ACTIVE																									2194
ASSUME: 450 BTU/H POP. MODERATELY ACTIVE ADULT MALE 340 BTU/H POP. SEVENTHARY ADULT MALE (.5)(BTU/H) POP. ADULT FEMALE (.75)(BTU/H) POP. MALE OR FEMALE CHILD																									73,040 BTU/DAY

(7) People - Weekday
Internal Heat Sources

SOURCE	TIME																								BTU/DAY TOTALS
	(M)	1	2	3	4	5	6	7	8	9	10	11	(N)	1	2	3	4	5	6	7	8	9	10	11	(M)
KITCHEN																									
(1) PERMANENT FIXT.																									8128
W/(2) 100W LAMP																									
LIVING ROOM																									
(1) LIGHT STAND																									1365
W/(2) 100W LAMP																									
(1) TABLE LAMP																									428
W/(1) 75W LAMP																									
(1) TABLE LAMP																									247
W/(2) 40W LAMP																									
MASTER - B'DRM																									
(2) TABLE LAMP																									1279
W/(1) 75W LAMP																									
BEDRM.COM #2																									
(1) TABLE LAMP																									1024
W/(1) 100W LAMP																									
BEDRM.COM #3																									
(1) TABLE LAMP																									542
W/(1) 100W LAMP																									
MASTER, BATH																									
(1) CEILING FIXT.																									542
W/(1) 75W LAMP																									
BATH																									
(1) CEILING FIXT.																									542
W/(1) 75W LAMP																									
NOTE: 1. FOTER, CEILING FOTURE NOT INCLUDED																									14,100 BTU/DAY

(8) Lights - Weekday
Internal Heat Sources

SOURCE	TIME																								BTU/DAY TOTALS
	(M)	1	2	3	4	5	6	7	8	9	10	11	(N)	1	2	3	4	5	6	7	8	9	10	11	(M)
KITCHEN APPLIANCES																									
RANGE																									
BURNER #1																									5000
BURNER #2																									1500
BURNER #3																									933
BURNER #4																									
OVEN																									6106
REF. COOL.																									
MICROWAVE COOL.																									
* REFRIGERATION																									14,200
DISHWASHER																									1444
CLOTHES WASHER																									888
† CLOTHES DRYER																									1100
TOASTER																									500
COFFEE MAKER																									1157
BLENDER																									25
CAN OIL																									746
CARTRIDGE MOTOR																									135
□ DENOTES MINUTES OF USE WITHIN THE HOUR. * SEE TEST PAGES FOR A DISCUSSION OF REFRIGERATION, HEAT TRANSFER. † ASSUME THE SELECTION OF 23,000 BTU/H UNIT																									33425 BTU/DAY

(9) Kitchen Appliances - Weekday
Internal Heat Sources

(10) Miscellaneous Appliances - Weekday
Internal Heat Sources

and the day-care center in early afternoon, followed soon thereafter by both parents. The family eats the evening meal together and spends the evening at home. Most activities take place in the living area, as suggested by the lighting and use of the television.

During the week, the children retire early. The parents go to bed somewhat later, perhaps after the evening news. Only the parents shower before bed.

Figure (12) contains the hourly breakdowns for the people, lighting and appliances. The 55,204 BTU/day total represents 34% of the 160,000 BTU/day cooling load predicted for a sunny July 21st day. This is very close to the estimated 31% determined by computer analysis for the MED. The daily percentage breakdowns of the internal heat production for the weekday is as follows:

People	-	23,057 BTU/day	-	42%
Lighting	-	15,188 BTU/day	-	28%
Appliances-	-	15,959 BTU/day	-	30%
TOTAL				100%

(11) Showers - Weekday
Internal Heat Sources

The internal heat loads resulting from the people and lighting correspond almost exactly with national averages as well as computer projected MED predictions. The major appliances also are in line with national consumption figures. The day use patterns include additional miscellaneous appliances and heat loads from showers which are not included in national average computations. Consequently, the MED totals are somewhat higher in this area.

Figure (13) "Internal Heat Production for a Typical Weekday" graphs the hourly totals for each category. Some interesting observation can be made

INTERNAL HEAT SOURCES

SOURCE

M

1

2

3

4

5

6

7

8

9

10

11

N

1

2

3

4

5

6

7

8

9

10

11

M

WEEKDAY

PEOPLE

LIGHTING

APPLIANCES

HOURLY TOTAL

DAILY TOTAL

1288	1288	1288	1288	1288	1288	1288	1455	385	360	360	360						338	676	1261	1486	1486	1486	1396	1396	1396
							2260	810	682	682	1322						341	810	938	938	2149	2064	1211	597	384
-718	-718	-718	-718	-718	-718	-718	4335	408	2262	476	1536	-718	-718	-718	-718	-718	10,494	-121	2464	749	476	476	2020		
570	570	570	570	570	570	570	8050	1803	3304	1518	3218	-718	-718	-718	-39	768	12,963	2303	6099	4299	3083	2469	3800		
55,204		People - 23,057										Lighting - 15,188					Appliances - 16,959								

SATURDAY

PEOPLE

LIGHTING

APPLIANCES

HOURLY TOTAL

DAILY TOTAL

898	1147	1342	1288	1288	1288	1288	1288	1378	1486	698	698	1486	810	0	0	979	1148	1486	1486	988	943	898	898		
938	256	384	0	0	0	0	0	0	1406	810	682	682	746	746	0	0	0	682	1364	2405	1680	1279	256	938	
476	-121	-718	-718	-718	-718	-718	-718	-405	476	2073	3453	1341	-718	-718	-718	-718	476	15,768	476	4812	1374	1374	476	476	
2312	1282	1008	570	570	570	570	883	3260	4369	4833	2721	2189	2305	-718	718	1455	17,998	3326	8703	4042	3596	1630	2312		
68,668		People - 25,209										Lighting - 15,254					Appliances - 28,205								

SUNDAY/HOLIDAY

PEOPLE

LIGHTING

APPLIANCES

HOURLY TOTAL

DAILY TOTAL

1396	1288	1288	1288	1288	1288	1318	898	898	988	1036	1036	360	810	810	810	0	0	0	0	676	631	3016	3016		
256	0	0	0	0	0	0	405	0	0	767	746	682	0	0	0	0	0	0	0	1620	1790	1790	938		
-718	-718	-718	-718	-718	-718	-718	-718	-718	-718	-718	4712	-445	-718	-718	2142	4064	-718	-718	-718	1226	805	-445	-718	-718	
934	570	570	570	570	570	1005	180	180	1037	6494	1273	-358	92	2952	4874	-718	-718	-718	1226	3101	1976	4088	3236		
32,986		People - 24,139										Lighting - 8,994					Appliances - 147								

(12) Internal Heat Sources

through careful examination of the plots.

For instance, between midnight and 7:00 a.m., with the lights and appliances off, the heat rejection provided by the refrigerator counters the 1288 BTUH produced by the sleeping family. This results in an hourly average much lower than would be realized if the refrigerator were installed in a conventional manner.

This phenomenon is even more apparent immediately after noon when the home is vacant and no lights or major appliances are in use. The refrigerator actually provides a net cooling effect of -718 BTUH, effectively countering any internal heat source. Under such conditions, the refrigerator is acting in conjunction with the mechanical system in trying to rid heat introduced to the living spaces from exterior sources.

Also of particular interest in Figure (13) is the peak loading occurring at meal times. This is a result not only of "cooking loads" but of the concentrations of people who attend meals. The fact that the "Average Hourly Load" line falls above the main concentration of heat source plots is indicative of the impact of meal time peak loading. The suddenness is also of particular consequence. Within one hour, the internal loads range from a -718 BTUH to 12,963 BTUH. This imposes an additional one ton cooling demand at a time in the afternoon when heat gain from external sources is at a maximum. If this situation would arise at a time when the storage tank temperature was low, it may require auxiliary heat input to the absorption chiller from the boiler. (See "Mechanical Systems" chapter - Cooling From Auxiliary)

(13) Internal Heat Production For A Typical Weekday

The internal load patterns for a typical weekday follow fairly predictable patterns. The following tables for Saturdays and Sundays or Holidays are included to illustrate possible

deviations from the normal everyday living pattern.

Saturday. Occupancy patterns for a typical Saturday are characterized by the parents rising later in the morning. (14) Occupancy is generally more sporadic as weekend chores and the presence of the children result in more "coming and going". Also, the children are permitted to stay up a few hours later. A babysitter is substituted for the parents who choose to spend the evening out.

Noontime internal loads are greater because of the family being present for lunch. (15) (16) (17) An exceptionally larger and diverse meal contributes significantly to the evening's internal heat production.

The parents shower early in the evening in preparation for going out. (18) The children also take evening showers.

Compared to an average cooling requirement of 55,000 BTU/day, the hourly totals would be as follows:

People	- 25,209 BTU/day	38%
Lights	- 15,254 BTU/day	22%
Appliances	- 28,209 BTU/day	40%
TOTAL		100%

Sunday/Holiday. The occupancy patterns for the Sunday/Holiday study were designed to show the impact of outdoor living. (19) (23) The father leaves early in the morning, perhaps for a round of golf. The children spend the afternoon outside, and friends are invited for an afternoon cookout. The lighting, appliances, and bathroom activities are programmed accordingly. A day spent in this manner would result in the following totals:

People	- 24,139 BTU/day	73%
Lighting	- 8,994 BTU/day	27%
Appliances	- -147 BTU/day	0%
TOTAL		100%

(14) People - Saturday
Internal Heat Sources

(15) Lights - Saturday
Internal Heat Sources

(17) Miscellaneous Appliances - Saturday
Internal Heat Sources

(19) People - Sunday/Holiday
Internal Heat Sources

(18) Showers - Saturday
Internal Heat Sources

(20) Lights - Sunday/Holiday
Internal Heat Sources

(20) (21) (22) The influence of lighting and appliances is readily apparent in the above comparison. By preparing the evening meal outside, a major source of internal heat production is removed. This results in a net cooling load in the appliance category because of the refrigerator's ability to reject heat.

Figure (24) "Comparison of Internal Heat Production Hourly Totals" offers some interesting observations. The numerous peaks and dips occurring throughout the day is an indication of the diversity of internal load conditions possibly with different day use patterns. It graphically illustrates the effect of eliminating a meal as an internal heat source as evidenced by the Sunday/Holiday plot at 5:00 p.m. The difference between early morning hours and early evening hours represents the effect of various activities as opposed to the predictably consistent values plotted throughout the night.

This begins to suggest a very important aspect of internal heat production. Figure (12) "Internal Heat Sources" reveals that the daily total heat production from people is very similar for all three days. The lighting totals are similar for weekdays and Saturdays. The outdoor activities on Sundays and Holidays are responsible for lower totals in the latter categories. The only category that differs significantly is appliances. This suggests that it is not lifestyles, but use habits which are responsible for internal heat production and, ultimately, energy consumption. How intelligently this heat is handled will determine whether the energy involved is taken advantage of or wasted.

Thus far, all the discussions have been based on the MED and its thermal response characteristics. The internal loads were considered to be detrimental because the building will be in a cooling mode most of the year. It should be readily apparent that the

(21) Kitchen Appliances - Sunday/Holiday Internal Heat Sources

(22) Miscellaneous Appliances - Sunday/Holiday Internal Heat Sources

(23) Showers - Sunday/Holiday Internal Heat Sources

(24) Comparison Of Internal Heat Production
Hourly Totals

opposite will be true if the building demand is predominantly heating. The entire question of whether or not internal loads are desirable or undesirable becomes a matter of regionality.

For example, a home in Albany, New York, similar to the MED and designed with local materials in a vernacular manner may have a daily maximum heating requirement of 103,200 BTU. The total heat production as quantified earlier for a typical weekday would be 86,782 BTU if the refrigerator were installed in a conventional manner, rejecting 400 BTUH into the space. The internal loads in a heating mode such as this would account for 12% of the heating supply. This, of course, suggests an energy and cost savings of 12%, as well. Under less severe heating conditions such as the Spring and Fall, internal heat sources can account for as much as 100% of the heating requirement. In Mission Viejo, if the appliances were installed conventionally, 86,782 BTU would represent a detrimental 54% of the total cooling load. A comparison of this sort may be taken to an extreme by comparing buildings in Bangor, Maine and Miami, Florida.

The question of internal loads must, therefore, be considered on a regional basis. A total design approach utilizing detailed climatic data, close scrutiny of building skin behavior characteristics, and eventually occupancy patterns should be undertaken to deal effectively with the consequences of internally produced heat. Architects and engineers must accept the challenge of discovering new and cost effective means of eliminating or utilizing internal heat sources.

On a residential level, there are many possibilities for inducing or reducing internally produced heat which were not considered for the MED because of the seasonal aspect of Mission Viejo's climate and the less than extreme conditions which exist there.

For instance, in climates having abnormally high heating requirements, heat pipe recovery systems immersed in grey water system storage tanks may yield additional heat. (See "Plumbing" chapter for an explanation of grey water system.)

Major appliances using untempered 140°F. supply water will typically have drain water temperatures between 120°F. and 135°F. Assuming a 10°F. temperature drop in water temperature during a hot shower, drain water may be between 80°F. and 90°F.

In areas where heat requirements are severe enough to warrant such a system, supply water temperatures are most likely quite low if taken from wells or surface sources. Consequently, using heat recovered from drain water could be used to preheat supply make-up water, lowering the amount of energy required to boost supply water to usual domestic hot water temperatures.

Under extreme conditions, it may also prove cost effective to recover heat exhausted from the clothes dryer. Assuming the dryer will exhaust 95% of a 22,000 BTUH input, 20,900 BTUH is available for collection. The efficiency of the recovery process will determine what amount is actually collected.

Clustering the major appliances in the kitchen under a common exhaust hood may prove a cost effective way of gathering heat from diffuse sources. Appliances which individually produce insignificant amounts of heat will together comprise a usable sum if collection can be accomplished economically.

Fireplaces offer obvious opportunities for heating. Unfortunately, most "custom designed" fireplaces have a net negative heating result whether they are integrated or free standing. This is primarily because supply air is drawn from the room for combustion. The consequences are twofold.

"The efficiency of an ordinary fireplace is about 10 to 15 percent."

350 Ways to Save Energy

OUTSIDE AIR MAY BE
DRAWN INTO CHAMBER,
ADJACENT TO FLUE,
WARMED BY CONVECTION
AND DISCHARGED
TO INTERIOR.

HOLLOW METAL TUBES
SERVE AS LOG CRACK,
TAKE IN OUTSIDE AIR,
WARM IT IN FIRE CHAMBER,
AND DISCHARGE IT TO INTERIOR.

(25) Heat Producing Fire Place Design

- Make-up from the outside must be introduced either by the mechanical system or by natural infiltration. In periods when the fireplace is in use, it is very likely that make-up air at outdoor temperatures would be highly undesirable.
- Most heat generated in a fireplace is lost up the flue. Perceptible heating is accomplished only in the immediate area of the fireplace itself.

The first problem can be remedied by introducing outside air at hearth level inside the fire chamber. Care must be taken to insure a weatherproof seal of this supply route to prohibit undesirable infiltration when the fireplace is not in use.

The second problem is simply a matter of efficient design. (25) Numerous design principles and apparatus may be incorporated to greatly improve heat output from fireplaces. Fire chamber surface angles and materials should be studied and verified to insure minimum flue losses. Ducts may be installed in various ways to extract heat absorbed by the fire chamber enclosure. Massive materials which absorb heat will re-radiate heat back into the space long after the fire is out. (See "Mass" chapter)

Numerous other suggestions are available from fireplace manufacturers and accessory distributors. The primary concern is providing a fireplace which is more than aesthetically pleasing--an installation which will not sacrifice the rest of the home in order to inefficiently heat a small area.

Excessive heat production in climates where cooling is the major requirement offers additional challenges to the design professional. Once again, intelligent utilization of existing principles and technologies can be incorporated into residential design without sacrificing comfort or convenience.

Residential lighting is one area in which the designer can improve the environment while reducing internal loads. Substituting fluorescent for incandescent lamps will provide more lumens per watt. This in itself will reduce heat production and energy consumption. Opting for task lighting instead of needless general illumination whenever possible and appropriate will have similar results.

Great care should be taken to maximize the utilization of natural light without undesirable heat gain and heat loss. Good quality, thermal insulated skylights in strategic locations and well-oriented clerestories can be designed and positioned in a manner which supplies light to an area at a time when it is most commonly used. Careful layout of the home can insure natural light in this manner without the detrimental effect of solar gain resulting from direct sunlight.

Conscious considerations of lighting schemes using both natural and artificial light could easily contribute to more interesting and more aesthetically pleasing design resulting in an all-around better environment.

Efficient appliance design could contribute significantly to decreasing internal heat production and energy consumption. In areas requiring heating, this energy savings could be better utilized in more efficiently designed heating equipment, which could, in turn, provide for more desirable conditioned heat on demand.

For example, if ranges having proximity ventilation systems, as discussed previously, would have accommodations for outside air intake, the appliance would be less energy intensive and could more effectively accomplish the purpose for which it was intended. (26) Mass production would make the concept far less expensive to the consumer.

The same is true for the refrigerators and freezers. Kitchen appliance

(26) Range With Proximity Ventilation

manufacturers could coordinate which cabinet designer to allow the introduction of a model line of refrigerators which do not have to sacrifice insulation for standard cabinet dimensions. Extrapolating the regionality aspect of appliance design would suggest other innovations, such as refrigerator and freezer packages with easily removable condensers. Package options for clothes dryers which simplify discharge fan removal and substitution could also make such modifications possible for the consumer without special tools and undue costs.

In homes which require cooling, decisions made early in the design process could provide for mechanical equipment and other heat producing items not necessary on a day-to-day utilitarian basis to be housed in unconditioned spaces. Removing as many heat producing items as possible will serve to decrease the cooling load accordingly. The opposite is true, of course, for buildings which require heating.

As illustrated in the Sunday/Holiday day use pattern, outdoor living can dramatically reduce internal heat production. Preparing and eating a meal outdoors removed approximately 15,000 BTUs of moist heat from the interior during the evening meal hour. The designer can encourage such activity by providing screened outdoor spaces, decks or patio areas. A well designed outdoor enclosure in combination with a patio or barbecue pit can be an unresistable place to prepare and enjoy an evening meal. It is also a good way to start the day, adding a great deal to breakfast.

On a residential level, some of the previous suggestions have marginal financial justification. More lucrative possibilities begin to present themselves, along with some additional opportunities for internal heat rejection or utilization when one goes beyond the scope of residential application.

Systems exist already for commercial, industrial and institutional facilities which recover heat generated by light fixtures by drawing air introduced low into the space up and over luminaries, cooling them in the process. (27) In buildings with uneven loads or simultaneous heating and cooling demands, the heat can be redistributed as needed. In buildings operating in a cooling mode, the heat produced by the fixtures is eliminated as it is created, minimizing the heat gain from the lamps.

Heat pumps can be incorporated to transport heat from one zone to another. (For instance, from perimeter spaces to interior spaces.) This provides a cost effective way to shave peak loads, enabling more efficient and hence more economical equipment operation.

High heat concentrations from factories, food service areas, mechanical equipment rooms, and industrial processes can be exhausted through heat wheels. These in turn could warm incoming supply air enroute to mechanical equipment servicing other zones within the facility which may have a simultaneous heating demand.

Industrial and commercial heat reclamation and rejection possibilities are numerous. However, their complexity and diversity are beyond the scope of this report. It is interesting to consider, however, the possibilities of exchange which could exist between an industrial park and an adjacent residential development.

Within such an arrangement, heat produced from industrial processes, or removed from mills and manufacturing plants could be gathered and redistributed for heating or used to drive refrigeration and air conditioning equipment. It is not unusual, for example, for industrial complexes to flash off large quantities of high pressure steam. Hundreds of manufacturing processes produce hot and super heated water as a result of

(27) Air-Cooled Luminaire

product cooling demands. In an industrial park, many of these sources are close together, hence the major problem of collecting the heat is minimized. With the residential community in close proximity, transportation and redistribution of the heat is also more economically feasible.

Waste steam could be condensed within the industrial park using discharge water from other industrial processes. By converting the steam to hot water, all the heat is contained in one medium. Hot water could then be collected and stored in a common tank, eliminating the need for expensive pressure systems and high temperature steam components. Also, hot water transported to the community underground to minimize heat losses could be used directly in home hydronic systems. The problem of pollution and toxicity could be eliminated by utilizing a closed loop heat exchanger at some point in the distribution system.

Once delivered to the community, the hot water could feed a loop distribution system from which individual units or cluster developments could draw as required for heating or cooling purposes. A hot water supply to each home could also boost municipal supplies, or perhaps provide 100% of the heat energy for domestic hot water heating. Other community facilities such as churches, community centers and municipal buildings could also enjoy the same benefits. Applications such as pool heating, public or private, or even snow melting could possibly be accomplished as a by-product of industrial thermal discharge.

In essence, the community would function as a heat sink for an industrial complex. As a result, economic arrangements could be made by which the community could pay the contributing commercial parties for their heat energy. This in turn would offset the initial investment necessary for the heat transfer network and may eventually begin to be realized as a profit

for the industrial participants. Under such circumstances, everyone-- industry, the public, and the environment would benefit.

In conclusion, internally produced heat must be considered from a number of different viewpoints. It may be a benefit or a detriment depending on the mechanical system's mode of operation. Loads imposed by internally produced heat are complex, sporadic and infinitely variable. Hence, heat retention or rejection requires close examination and ingenuity to be effectively and economically dealt with. Numerous means are available for incorporation on a residential scale at the present time, without undue modification or expensive alteration of appliances, building design, or mechanical systems. Others become more feasible only when considered on a large scale, involving complex interrelationships between process needs and economic considerations.

As energy availability dwindles and costs escalate, the design professional is forced to use every possible means at his disposal to reduce consumption. An awareness and working knowledge of internal heat sources will contribute significantly to this effort.

VENTILATION & INFILTRATION

A vapor barrier is an important component in halting infiltration into a building interior. Although primarily installed to prevent moisture migration, the polyethylene wraps the Minimum Energy Dwelling from foundation to ceiling with a thin, nondescript plastic film. A chicken wire mesh is then applied as a base for a cement stucco completing the exterior wall surface. The control of air is one of the least predictable areas of energy conservation, but one which is becoming important as energy techniques in other areas are implemented.

When unconditioned outside air is introduced by ventilation or infiltration to displace inside conditioned air, a mechanical system must expend energy to cool, heat, humidify, or dehumidify the outside air to bring it within the range of comfort. The magnitude of that displacement, of course, will determine the magnitude of energy consumed. Reducing the energy consumption required to condition this air will demand the knowledge of the ways in which air infiltrates a building, the standards for ventilation that the occupants of a building require methods for quantifying the influx of outside air, and finally, finding means for reducing its affects on the building's energy consumption. As with other aspects of artificial climate within buildings, the amounts of ventilation needed to help maintain body comfort surpass man's basic biological need for oxygen.

In order for man to comfortably sustain the life activities performed within the buildings, minimum amounts of fresh outside air must be introduced to replenish oxygen and carbon dioxide contents, remove odors and pollutants, and relieve vapor buildup to prevent the growth of mold and mildew. Logically, if the controlled minimum displacement of required air was accomplished and unwanted air blocked from entry, the amount of energy needed to condition the desired outside air could be limited to only necessary amounts, thus avoiding waste. In the climate of Mission Viejo, California, infiltrating air and ventilation requirements will have a large impact on the energy consumption within the Minimum Energy Dwelling. Therefore, a focused effort on this aspect of energy consumption must be undertaken to fulfill the goal of the project.

The temperature difference between the uncomfortable air and the comfortable interior air is maintained by the use of energy to heat or cool the interior air. If all the conditioned air in a building could be theoretically isolated from the interior, it could retain the inertia of its original conditioning to allow only small efforts

from the mechanical system to heat or cool it as its temperature dipped or rose slightly from the comfort range. In reality, large amounts of outside air are introduced intentionally through ventilation or unintentionally by infiltration. Thus, the inertia of conditioned air is reduced, and the system must frequently heat or cool, humidify or dehumidify, new quantities of "raw" outside air. The implications of this are obvious to the designer who must maintain the fresh air needs of the occupant but minimize infiltration of unneeded air.

Using present facts to predict future possibilities defines the designer's activity and his ability to secure enough quality information will enhance the chances of good design. This ideal principle is especially hard to maintain in the prediction of infiltration rates. Much is known about the individual elements that cause infiltration, yet accurately calculating for the sake of good design, the combined energy impact of needed ventilation and unwanted infiltration is nearly impossible - the factors involved behave with unmanageable complexity. Because the effects of infiltration can be a substantial portion of energy requirements, it must not be ignored. Simplified methods for rough approximations have, therefore, been developed for the designer.

Detailed methods of calculating infiltration, the unwanted air which seeps into buildings through cracks, windows, doors, walls and floors, requires the knowledge of the size and number of openings caused by the particular construction, workmanship and condition of the building. Knowing the size and location of these openings is only the threshold of a much larger problem. Experience tells us that an opening can remain the same size, but the amount of air flow can fluctuate to stream through in large or small volumes. The changing magnitudes are a function of the erratic pressure differences between the

inside and outside of the building. The pressure differences are in turn functions of wind speed, differential air densities caused by temperature differences across the skin of a building, or the positive or negative pressure by air handling equipment in the mechanical system.

Wind will flow around a building creating regions of positive and negative pressure forcing air through cracks in the windward side and causing internal air to exfiltrate into 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. In winter or summer, heated air rising through a building to exfiltrate high points will draw in unconditioned air at the low inlet openings.

Buildings in the wind are like the rocks or other obstructions in a stream which disrupt the uniform even pattern of the waters flow. (1) The disturbing effect of a house in the path of wind creates pressures that are both above and below the static pressure of the air stream. Wind which perpendicularly confronts a wall will compact, thus forming 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 to the wind will also undergo exfiltration through their openings. 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 pressure difference between inside and outside, and thus the magnitude of new air volume penetrating the structure.

(1) Positive And Negative Pressure Due To Wind

These pressure differences would seem easy to calculate, but in reality,

other factors which complicate the situations make accurate predictions difficult.

- Buildings are built near the surface of the earth where wind velocity varies with height and thus varies the general pattern of high and low pressures.
- The complex shape of a building and its texture will further complicate the once simple picture, and the texture of terrain, whether open, flat, hilly, near the water, in the city, or out in the suburbs will finally complicate the generalized pressure system. The micro-climate and its foliage will also have an impact.

All of these forces indeed influence inside-outside pressure differences, but accurately representing them with anything rational cannot be done. An accounting is made, then, by reverting to a generalized model of wind pressures which can only yield estimations of actual wind behavior.

Temperature Differences

A temperature difference varies air density which promotes a pressure difference giving rise to air movement that attempts to re-adjust the imbalance toward equilibrium. (2) A chimney is the simplest illustration 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 outward flow at the top of the chimney. (3) The higher the stack, the greater the flow of air. At some point between these extremes lies a neutral pressure difference across the walls. From this neutral point, the magnitude of pressure difference varies with the distance from the neutral zone.

Buildings are roughly analogous to chimneys but differ because of the walls and floor within the space.

(2) Stack Effect Due To Temperature Differences

(3) Stack Effect

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

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.

Two of the more important problem areas in the home involving the stack effect are chimneys and mechanical equipment flues. Because of the large difference in temperature between the heated air and normally conditioned air, a large pressure difference is created, drawing out large amounts of conditioned air. A method of avoiding this problem in fireplaces is the use of unconditioned air vented from the outside to supply air for combustion. One solution for mechanical equipment and the attendant vents is to place them in unconditioned spaces. The stack effect exists in tall buildings which can be imagined as large chimneys. The increased height produces a large pressure difference between the top and bottom of the building. To resist the stack effect, tight separation between floors must be maintained. A common problem in high rise structures is air ducts or elevator shafts which extend from ground level to the top floor. Tight seals must be incorporated to minimize the possible unwanted stack effect.

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. At night, after a day of solar energy collection,

the material will heat air and cause it to rise and pull cooler outside air into the living space through low openings in the building.

A quick way to calculate the air movement by a stack action involves the following equation:

$$Q = 9.4 A h(t_i - t_o)$$

Where:

- Q = Air flow, cubic feet/minute
- A = Free area of inlets or outlets (assumed equal), square feet
- h = Height from inlets to outlets, feet
- t_i = Average temperature of indoor air height h, Fahrenheit
- t_o = Temperature of outdoor air, Fahrenheit
- 9.4 = Constant of Proportionality

The preceding equation assumes temperatures close to 80°F.

An example of a rough approximation of the effectiveness of a passive ventilation is shown. Assume a 20' high, 20' long masonry wall with an internal 1' wide cavity in the upper 10 feet. The cavity has movable dampers on top and bottom in the open position. The bottom vent opens into the living space. Assuming the cavity air temperature could be maintained at 85°F. from heat dissipated from the solar heated masonry wall and a room temperature of 75°F., the air flow through the cavity can be calculated:

$$\begin{aligned} Q &= 9.4 (1')(20') 10' (85^\circ\text{F.} - 75^\circ\text{F.}) \\ &= 9.4 (20) 100 \\ &= 1880 \text{ cfm} \end{aligned}$$

Calculating Infiltration

Infiltration may account for a large portion of the heating and cooling requirements of a building. Therefore, adequate estimates of its effect are a necessary part of mechanical system design. Two acceptable methods which give approximate values are used by engineers.

• The "Crack" method is an attempt to reckon with building openings by the measurement of the length and width of cracks around the doors and windows, plus the air seepage through the wall materials. The crack method is generally considered more accurate if pressure differences and cracks around doors and windows are suitably accounted for.

• The air change method assumes a number of air changes per hour for each room with its location, size, use and number of windows or doors governing the number of air changes it undergoes.

The choice of method usually depends on the type of building and the degree of accuracy needed in the calculations. For instance, the crack method must be applied to commercial buildings where crack conditions around the numerous doors and windows are usually too unpredictable for confident use of the air change method. Laboratory data about air leakage in exterior wall components is usually straightforward, dependable, and simply expressed in air flow per foot of crack. If enough data can be gathered, the crack method is preferred. (4) Significant discrepancies can occur if there is a difference between laboratory conditions and the actual site installation of the particular component, plus the difficulty in assessing the proper infiltration values for varying crack construction details, quality of weatherstripping, etc. Actual infiltration rates for a selected window or door can be obtained from the manufacturer.

In other types of structures, the opening of doors may be the chief sources of infiltration. In this case, the air change method is a more appropriate procedure to follow. Infiltrating air in residences is usually always assessed by the air change method. Figure (5) tabulates the air changes which engineers consider reasonable for various types of rooms. Each room in the building is assigned

Type of Window	Infiltration cubic ft./hr. (ft. of crack) ^a
Wood Double-Hung Window (Leakage expressed as cubic feet per hour per foot of sash crack; only leakage around sash and through frame)	
1. non-weatherstripped, loose fit	77
2. non-weatherstripped, average fit	27
3. weatherstripped, loose fit	28
4. weatherstripped, average fit	14
Frame-Wall Leakage (Leakage is that passing between the frame of a wood double-hung window and the wall)	
1. around frame in masonry wall, not caulked	17
2. around frame in masonry wall, caulked	3
3. around frame in wood frame wall	13

^a Assuming a pressure difference of .10 inches of water or equivalent of fifteen miles an hour

(4) Infiltration Due To Crack

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

a value and then all are summed to give a total value.

Ventilation

Ventilation is the positive introduction of outside air into a building. For the health and well-being of the occupants, air must be introduced within a building to maintain normal and efficient activities. Throughout several decades, scientists and engineers have studied the physiological and psychological benefits of ventilating air.

From this research, they have been able to define minimum standards for quality, quantity, temperature, and humidity of required air for various occupancy types. Within buildings, according to the amount of mechanical control desired, a portion of the infiltrating air may be regarded as desirable ventilation. In other buildings, however, strict control over the internal climate is required. In these instances, infiltrating air is suppressed by "tightening" the building's exterior skin to prevent air exchanges.

A net positive pressure is then maintained by the mechanical system so that only exfiltration can occur. Replacement air is then introduced only through controlled intakes. This positive pressure is usually maintained by introducing more outside air than is exhausted through powered exhaust systems. Air pressure differentials are often employed to prohibit the flow of air from a contaminated or odor producing space to a "clean" space. Ventilating air is then introduced in measured quantities through special openings in the building.

Natural ventilation then can be defined as the intentional displacement of air through specific openings-- windows, vents, doors, and ventilators. The specific standardized quantities necessary to maintain health and comfort have been established under controlled laboratory conditions. The

Air Changes Taking Place under Average
Conditions in Residences, Exclusive of Air Provided
for Ventilation*

Kind of Room or Building	Number of Air Changes Taking Place per Hour
Rooms with no windows or exterior doors	$\frac{1}{2}$
Rooms with windows or exterior doors on one side	1
Rooms with windows or exterior doors on two sides	$1\frac{1}{2}$
Rooms with windows or exterior doors on three sides	2
Entrance halls	2

*Air changes taking place under average conditions in residences, exclusive of air provided for ventilation. For rooms with weatherstripped windows with storm sash, use $\frac{2}{3}$ these values.

(5) Air Changes In Residences

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

uniformity of those standards, however, will vary greatly under the circumstances of local natural climate and the influences of polluting industrial processes.

The Functions and Requirements Of Ventilation

Givoni¹ divides the function of ventilation into three distinct categories:

- . Health Ventilation
- . Thermal Comfort Ventilation
- . Structural Cooling

Health ventilation maintains the quality of indoor air, stale from oxygen depletion and odor contamination, by replacing it with outdoor air. In densely occupied spaces, outside air is considered necessary for dilution of micro-organism concentrations to reduce the opportunity of spreading communicable diseases. Quantities necessary for this "dilution" have not been well supported by research.

Thermal comfort ventilation prevents bodily discomfort by removing excess moisture from the skin that ordinarily would inhibit proper heat dissipation.

Ventilating air can cool the structure when indoor temperatures are higher than outdoor air. As mentioned, the relative importance of each of these three categories will depend on climatic factors and the specific influences of the occupancy type and local air quality.

Health ventilation replenishes oxygen supplies for breathing and oxidation of fuel in cooking and heating processes. It prevents high levels of carbon dioxide and prevents the build-up of carbon monoxide generated by flueless heating and cooking appliances. Bodily odors, smoke from

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

cigarettes and other malodorous pollutants are diluted by the ventilating air.

Alleviating these conditions and restoring good air quality depends on the quantity and the quality of the instreaming outside air. Figure (6) outlines maximum allowable contaminant concentration for ventilating air. The levels listed are met by ambient outdoor air in many major cities, but if below standard, the air must be filtered through a treatment device to bring its quality to or above the minimum level. Acceptable ventilation air may contain a mixture of suitable treated recirculated air and outdoor air such that the mixture meets or exceeds quality limits established for various occupancy types. Ventilation standards for required ventilating air in cubic feet per minute per human occupant are listed in Figure (7) for various functions in residences, commercial establishments, and certain industries.

Air is a mixture of a number of substances which operate independently in affecting the occupants of a building. Therefore, the amount of ventilation air necessary to reduce the concentrations of the most dangerous or offensive substances will establish the criteria for ventilation standards. Recent studies have shown that oxygen levels can drop 3-4% and carbon dioxide levels rarely fluctuate above 1%. The concentrations of oxygen and carbon dioxide, then are rarely used as direct criteria for establishing ventilation standards.

The level of odor within a building is not necessarily a health factor but influences the comfort and well being of the occupants. Reducing odors to an acceptable level usually required a greater volume of air than that needed to replenish oxygen supplies. The odor control required within a building is simply that disagreeable odors should not be noticeable. The fresh air supply to an occupied room should be sufficient to remove perceptible

Contaminant	Annual Average (Arithmetic Mean) g/m ³	Short-Term Level (Not to be exceeded More than once a Year) g/m ³	Averaging Period (hr)
Particulates	60*	150*	24
Sulfur Oxides	80	400	24
Carbon Monoxide	20,000	30,000	8
Photochemical Oxidant	100	500	1
Hydrocarbons (not including Methane)	1,800	4,000	3
Nitrogen Oxides	200	500	24
Odor	Essentially Unobjectionable**		

*Federal criteria for U.S. by 1975.

** Judged unobjectionable by 60% of a panel of 10 untrained subjects.

The levels listed are met by ambient outdoor air in many major cities, or will be met by such outdoor air when passed through minimal air treatment systems (containing suitable combinations of heaters, coolers, humidifiers, etc., and including roughing particulate filters.)

(6) Maximum Allowable Contaminant Concentrations For Ventilation Air

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

Application	Smoking	Cfm per Person ^b		Cfm per Sq. Ft. of Floor ^b
		Recommended	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	---
Brokers' 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	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 (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 govern; 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 explosion hazard

(7) Outdoor Air Requirements^a

SOURCE: Reprinted from ASHRAE Handbook of Fundamentals, 1972.

body odors, cooking smells, and cigarette smoke. For certain substances, the threshold stimulus for the olfactory sense is extremely low--concentrations of less than one part per million can be easily detected. For this reason, qualitative judgment by tested individuals is used in lieu of mechanical sensing devices. This technique establishes quality levels ranging from no odor through overpowering, unbearable odors by the majority agreement of the tested subjects.

These determinations are made under strict laboratory control, but the perception of certain intensities of different odors substantially vary under certain circumstances. Adaptation to odors occurs rapidly. Consequently, a person entering a room will have a different sensation of odor than a person who has remained within the room for a period of time. The air volume requirements per person may vary according to the number of people within a space and with presence or absence of smoking. Yaglou and Witheridge² related ventilation requirements to occupant density and found that the number of persons within a space is an important factor in determining the amount of required ventilation. They found that the ventilation rate could vary from 7 cubic feet/min./person with three occupants to 25 cubic feet/min./person with 14 people. This increase in ventilation rates was attributed to a reduction in the efficiency of ventilation in removing odors.

Different types of odors, themselves, will require different ventilation rates. Bodily odors will spontaneously degrade, disappearing with time even without any air change. Conversely, cigarette smoke may increase in intensity for a number of hours and then begin to slowly decrease over many

²Yaglou, L. P. and Witheridge, W. N., Transactions, Vol. 43, "Ventilation Requirements," ASHVE Research Report No. 673, American Society of Heating and Ventilation Engineers, New York, 1923, pp. 425-437.

hours, depending on the number of cigarettes smoked. For this reason, ventilation rates for areas where smoking is likely to occur require higher rates to control cigarette smoke and, therefore, are used as the criteria for establishing air volume requirements.

Even the high air volumes necessary to remove the most intense odors may be of insufficient quantity to dilute carbon monoxide concentrations in areas where flueless heating devices such as petroleum stoves, coal braziers, etc. are used. The toxic effect of carbon monoxide is well known. Hemoglobin in the blood will form relatively unstable compounds with both oxygen and carbon dioxide. This allows the exchange of these two substances both in the body and the lungs. Carbon monoxide, on the other hand, has a greater chemical affinity for hemoglobin than either oxygen or carbon dioxide. When inhaled, the carbon monoxide will form stable compounds with hemoglobin and prevent it from carrying out its vital role of supplying oxygen and eliminating carbon dioxide. If enough hemoglobin is robbed of its function, insufficient oxygen supplies will reach vital parts of the body, and the person will literally suffocate.

Unfortunately, the toxic level of carbon monoxide concentrations can be as low as 0.3%. Ventilation standards for workshops in the United States require air volumes sufficient to keep the level of carbon monoxide at or below 0.01%. Regardless of the variety and number of odors, contaminants, or poisons, the amount of air necessary to dilute or eliminate the most dangerous or most offensive substances is always used as the criteria for establishing standard ventilation rates.

Health ventilation has not been of great concern to residential builders in the past because of the great amounts of natural ventilation occurring in our older, poorly constructed

homes. However, with better construction methods, natural infiltration may not meet health ventilation requirements of a family. As in the case of the Minimum Energy Dwelling, the use of pilotless ignition to eliminate unwanted carbon monoxide production and air cleaning equipment in the air handling system may become mandatory.

The use of recirculating fans in bathrooms and kitchens containing activated charcoal for odor control eliminate the need to exhaust to the exterior. These can be used when odor control is the governing requirement for ventilation. Kitchen recirculating fans usually contain a cleanable metal filter as a grease trap.

Thermal Comfort Ventilation

Thermal comfort ventilation implies the maintenance or improvement of indoor thermal conditions. More specifically, it involves preventing uncomfortable feelings of warmth or skin wetness by the introduction of air. When such feelings overcome a person, he is likely to unconsciously adjust his clothing or open a window. Unlike permanent health ventilation requirements which are independent of climatic conditions, thermal comfort ventilation depends on the conditions of temperature and moisture content of inside and outside the building.

The actual physical relationships that govern heat exchange between man and the thermal environment with the building are numerous and complex and seem quite distant from the simple act of opening a window. In reality, the ability of the body to lose heat to the surrounding environment depends on dry heat exchange by convection and long-wave radiation, and evaporative heat loss and the geometry of the space affecting air movement and location of ventilating openings.

All these factors operate in a complex manner and are difficult to easily represent in engineering calculations. Since the degree of comfort can simply

relate to amounts of air passing over the skin to cool it, easier methods have been developed for determining how much ventilation is required. 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 laminar flow of air, large in volume and pressing 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.

Structural Cooling

The third function of ventilation is to cool the structure of the building when the inside temperature is higher than that outdoors. In buildings during hours when the indoor temperatures are above the outdoor level, ventilation lowers the indoor temperature. During the evening and night, the indoor temperatures are nearly always higher than outdoor temperatures and ventilation always has a cooling effect. In the daytime, however, the difference between indoor and outdoor temperatures will depend more on the color of the exterior walls, their thermal resistance and heat capacity, and the size and shading of the windows. It can be generally concluded that buildings with white walls, high resistance and heat capacity, and small, well-shaded windows will have indoor temperatures that are lower than those outside. Opening the windows would introduce warmer air.

The opposite is true for dark colored buildings with small heat capacity and resistance, and large unshaded windows. Here, indoor temperatures are higher than outdoor and daytime ventilation is required. If enough air is moved through the house, the indoor-outdoor air temperature difference may be relatively small. The internal surfaces of the external walls are also

reduced in temperature by daytime ventilation, but the effect is less pronounced than with the reduction in indoor air temperatures. These determinations made by laboratory testing clearly point to the importance of white walls in reducing indoor temperatures and the need for large amounts of ventilation.

Since houses are being more tightly built than in the past, the likelihood of intentional natural ventilation or mechanical cooling becomes greater. Outside air can be admitted by manual operation of windows or vent or by mechanical sensing and automatic opening of air vents. During the early design phases of the Minimum Energy Dwelling, the use of both methods was considered.

The use of natural ventilation for cooling in the Southern California area was considered ideal. Mission Viejo is within five miles of the modifying effects of the Pacific Ocean. As explained in greater detail in the "Comfort and Climate" chapter, there is a very consistent daily swing in wind direction. During the day, a strong wind is generated in a westerly direction, and at night a more moderate east wind blows. Because of this definite shift, the design could block the hot day wind allow the cool night wind to ventilate the home.

Difficulties arise when trying to incorporate these ideas in a standard developer home. The home could be directed in one particular orientation on one lot and in a completely different orientation on another, making natural ventilation hard to adequately design. Accurately predicting the effect of ventilation over a year is also difficult. The wind, as a dynamic force, is hard to quantify and predict results and can change dramatically on individual days from the published average date. Therefore, a great deal of further investigation needs to be done by scientific research to establish easily predictable gross results. Until that day comes, application of

natural ventilation by engineers will be limited no matter what the practical implications. Intuitive design concepts, however, will continue to be incorporated in special custom projects.

The concept of thermal comfort ventilation for MED is based on the use of an economizer ventilation system or economizer cycle. It is based on electronic sensing and forced movement of air. Further explanation is given in the "Mechanical Systems" chapter. The economizer cycle contains a sensing device which measures the humidity and temperature of the outside air. If it is not above the comfort range and the home requires cooling, outside air will be introduced mechanically to cool the interior spaces.

A great advantage in this particular system is the predictable cooling of the home without an air conditioner. Application is ideal at Mission Viejo. The climate is relatively dry and mild year around with a great percentage of opportunity for cooling with outside air. The system offers further advantages in well constructed homes such as MED. A tighter and better insulated house allows less heat to escape, increasing the need for cooling although the air temperature is below the comfort zone. In the California area, based on an extensive computer study, the economizer cycle was shown to reduce air conditioning requirements up to 60%.

Attic Ventilation

One of the most important aspects 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 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 (8) and (9). Wind blowing roughly perpendicular has a reduced effect, causing only local air movement near each vent without the benefit of cross ventilation. (10) Soffit vents will move air only along the attic floor or (11) will intake and exhaust along the length of each vent. (12) (13) Combinations of both gable ends and soffit vents still are not totally effective; both tend to act independently of each other.

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. (14) (15) This arrangement allows the air moving 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.

(8) Gable End Louvers - Parallel To Wind
Parallel To Wind

(9) Gable End Louvers - Perpendicular To Wind

(10) Soffit Vents - Parallel To Wind.

(11) Soffit Vents - Perpendicular to Wind

(12) Combination - Parallel To Wind

(13) Combination - Perpendicular To Wind

(14) Ridge And Soffit - Parallel To Wind

(15) Ridge And Soffit - Perpendicular To Wind

The effectiveness of attic ventilation will be shown by reduced attic floor temperatures in the summer. Figures (16) and (17) 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 (16) shows the effect attic venting has in reducing attic floor temperature. (18) 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.

One might surmise that a similar result would occur in the winter. Wind velocities (usually higher in the winter) would exhaust any heat in the attic to increase heat loss through the ceiling. This usually leaves the attic floor no more than 2°F. above the outside air temperature regardless of the amount of free area in the attic vents. If the ceiling is adequately insulated, the amount of ventilation will show little effect on heat loss. The conclusion drawn from this information implies a "drawn for summer" rule because the benefits are much more pronounced in hot weather conditions.

It is obvious from this review that the attic ventilation will contribute a substantial energy savings for domestic cooling plants if proper venting is installed. This savings of a cooling load, however, springs only from passive attic ventilation that uses only vent openings. Mechanical venting, with the use of a fan, moves more air but usually is not cost effective requiring more energy to run the fan than to allow the heat to penetrate the roof insulation and be removed by an air conditioner.

(16) Attic Floor Temperature

SOURCE: Fundamentals of Residential Attic Ventilation

(17) Roof Sheath Temperature

SOURCE: Fundamentals of Residential Attic Ventilation

(18) Ridge And Soffit Ventilation System

If a home has no air conditioning system or economizer cycle, a house fan becomes a good investment. It can be used to reduce temperatures and increase air movements on windless summer days when the sun is shining and at night, can bring in cool night air. The fans can vary but are generally sized according to the number of air changes that may be appropriate. The rule of thumb states that southern regions of the country may require one air change every 3 minutes while northern climates need only one change every 10 minutes.

The "ventilation" reading is a number used in choosing a fan and is found by dividing the cubic foot volume of a house by the air change per minute. Thus a house over 10,000 cubic feet at two changes per minute would have a ventilation reading of 5,000 cubic feet per minute. This number is not the free air capacity of the fan, which describes maximum output, but its rating under the load of resistance (ducts, louvers, screens, etc.), that will reduce the maximum of output volume. The fan should be well built for maintenance-free operation and should have the flexibility of two speeds for cool nights and evenings when a lower speed will still supply adequate air with quieter operation.

Weatherstripping on doors and windows is becoming increasingly important as infiltration becomes a dominant component in the energy consumption of a house. (19) 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 point where two

INTERLOCKING WEATHER STRIP		Bronze And Zinc	Performs very well to stop leaks, drafts, dust and light. Very unobtrusive.	Condensation may freeze and lock strip in severe weather. Easily damaged by rough usage. Expert adjustment required. Not for metal doors.	Low	Higher Than Most	Requires An Expert
COMPRESSION SEAL GASKET		Bronze Aluminum Stainless Steel	Good draft control; fair control of leaks and dust. May be used in cold climate; may be used on metal doors also.	Easily deformed. May tear. May hum in wind. Doors may be difficult to close. Not effective against light, humidity or noise. Damageable and non-adjustable.	Low	Low	Generally Requires Experience
NEOPRENE GASKET		Aluminum And Magnetic Vinyl In A Vinyl Bellow Strip	Automatic magnetic seal. Excellent sound, light and weather seal.	Primarily metal doors. Requires extra strip for wood doors.	Medium	Low To Moderate	Surface Applied Magnetic Strip Secured To Jamb And Header Compression Seal To Hinge Side Of Door
SPONGE PAD		Aluminum And Neoprene Or Vinyl	Cold weather vinyls available for use to -50°F. Compression seal is very effective when properly insulated.	Some types are obstructive. Many types require close alignment of doors.	Low To High	Low To High	Some Experience Necessary
METAL DOOR GASKET		Aluminum Or Bronze Cover Strip Holding Gasket Of Vinyl Extruded Or Sponge Neoprene Felt Or Wool Pile	Excellent seal against leaks, drafts, noise, light, humidity. Very durable, should last life of door. There is a gasket weatherstrip for every climate. Cover strip may be painted.	Can be seen, but usually not obtrusive.	Medium To High Depending On Materials	Low	Surface Applied Usually Easy To Install And Generally Does Not Require Experience
METAL DOOR GASKET		Aluminum And Neoprene	Threaded adjustable compression strip captured in housing—may be moved in and out to give ideal seal. Excellent sound, light and weather seal.	Can be seen, but usually is not unsightly	High	Low To Moderate	Surface Applied Secured To Jamb And Header With Screws. With Or Without Integral Door Stop
JAMB		MATERIALS	EFFECTIVENESS	DISADVANTAGE	MATERIAL COST	INSTALLATION COST	INSTALLATION
ASTRAGAL							
SINGLE ACTION DOUBLE DOOR		Wide Variety Depending On Condition	The simplest solution is usually the best. Some facility of adjustment is important.	Some types are obtrusive in appearance. Many types require close alignment of doors.	Low To High	Low To High	Some Experience Necessary
NEOPRENE BUMPER		Wide Variety Depending On Condition Neoprene Bumper	Many types to choose from.	Expensive - Surface types may be unsightly Concealed design is attractive.	Low To High	Low To High	Some Experience Necessary

(19) Weatherstripping Matrix

Simple	Low	Low To Medium	May become inoperable Out of adjustment when clogged with gravel.	Simple surface applied. Weatherstripping attached to door bottom and contacts threshold sealing out drafts, dust, light.	Wide variety of metals depending on condition		INTERLOCKING SADDLE
Simple	Low	Low To Medium	Fastens on side of door. Exposed to view. On swinging door not ef- fective against leaks. may drag.	Adjustable. Effective against drafts, dust, noise, light and humid- ity.	Metal retainer holding vinyl extruded on sponge neoprene or felt.		NEOPRENE SWEEP
Simple	Low	Low To Medium	Wears out and becomes flattened with use.	Short life span. Excel- lent seal against leaks, drafts, noise, light, dust, humidity. Wiping action. Seals with very light pressure. Con- cealed with exposed rain drip. Adjustable and long lasting.	Aluminum extrusion holding vinyl on neo- prene extrusion.		THRESHOLD BUBBLE SEAL
Generally Requires No Experience	Medium	Low	Some types fasten on side of door and are partially exposed.	Excellent seal against leaks, drafts, noise, light, dust, humidity. Wiping action. Seals with very light pressure. Concealed with exposed rain drip. Adjustable and long lasting.	Aluminum extrusion holding vinyl or neo- prene extrusion		UNDER DOOR BUBBLE SEAL
Requires An Expert	High	Low To Medium	Most doors, especially metal doors must be specially prepared.	Excellent sealing action against leaks, drafts, humidity, noise, dust, light. Adjustable	Steel, galvanized steel or aluminum, with felt or closed cell neoprene drop.		CONCEALED AUTO. DOOR BOTTOM
Fairly Simple	Medium	Low To Medium	Exposed to view and not very attractive.	Excellent sealing action against leaks, drafts, humidity, noise, dust, light. Adjustable.	Aluminum, bronze or stainless steel with felt or closed cell neoprene drop.		EXPOSED AUTO. DOOR SWEEP
INSTALLATION	INSTALLATION COST	MATERIAL COST	DISADVANTAGE	EFFECTIVENESS	MATERIALS	THRESHOLD	
						ASTRAGALS	
Some Experience Necessary	Low To High	Low To High	Some types are obtrusive Many types require close alignment of doors.	The simplest solution is usually the best. Some facility for adjustment is important	Wide variety of metals depending on conditions with closed cell neo- prene sponge		SINGLE ACTION DOUBLE DOOR
Some Experience Required	High	High	Expensive surface types may be unsightly, al- though design is attrac- tive.	Withstands heavy use. Adjustable mortise type is unobtrusive. One side may have wool pile for close fit.	Aluminum and bronze extrusion		HEAVY DUTY SINGLE ACTION

(19) Weatherstripping Matrix

SOURCE: Weatherstripping & Thresholds, 1970.

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.

- 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.

The amount of unwanted outside air is reduced considerably in the Minimum Energy Dwelling from the standard in residential construction. The walls of the home are wrapped with a continuous polyethylene sheet, serving both

as a vapor and infiltration barrier. When installed, care was taken to protect the polyethylene sheet from punctures or tears. If properly installed, a nearly perfect barrier will result with only the doors, windows, and sill plate remaining for infiltration to occur. These problem areas were resolved by some standard techniques.

The sill plate is sealed by the use of a putty-like material placed between the bottom 2" x 6" sill plate and the foundation wall. The use of a sill sealer fills the break in building materials occurring at the sill. The interior and exterior materials of the wall stop at the sill creating an easy passage for energy. The sill sealer will prevent this loss. The putty is rolled out on cleaned concrete and the wall section is placed on top. The sill plate has pressure applied, and the putty is squeezed from under the sill plate to create a good seal.

The windows installed were manufactured by the Pella Window and Door Company. The type used is an operable casement window. The window sash closes against a compressible gasket tubing manufactured out of a flexible polyvinyl chloride and is placed in the window frame. The weatherstripping installed extends around the entire preimeter of the window. According to the manufacturer, the infiltration rate is reduced by as much as 14 times compared to accepted industry standards for infiltration per foot of window crack, from 45 cubic feet per hour to 3.2 cubic feet per hour.

(20) Between the rough opening and the finished window frame occurs another potential area of air infiltration. In MED, the opening was stuffed with fiberglass insulation and sealed with a silicone sealer.

The sliding glass door in the kitchen was also manufactured by the Pella Window and Door Company. A compression seal is placed along the side

(20) Rough Window Opening .

edges of the sliding door. The weatherstripping is placed in such a manner that the harder the wind blows against the door, the more compressed the weatherstripping becomes. The information supplied by the manufacturer gives a value of 2.0 cubic feet per lineal foot of crack or 63.6 cubic feet per hour per door with a 25 mph wind velocity.

The entryway of the MED home has three doors connected to it. One opens to the garage, one to the living room, and (21) the front door opens to the outside. The entryway provides a weather lock for the home, eliminating unnecessary air leakage. The occupants of the house, when entering from either the garage or the outside, will use two doors, thus preventing any direct air losses. As designed, the entryway has become an additional storage room for the family and, therefore, a saleable feature. The front door is metal with a magnetic weatherstripping around the edges of the doorway.

The only other openings besides the sliding exterior doors in the rear of the home are for ventilation purposes. The air handler is connected to the outside and by air ducts to the living spaces. Unwanted outside air, if not properly dampered, may find its way through the ductwork and into the living space. A more serious area of possible infiltration is at the relief damper in the upper wall of the kitchen. The relief damper is a gravity vent operating whenever the pressure difference in the attic is less than in the kitchen. As designed, the pressure difference is only greater when the air handler brings in outside air for the economizer cycle. A potential problem exists, however, if a lower air pressure is created by air patterns through the attic. The unintentional opening created by the pressure difference will suck conditioned air from the interior of the house.

The refrigerator has had its condenser coil placed in an adjacent closet connected to both the exterior and

(21) Entry To MED House

interior space. A complete description occurs in the "Internal Loads" chapter. A good quality residential damper was selected to prevent air passage from the outside to the inside, but the actual performance will need to be determined to ascertain if leakage is a problem. If the seal is of lower quality than expected, the desired benefit from removing the condenser from the refrigerator will be lower.

Preliminary results indicate the MED home lowers the infiltration rate to about one-third the value considered normal for a house of this size. The quality of the ductwork appears to be a problem, however, requiring greater care in future designs. In the past, the ductwork losses were not considered a significant problem. But with tighter construction, the need for better installation techniques for residential ductwork becomes necessary. With the mechanical ventilation system off, the infiltration with a 5 mph wind is approximately 50 cubic feet per minute.

(22) MED House Attic Configuration

The MED home has a limited amount of attic space. (22) The attic space occurs over the two smaller bedrooms, the hallway, and bathroom areas. In the MED home, the attic area is facing the southwest and the direction which the greatest intensity of sun and the highest outside temperatures occur. Ridge and soffit vents were installed in the attic areas of the MED home to increase the natural flow of ventilation. The ridge and soffit vents face perpendicular to the prominent wind direction. In order to achieve satisfactory results, 1.5 square inches of soffit vent were installed for every square foot of attic floor. The ridge vent area is equal to the amount of soffit openings.

SOLAR COLLECTORS

The Minimum Energy Dwelling uses an evacuated-tube solar collector. The collectors have a greater capacity in collecting the high temperatures needed (near boiling) than the standard flat-plate collectors. High temperature water is required in this project to be able to operate the air conditioning equipment. A central spline covered with a high performance insulation distributes water to the 48 evacuated tubes in each collector module. As solar collectors play an ever-increasing role in the energy supply systems of homes, the integration with architecture will become more dominant.

The solar radiation available outside the earth's atmosphere is quite constant at a value of 430 BTUH per square foot in a plane perpendicular to the sun's rays. This value, known as the Solar Constant, undergoes considerable change when the sun's radiation traverses the earth's atmosphere. Some rays penetrate to directly strike the earth's surface while others are scattered by water vapor, dust particles, or other contaminants in the air before reaching the earth. The sun's radiation, then, arrives in two components--direct and diffuse. The relative proportion of the diffuse component depends on atmospheric conditions and varies from 10% in arid regions to 100% under dense cloud cover. During periods of solar collection, the diffuse component comprises a relatively small fraction of the total, usually 8% to 10%.

Man's use of solar energy has been suggested as an energy source for thousands of years. In fact, the Greek inventor, Archimedes, used mirror-like reflectors to concentrate the sun's energy on a fleet of attacking Roman ships. The focused energy set the Roman galleys afire and thwarted their attack.

The two factors responsible for the increased interest in solar energy is:

- the availability of inexpensive transparent materials along with
- an increase in the cost of non-renewable energy resources.

In earlier times, the making of glass was a time consuming and costly process. During the latter part of the 19th century, factory methods were introduced making glass a widely used commodity. Advances have continued into the 20th century with the introduction of a variety of transparent glazing materials made from plastics. Although inexpensive glazing for solar collectors has been available, the rapid increase in fuel costs in the latter part of 1973 has made the advantages in the use of solar energy apparent.

Shown in Figures (1), (2), and (3) is the cost of the three main forms of energy as of July, 1976.¹ In Figure (1), the cost of electrical energy is shown. In the Pacific Northwest, the lowest electrical rates in the country exist due to the abundance of renewable hydro-electric power. The opposite condition occurs on the other end of the continent. In New York City, the electrical rates are over six cents per kilowatt hour, based on a winter rate of 500-750 KWH. The costs in the Pacific Northwest are greater by a factor of six than those in New York City.

Oil does not have such a price discrepancy. The price is .48 cents per gallon in the northern interior of the country and drops to a low of .34 cents per gallon near the Gulf Coast giving a ratio of 1.4 between the high and low prices.

Natural gas remains the most economical in relation to the cost of the other fuels. Natural gas prices are most expensive in the coastal eastern and northwestern United States. As a comparison, using the most expensive rates available for each of the three fuels, the cost per million BTU for electricity is \$17.60, \$3.40 for oil, and \$2.86 for gas.

In the future, the prices will continue to ascend. Although difficult to predict, in general the price of fuels can be expected to increase at a rate of approximately 10% per year. Natural gas will increase at a slightly faster rate.

In order to determine the economic feasibility of solar energy, the cost of the alternate fuel must be compared with available sunlight. Figures (4), (5) and (6) indicate the solar potential in various areas of the country. The solar benefit for a given fuel was

¹Energy Research & Development Administration, Division of Solar Energy, An Economic Analysis of Solar Water & Space Heating, U.S. Government Printing Office, Washington, D.C., November, 1976.

(1) Cost of Electrical Energy
(¢/KWH) July, 1976

(2) Cost of Oil Energy
(¢/Gal.) July, 1976

(3) Cost of Natural Gas
(\$/MCF) July, 1976

(4) Solar Benefit - Electricity
(H/Year) (\$/10 BTU)

(5) Solar Benefit - Oil
(H/Year) (\$/10 BTU)

(6) Solar Benefit - Natural Gas
(H/Year) (\$/10 BTU)

derived by multiplying the average yearly radiation falling on a horizontal surface per day and the cost of the alternate fuel per million BTU. The value calculated was divided by 10,000 to obtain a readable one or two integer number.

In looking at the three figures, the solar benefit is more dependent upon the cost of the alternate fuel than the availability of sunlight. Since the numbers in each graph are directly comparable, some interesting inter-relationships exist. The lowest value on Figure (4), electricity, is four which is greater than the highest value on Figure (6), gas. Also of interest in the electricity graph (4) is the solar benefit around New York City which is greater than the sunny southwest. This is due to the high cost of electricity.

The numbers generated are not specific to a particular use such as domestic hot water heating or space heating but do give an indication of the relative feasibility of solar energy in comparison with other areas of the country and different alternative fuels. To determine the economic justification, the actual project specifics would need to be determined.

Also not included in the solar benefit numbers is the efficiency of use. Electricity is more efficiently used at point of use. Heating a home with electricity is nearly 100% efficient. To heat a home with oil, a furnace is required burning at an efficiency of 70%. Therefore, if the efficiency of use is known, the value of solar benefit for a particular area should be divided by the efficiency to determine more realistically the solar potential.

Solar energy can be used for a variety of uses. Shown in Figure (7) are some of the common uses of solar energy in a residential system. The uses of solar energy are listed in order of economic feasibility.

USES OF SOLAR ENERGY

	SWIMMING POOL	DOMESTIC HOT WATER HEATING	SPACE HEATING	SPACE COOLING	ELECTRICITY
DESCRIPTION OF USE	The use of solar energy to heat water for swimming pools. The best application is in moderate climates. Utilizing solar energy for swimming pools yields one of the best returns on investment. A rough guide for collector area is one square foot of collector for each square foot of pool surface.	Use of solar energy to heat water for domestic use as for showers, baths, dishwashers & washing machines. The amount of collector depends on the geographic area and required uses. A rough estimate would be 20 sq. ft. of collector per person. 88% of the yearly energy requirements are usually supplied.	Use of solar energy for space heating. Primary sizing is 1/3-1/2 the floor area of a home in sq. ft. Two primary methods of collection are w/water or air systems. Another method involves using building materials to accept sunlight (passive use). 60% of yearly energy requirements are supplied with a proper design.	Use of solar energy for air conditioning a home. A rough guide for collector area would be 15-50% of the floor area of the house. The amount of collector ranges widely due to variations of cooling requirements and collector performance. 80% of yearly energy requirement is usually supplied.	Conversion of solar energy to electricity (still highly experimental). A primary string would be 20%-30% of the floor of the home. Photovoltaic systems preferred & are integrated with other solar space conditioning systems. The electrical system can be expected to supply 85%-100% of the requirements.
MATERIALS	Plastic is a common material for the absorber plates, along with metal, primarily copper. Most collectors (because of the low temperature required for swimming pools) do not require back panel insulation or glazing.	The collectors used for domestic hot water heating can be of medium quality and are manufactured with a metal absorber plate. The collectors should be well insulated to prevent back and side edge loss. The collectors must be glazed with at least a single pane of glass.	The collectors required are medium quality with one or two glazing covers. The use of a selective surface on the absorber plate and water white crystal can be justified in many cases.	Materials used must withstand high temperatures required to produce solar cooling. A problem of high temperatures is the insulation in contact with the absorber plate which can cause disintegration of insulation. High performance collectors are required.	Two collector materials are presently being investigated—Cadmium Sulfide and Silicon. Silicon is a common material and low in cost, but production is difficult in mass.
DESIGN FEATURES	Most swimming pool collectors are used to heat the water during the cold Spring and Fall. In order to obtain a maximum efficiency, the collectors should be tilted at an angle equal to latitude. The temperature of the water going into the collector is 75°-80°F.	The domestic hot water load remains relatively constant throughout the year. To obtain year-round production, the collectors should be tilted at an angle equal to latitude. The temperature of the water, at optimum operating conditions, is 110°-120°F, entering the collector.	The space heating load varies widely over the year. Usually the maximum load occurs in December or January when solar is at its lowest. The collectors are usually tilted at an angle of latitude +10°. Temperatures for space heating required range between 60°-110°F.	A good match is usually between energy requirements and supply of a solar cooling system. An increase in sunlight increases both the cooling load and the solar energy collected. The collector tilt optimum is latitude minus 10°. The inlet temperatures into the collector, for best operation is 175°-195°.	Most photovoltaic systems are designed to supply a portion of the air conditioning requirements. Therefore the collectors are tilted to maximize summer production at latitude +10°. The solar cells operate most efficiently at lower temperatures and must be cooled by air or water. The heated air or water is used similarly to that of a standard system.
MECHANICAL SYSTEM AFFINITIES	The collectors are placed before the booster heater in the water circulation loop to obtain maximum solar benefit. Therefore, the lowest temperature water enters the collector and the smallest heat loss from the absorber plate occurs. This condition produces the greatest efficiency in production.	The system can be installed alone or as part of a space cooling or heating system. An additional hot water storage tank is usually installed with an integral heat exchanger.	A large number of possible mech. systems can be incorporated & in most cases require an experienced designer. One of the best combinations is the use of a solar system w/a heat pump, which derives usable energy from low temperature sources, keeping collector efficiency at maximum.	The system is usually sized for the cooling load; therefore, a substantial amount of the heating and DHW requirements are supplied by the overproduction of the solar collectors. Chilled water storage should be considered during system design.	The power collected from the solar cells is in D-C current. An inverter is required to convert to A-C for use with standard appliances. The cooling system is usually standard vapor compression machine.
INSTALLATION	Installation is the easiest of any system type, and can be designed with little or no engineering help. Many local suppliers in areas with a greater than average number of swimming pools have the needed experience and materials.	Packaged systems which include all required equipment are available from many local suppliers in many areas of the country. The availability of systems is increasing.	Portions of htg. systems come pre-packaged; i.e. collectors, controls, auxiliary heating system. The components must be assembled on site, possibly adding some complications. A few manufacturers offer complete packages, but attempts are being made to establish national service network.	Very few solar-cooled residences are built. Therefore, for the near future, at least, development of pre-package systems lags behind other solar uses. Solar cooling is the most complex system for buildings. A great amount of care is required in engineering and installing the system.	An actual home has not been built. Future installations may be simple for solar collectors. An array may come to the site similar to a rolled roofing. The array could then be nailed to the roof sheathing to form a waterproof roof membrane.
ECONOMICS	The cost of collectors for swimming pool heating is at the lowest end of the cost scale. Prices of \$4-\$8 per square foot are common. Total system cost can be estimated at \$10-\$15 a square foot. The price includes all additional costs such as piping and controls.	A medium-priced collector between \$8 & \$12/sq. ft. is required. The total system cost can be estimated to be approximately \$15-\$20/sq. ft. Use of solar domestic hot water systems can be justified in geographic areas where electricity is the alternate fuel.	A medium-priced collector between \$8 and \$12/sq. ft. is required. The total system cost can be estimated at \$18-\$25. The use of solar for space heating can be justified in most areas of the country where electricity is used as the alternate fuel.	A high performance collector will cost between \$12 and \$25 a square foot. The total solar system cost can be estimated at \$35-\$60/sq. ft. The use of solar cooling is still marginal at best in most areas of the country. Newer developments, could however, reduce cost.	A photovoltaic array for a home presently costs up to 1 Million Dollars. The price is expected to come down in the future & to compete with other space conditioning methods by 1990. Solar cells are produced by the same process as is used in the computer field; lower prices will come with mass production.
EFFICIENCY OF USE	The efficiency of solar swimming pool collectors is between 40% to 60%. The efficiency is computed by the division of the sunlight striking the collector into the amount of energy supplied to the pool.	The efficiency of use is between 40% to 60% when medium priced collectors are used.	The efficiency of use is between 40% to 60% when medium-priced collectors are used.	The efficiency of use is between 20% to 40%. The low efficiency is primarily due to the absorption chiller efficiency of .6.	The efficiency of silicon cells is around 10%-20%, and cadmium sulfide is around 6% to 8%. System efficiency can be expected to be 95% of these values.
MAINTENANCE	The collectors, if made of plastic, will degrade in a few years from continuous exposure to sunlight. It will be necessary to drain the system in late Fall to prevent freezing. A heat exchanger can prevent possible scaling, but will lower efficiency.	This is an easy system to maintain, although a possible area of concern would be maintaining proper levels of antifreeze if this solution is used. This should be checked once a year.	The freeze-control mechanism, either drain-down or anti-freeze, need to be checked yearly.	A potentially difficult system to maintain. The high temperatures required can cause a more rapid disintegration of component parts. The absorption chiller should be serviced once a year.	The array should require very little maintenance. Replacement of battery storage would be necessary periodically.

(7) Uses of Solar Energy

(8) Flat-Plate Solar Collector

"A solar collector and its construction's "total energy cost" can be generously estimated at 25,500 KWH whereas the expected annual receipts are well over 10,000 KWH. It should, therefore, recover its energy outlay in three years."

Peter Harper

Conventional flat-plate solar collectors are usually composed of a collector plate which absorbs the sun's energy in a glass cover plate which prevents its escape. (8) The sun's radiation, which has short wavelengths, readily passes through the single or double glass cover and strikes the blackened collector plate causing it to heat. The collector plate, being a good absorber, conversely is a good emitter. However, the radiation emitted from the black body collector plate is in the infra-red portion of the spectrum. Since normal glass is opaque to these long wavelength their exit is blocked and the heat trapped inside. This one-way passage of the sun's radiation is known as the "greenhouse" effect and is one of the basic principles on which flat-plate solar collectors depend.

The coating of the collector absorber plate for most heating applications can generally be commercially available flat black paint which has an absorptivity of approximately .94 and an emissivity of .94. Higher temperature collection, however, will require the use of an optically selective surface which can have an emissivity that is substantially lower than its absorptivity. There are coatings for copper, aluminum, or steel collector plates which have absorptivities of .94, with emissivities of about .10. The selective surface minimizes the re-radiation outward from the collector plate to the glass covers and thus increases collector efficiency by reducing heat losses to the outside by conduction. Collectors in low temperature applications do not need a special coating, but as the desire for higher temperatures increases, so does the need for a selective surface. It is important to note, though, that the quality of emissivity is far less important than the quality of absorptivity which should be maintained above .93 for solar collectors.

Once the collector surface has been heated, it is necessary to extract this heat by a transfer fluid which

can either be a gas as in air collectors, or a liquid which is more typically used. Water, with additives, is the most common liquid heat transfer fluid. It is circulated through a tubing array which is bonded to, or integral with, the collector plate. It then flows into a header system which returns it to an insulated storage tank where the heat there retained can be drawn upon for use in the house.

Figure (9) illustrates the Owens-Illinois "SunPak". (10) It is an evacuated tube collector that is structured differently, but operates similarly to absorb and collect the sun's energy. (11) It differs significantly from flat-plate collectors by exploiting the capabilities of existing glass manufacturing techniques to:

- Incorporate an insulating vacuum around an internal absorber surface;
- Form glass into strong tubular shapes which can be used to both absorb the sun's heat and contain the circulating heat transfer fluid.

Achieving these features requires more extensive manufacturing and greater factory control than is needed in the making of flat-plate collectors. The consequent price increase that ensues is partially offset by the Owens-Illinois' comparatively greater heat production capabilities during its operation within a solar system. Rapid manufacture in large numbers with the existing perfected techniques of the industry will further increase the competitiveness of the Owens-Illinois Collector.

Physical Description

The Owens-Illinois "SunPak" differs widely in appearance from conventional flat-plate collectors on the market. Instead of using flat glass, it is made from a series of glass tubes which stem from a central manifold that is designed to deliver water in a series flow pattern to a rack of 24 tubes. This number of tubes form a nominal 4 x 8 collector panel which can be chained to others to form larger arrays as illustrated in Figure (12). This

(9) Owens-Illinois Evacuated Tubular Solar Collector

(10) Tubular Collector Components

(11) Flat-Plate Collector Components

This open framework of tubes and manifold has the image of machinery and appears strikingly different from a flat-plate collector array which, like a glass curtainwall, presents a flat, smooth, continuous surface.

Each module is composed of four main components:

- Glass tube collector elements which absorb the sun's energy and channel circulating water that collects the heat.
- A piping manifold which routes water to the individual tubes.
- End support structures which hold the collector tube ends in place.
- A reflector that lies underneath the collector that reflects radiation up into the tubes.

Figure (13) is an end view of these four components.

Collector Tube Elements

A single glass tube collector element, approximating four feet in length and two inches in diameter, consists of three tubes inside one another. (14) The middle tube is the absorber tube which is covered on its outside surface with a coating that has properties of high absorptance in the solar spectrum. The largest tube or cover tube surrounds the absorber tube and is heat-sealed to it at one end, after the air in the annular space between them has been drawn off to form a vacuum. This evacuated surface virtually eliminates heat transfer from the absorber tube to the outside air. Because of this low loss property, anti-freeze solutions normally used to prevent freezing of a collector fluid can be eliminated, according to the manufacturer. However, further testing will be required to substantiate this claim for more northern climates. Even with continuous circulation, the possibility may exist for freezing in the event of inadvertent power loss or pump failure, particularly an extended shutdown in sub-freezing conditions. Recommended practice at this time is to design for freeze protection under extended no-flow conditions, considering

(12) Configuration Of A Collector Module

(13) Main Components - Owens-Illinois Solar Collector

(14) Basic Tubular Components - Owens-Illinois "SunPak"

SOURCE: Owens-Illinois

(15) Section Through Collector Tube

SOURCE: Owens-Illinois

piping as well as collectors. Water alone can be used in cold climates without fear of freeze ups. Besides containing the evacuated space, the cover tube also isolates the selective surface of the absorber tube from the damaging effects of the environment. A small, but important detail at the tube ends helps hold these two tubes together for a longer life. Figure (15) is a cross section through the end of a collector tube and depicts the triple tube-in-tube concentricity of cover, absorber, and distribution tubes. Located at the end in the evacuated annular space is a spring which serves two functions. It supports the absorber tube which is only attached by heat fusion to the cover tube at the opposite manifold end, and it absorbs expansion of the absorber tube. Without this spring, the absorber tube would be precariously cantilevered within the cover tube, and the weight and pressure of water within it would surely cause this solitary joint to snap. The spring, therefore, gives it the structural support of a simple beam and keeps it concentrically aligned with the cover tube. Second, it acts as a cushion to absorb a differential expansion and contraction that occurs between the hot absorber tube and the cooler cover tube. The smallest innermost tube is glass and delivers the working fluid that circulates through the tubes to pick up heat from the absorber tube. In actuality, this tube is not attached in any way to the glass tubes but is cantilevered from the sockets in the manifold. An individual absorber-cover tube assembly is slipped over the inner tube and seated into the manifold socket. Metaphorically, this triple tube assembly can be considered a thermos bottle with a straw in it that delivers or carries away the collector fluid.

All the tubes in a module are not rigidly attached to the manifold but are only firmly held in place there. In order to prevent leaks at this jointure, an O-ring is set within each socket. Each tube, when slipped into its O-ring, is cushioned and sealed at

(16) Copper Cups and Pipes Are Brazed To Form Internal Fluid Passageways Of The Owens-Illinois Manifold

SOURCE: Owens-Illinois

its lip to allow a simple pressure fit that avoids the complications of threaded joints or permanent seals, permits the circulation of water between the manifold and tubes without fear of leaks, yet allows quick, simple installation or removal of any tube for maintenance. The replacement of the O-rings themselves every 20 years is expected by the O-ring manufacturer. In a normal residential installation, they can be replaced by two men in a day.

The Manifold

The manifold is the second main component of the "SunPak" collector. It looks simple from the outside, but reveals a greater complexity when its internal parts are examined. Figure (16) depicts the bare internal fluid passageways of a portion of a manifold. Inlet and outlet header pipes run between stamped copper cups and tubing which have been brazed together to form channels for the collector fluid. This metal backbone is the skeleton of the manifold, which in the final product, is hidden by urethane foam which completely surrounds it and forms a 16" diameter cylinder. In order to completely cover the internal parts, the 4' copper manifold assembly is placed in a mold where urethane

foam is injected. The foam expands throughout the entire volume of the mold, entirely covering the copper parts. When removed from the mold, the manifold parts are completely insulated against heat loss and protected from damage. An additional benefit of the molding process is the nicely manufactured appearance of the manifold.

At the ends of each manifold length, the copper inlet and outlet header pipes protrude. They can be connected to supply and return lines, joined to other lengths of manifold, or capped off if it is an end module. Special insulating joint covers and end caps are supplied for each of these conditions to keep the manifold entirely insulated. Underneath each modular length of manifold are four bolt holes drilled at a conventional 6" on center. This permits firm anchorage of the collector manifold at rafter framing points.

End Supports

The third main component of the Owens-Illinois Collector is the end support structures which hold the tube ends in place. (17) They are designed to keep the tubes parallel to each other and

TOP VIEW

SIDE VIEW

(17) End Support Structure for Owens-Illinois "SunPak"
As Mounted On The MED Home

to the reflector surface, and squarely aligned with respect to the manifold. Besides aligning the tubes, they also prevent any movement. Without proper restraint, the tubes would be expelled from the manifold by the hydraulic force acting on them. Since the pressures can be substantial, the end supports are designed as structural members which support weight. Calculations indicate that an aluminum channel 4" x 1-1/2" can adequately overcome the reactions of the tubes under pressure.

For each tube in a module, a hole approximately 2" in diameter is cut from the channel web. In order to register these holes with the manifold sockets, the channel is raised from the mounting surface by two "Z" clips which also anchor it in place. Since the channel is point-supported by the two "Z" clips, it must have the stiffness of a strong beam. To give it further strength and help prevent possible deflections, four tension rods per module tie the end channels back to the collector manifold.

Another component in the end support structure is the retaining cup supplied for each tube. They twist-lock into the channel to form a pocket or seat for the tube ends and contain an internal secondary cup with a screw adjustment. When tightened, it presses the tubes snugly into the manifold sockets by taking up any slight dimensional inaccuracies at the tube ends. These retaining cups have been carefully designed to permit rapid installation or replacement of the tubes. A quick twist of the cup frees the tubes so they can be pulled from their O-ring seal and quickly replaced.

The Reflector

The Owens-Illinois Collector requires a diffuse reflector underneath its full area to enhance the heat production and efficiently use the tubes. They can be spaced apart since a large

component of the radiation falling between the tubes can be reflected up onto them. This can be accomplished by two methods--the use of a reflective building surface or the attachment of an integral metallic parabolic reflector which can be attached to the standard "SunPak" collector. (18) The use of the building surface for the reflector can be the cheaper of the methods and can offer some architectural advantages. For best performance, this surface should have a non-glossy, reflective nature such as would be obtained with a flat white paint.

Laboratory tests have shown that standard available light-colored roof membranes have sufficient reflectivity to work in cooperation with the "SunPak". This means that the "SunPak" can take credit for the reflective roof surface to (in effect) reduce its own cost. Unlike flat-plate collectors which often are depended upon to act as roof membranes, the Owens-Illinois "SunPak" does not eliminate or radically disturb conventional roofing, but uses it to an advantage. Because of this compatibility, its integration with existing accepted technology is more highly refined. The use of "SunPak's" parabolic Shaped Reflector (SSR) eliminates the need for the building surface to be reflective. An increased benefit is the specialized shape that improves the collector performance by 25% over the method not utilizing the specialized reflector. The Parabolic Shaped Reflector can be supplied with the collectors and is installed before installation of the evacuated tubes.

Installation

The collector has been designed to allow easy installation with manual labor. No heavy lifting equipment is required because each component can be easily lifted by one person. The installation can be carried out in a straightforward manner in six steps:

(18) A 360° Aperture And Optimal Spacing Increases Effectiveness Of Collector

SOURCE: Owens-Illinois

- Lay out the necessary dimensions on the mounting surface
- Mount the manifold and header pipes
- Mount end support channels
- Install heater tubes and collector tubes
- Connect external supply and return line
- Install insulation joint covers and end caps

Layout of Dimensions

The mounting surface should be flat to within $1/360$ of the span length. This means that the manifold and end supports may deviate from flatness as much as $1/4$ ". Greater irregularities will require shimming to bring the collector to a flatter aspect.

The distance relationship between the manifold and end supports is critical because loosely fitting or misaligned tubes may become unseated from their O-rings. Since the retaining end caps have only a narrow range of adjustment, the end support should be accurately placed within a plus or minus $1/16$ " tolerance. The end supports should also be positioned to hold the tubes perpendicular to the manifold. Where a number of modules are attached in a bank, occasional checks for proper alignment along the entire length of the manifold will prevent the accumulation of errors that would cause a rack in the tube positioning.

Manifold Assembly

All manifolds should be set in place one by one with each subsequent manifold joining the male-female header connections. After they are all accurately placed, they are bolted down and connected.

Tube Installation

After the manifold and end brackets are anchored in place, the distributor tubes are installed through the grommets in the manifold. The glass collector tubes are then slipped through the holes in the end channels and over the distributor tubes. The glass collector tubes are drawn completely over the distributor tubes and then seated in their O-rings at the manifold socket. The retaining caps are then twisted on at the end channels and the tubes adjusted to a snug fit.

Piping

The supply and return piping from storage may be connected at either end of a bank. The top header protruding from the manifold end is the outlet header and the bottom pipe, the inlet header. The connecting pipes should be properly supported to prevent excessive stress on the manifold. Since the headers are only supported in the manifold by urethane foam, undue force on them may crack the foam or rupture internal header joints. Vent valves near the inlet and outlet connections are recommended for several purposes. They can be used as air vents when the system is filled or drained, or can release steam in an emergency no-flow condition where boiling occurs. The maximum safe operating pressure is 25 psig. The system should contain appropriate pressure relief valves to vent hot water or steam before the O-rings fail under excessive pressure.

Insulating Covers

The collectors should be checked for leaks at the joints between the modules and at the supply and return connections from storage. The O-rings must also be inspected for

"Here Comes the Sun. . ."

The Beatles

leaks. If all joints are watertight, then the insulating foam joint covers and end caps are glued in place to complete the assembly of the Owens-Illinois Collectors.

Fluid Flow

When installed, all the components previously described work together to absorb the sun's energy and allow the free flow of collector fluid through the array. Water is the preferred fluid due to its low cost and good thermal performance. However, other fluids such as glycol solutions are acceptable.

When heat is needed, water from the storage tank is pumped to and from each module through two 1" O.D. (Outside Diameter) inlet and outlet header pipes that run through the length of the manifold and nest between the 24 copper cups and associated tubing. For each module, there is one branch point from the inlet pipe that introduces water into the manifold cup of the first tube. After making its pass through the module, the heated water exits near the last tube through a single opening in the outlet pipe. In between inlet and outlet, the flow pattern devised for a single Owens-Illinois module reveals the cleverness of the design.

If one imagines the array at a tilt, the pumped water begins rising up through the first absorber tube and around the exterior of the inner distributor tube within the same space until it reaches the top. Since the absorber is sealed at this extreme end, the water can only enter the open end of the distributor tube where it counterflows down toward the manifold, passing the rising water outside the copper tube walls. Even though the

distributor tube pierces the manifold, it has no openings in it. When inside the distributor tube, the water passes straight down through the manifold and only exits at the bottom of the second absorber tube immediately below the first. As more pours in, the water rises up through this second absorber tube toward its manifold cup at its end. Once inside, the water flows into an opening in the side of the cup which diverts the straightline flow pattern across to the next pair of tubes. Here, the same flow pattern is repeated. Water rises up to the top of the absorber tube where it enters the inner tube and descends straight down past the manifold into the bottom of the lower tube. It rises toward the manifold where it jogs over to the next pair of tubes. Figure (19) illustrates this pattern of flow for a number of tubes.

Water in a single module flows in series, but connected modules flow in parallel. This is schematically diagramed in Figure (20) which readily shows the single inlet and outlet branch for each module.

As many as 15 modules may be joined together to operate from the internal header. Longer arrays may be assembled using the internal headers, but attention should be given to the resulting header pressure drops and flow arrangements to prevent mal-distribution of flow between modules. Longer arrays will also need special provision for expansion of the header pipes. End-to-end assemblies of more than nine modules should have expansion devices built into the header pipe connections, recognizing that a 40-foot copper tube subjected to a 200°F. temperature rise will grow more than one-half inch.

Flow Rates

A flow rate of 0.3 gpm/module is a typical operating rate and could be expected to give a temperature rise per pass of 20°F. to 30°F. on a clear day. A minimum collector fill rate of

(19) Flow Path Through Owens-Illinois Collector

(20) Schematic Flow Through Multi-Module "SunPak" Array

.25 gpm/module is recommended. This prevents two-phase flow in the feeder tubes which could result in entrapment of air during the filling procedure. The water-filled collector can be operated at any flow rate provided the recommended operating pressure is not exceeded. Operation at flow rates above 0.20 gpm/module is recommended for best performance.

Solar Heat Production

Water circulating through the Owens-Illinois "SunPak" will collect heat throughout the summer and winter to offset both heating and cooling loads. Since overheating in Mission Viejo, California greatly predominates, the greatest effort logically must be directed toward solving the large cooling load. In winter when a heating load is in effect, space heating with solar heated water can be done directly by supplying water to a fan coil, but cooling is accomplished by first supplying solar heated water to an absorption chiller which produces chilled water that is then piped to the coil. The requirements for efficient chiller operation dictates the quality of solar heat necessary and

the type of collector which will satisfy this stringency.

The Arkla Chiller which was installed in the MED houses requires generator inlet water from solar storage at a temperature of 195°F.--a high level of heat production for flat-plate collectors to attain with any favorable efficiency. Unlike the flat-plate collector which has no insulation on its exposed face, the Owens-Illinois "SunPak" uses its insulating vacuum design to good advantage. This invisible insulation barrier allows radiation to pass through to the absorber tube while preventing substantial losses to outdoor air from the absorber tube. Accordingly, the "SunPak" can be efficiently run at higher temperatures without corresponding heat losses resulting from the increased temperature difference between ambient outdoor temperature and the collector fluid. The differences in heat production between the two types of collectors for various inlet temperatures are illustrated in Figures (21) and (22).

The Owens-Illinois Collector was selected chiefly for its capacity to satisfy the temperature requirement of the Arkla machine, even though both types of collectors have other characteristics such as cost differences, ease of installation, and availability, which could influence choice.

Figure (23) summarizes Figures (21) and (22) to graphically compare total incident radiation, tube collection, and flat-plate collection in BTU at 32°N latitude to demonstrate the large advantage the Owens-Illinois "SunPak" has over the flat-plate at 200°F. inlet temperature. One can see that the production is nearly twice as great for the evacuated tube collector. The Owens-Illinois Collector costs nearly twice as much as flat-plate collectors, but only one-half the area of collector is needed to produce the same amount of heat. Its price, then, becomes immediately competitive. It must be emphasized that the "SunPak's" outstanding performance occurs only at higher inlet temperatures. At lower temperatures, both evacuated tube and flat-plate collectors perform at similar efficiencies.

Collector Tilt and Orientation

A solar collector is like a ship's sail which is spread before the wind and set to catch its greatest force. The resulting force of the wind transferred to the sail is determined by the wind's speed, the direction of the wind pressing against the sail, and the area of the sail. Similarly, a solar collector spreads its area across a plane which is tilted toward the sun to intercept instreaming radiation. The sun's rays are analogous to the blowing wind and the tilt to the set of the sails, while the heat absorbed by the collector corresponds to the force against the sails. The magnitude of heat depends on the sun's intensity, the angle of incidence of the sun's rays to the collector, and the area of the collector surface. Nothing can be done to change the amount of sunshine available, but the

FLAT PLATE COLLECTOR

(21) Variation Of Inlet Temperature

EVACUATED TUBE COLLECTOR

(22) Variation Of Inlet Temperature

(23) Variation Of Collectors

tilt, orientation, and size of the collector can be designed to absorb a maximum amount of the energy that is available.

The angle of tilt of a collector for a particular application depends on several factors which influence the matching of collector production with load requirements over the length of a year. In general, a winter heating load is best satisfied with a south-facing array tilted at an angle of the latitude plus 10° to 20°. This is because the low winter sun will strike the collector more directly. A load which peaks in the summer such as a cooling load, would use a tilt equal to the latitude minus 10° to 20°. This new altitude makes a flatter array which faces upward to the high sun.

The tilt of south-facing collectors relates to the seasonal changes of the sun's altitude. The orientation of the collector array from due south will affect daily production. Arrays facing east of south will have increased production in the morning hours but will lose production during the late afternoon hours because glancing rays of the sun will provide little heat, or production will stop altogether if the collector goes into shade. (24) The opposite is true for the MED homes which are oriented 46° and 57° west of south. Production is lower in the morning but enhanced in the afternoon.

Even though collector tilt relates more to yearly cycles and orientation to daily production, they do not operate independently. In southern latitudes where collector tilts may be flatter for summer heat production, the array orientation can change more widely from due south because the sun climbs higher over the array earlier in the morning and remains high until late in the afternoon. In northern climates where heating modes usually predominate, it is important to receive a maximum of radiation from the winter sun whose rise above and range

across the horizon is considerably shortened. The collector must be more steeply tilted to directly intercept the winter sun and oriented southerly to collect as much radiation during hours of greatest intensity. Unlike the lightly tilted array optimized for cooling in the summer climates, the steeply tilted collector cannot range very far from due south without suffering substantial deterioration in heat production. Since the sun's period of greatest intensity in the winter is just a few hours at mid-day, it is important that the collector array face as squarely south as possible. A deviation to the east, for example, will give a direct orientation only to low intensity morning sun, will cause unfavorable incident angles at mid-day, or end production altogether as the steeply tilted collector goes entirely to shade in the late afternoon.

Since solar collectors are commonly integrated into the roof of a house, the problem of orientation has serious implications for developers interested in large-scale solar applications. In recent years, large-scale single family suburban developments have depended less on grid planning in favor of gently curving streets which set individual homes at different orientations. Developers that would build solar air conditioned homes in the south have greater freedom to use this planning strategy and still mount collectors on roofs roughly facing south. Non-air conditioned solar homes in the planned developments in northern latitudes that need heating will be restricted more severely to the south orientation. If a project-wide solar application is to be seriously considered, early planning should anticipate the proper orientation of all the lots. Innovative architects may possibly escape the rigid constraints of a due south orientation by designing a workable roof system with a number of surfaces that could receive a collector array. Even though the houses in a subdivision may be plotted in a radial

(24) Orientation Of Collectors

(25) Variation Of Tilt

(26) Percentage Of Heat Production By Orientation

fashion along a semi-circular street, the collector array could switch to a more favorable roof surface for those houses which deviate too far from south. Another tactic is to use the garage roof if it has enough mounting surface. Even when attached, a garage does not have to be strictly aligned with the house, but can swing off axis from the house to orient south. In a large development, all garages could face south while the houses could be freely arranged near them. This would allow greater freedom in planning and more variation from house to house.

If the array is to be oriented off of south, then a factor can be applied to modify the production results to account for the deviation. Figure (25) graphically represents these factors as percentage of production for all collector orientations at three different latitudes. Data for each latitude was calculated for flat-plate collectors tilted at latitude degrees. The partial disks shown represent a compass face with bearing points. Inside are concentric circles plotting percentage of production. The outermost line represents 100% production and each inner concentric line marks successive 10% drops in production. Over this is plotted lines showing collector performance at different latitudes. It is clearly seen that during winter months, production drops off considerably if the collector faces east or west of south. During summer, however, nearly full production can be maintained at orientations ranging as much as 50° off of south. The figures showing a percentage drop in production are necessary for adjusting tilt angle alternatives which are calculated for due south orientations only.

Figure (26) shows computer-generated curves that mark the yearly square foot production of various tilt angles for a south-facing Owens-Illinois Collector at 32°N latitude with a 200°F. inlet temperature. It is clear to see that the low tilt angles show improved production in the summer and

poor production in the winter. The steeper tilts show contrary behavior. The high summer sun glances off the steeply tilted collector and production drops off while the winter sun intercepts it more directly, deriving its relative performance upward. From these various tilt alternatives, a 20° collector tilt was chosen for the MED houses because its curve more closely matches the profile of the MED's yearly heat requirements. A 20° tilt also conveniently corresponds to a 4 and 12 pitch-the standard slope of the original Cordova roof.

Collector Array Size

Once the tilt has been chosen, then the collector size can be determined. Since these numbers or tilt are shown in BTU/square foot of collector, simple multiplication times the proper number of square feet of collector will give the total annual heat production. The profile of the curve will remain the same, but the absolute amount of heat collected will be increased. A collector is sized by plotting the building's yearly heat requirements and then comparing this curve profile to a number of collector heat production curves for a particular tilt shown on the same graph. The array size that most closely matches the building heat requirement is then selected.

Figure (27) charts three different "SunPak" array sizes against the yearly heat requirements for the MED homes. A collector tilt of 20° was used and its heat production was modified for the 46° west of south orientation only. The curves for six, eight, and ten modules follow the same profile but mark off a different total heat production corresponding to the respective collector area. These results show a substantial overproduction for a ten module array--the number used on the MED homes. Preliminary calculation in the earlier phase of the project conservatively indicated the need for eight modules at the MED's original orientation. When

(27) Collector Size Vs. Building Heat Requirement

the MED houses were relocated on different sites, they subsequently rotated even more west of south than when plotted on their original lots. In order to adjust for this change and provide a factor of safety, two more modules were added. Over production, not under production, is considered less evil because excess heat can be readily drained from the system. This is done by circulating water through the fin tube heat dump mounted at the rooftop above the ridge vent.

Not illustrated in the building heat requirement curve in Figure (27) is the effect of seasonal performance of the Arkla Chiller. The curve, as illustrated, assumes a coefficient of performance (C.O.P.) of .6. Because of the oversizing of the equipment, a seasonal C.O.P. will likely be around .2. The result will be reflected by a change, during the cooling seasons, of the building heat requirement of two to three times greater than that shown. A change of that magnitude will verify the justification of adding 10 collector modules.

Mounting the Owens-Illinois "SunPak" On The Minimum Energy Dwelling

Before the new in-support structures for the Owens-Illinois Collector were devised, the MED design was well underway. The use of the earlier end angle design, however, for the Owens-Illinois "SunPak" caused detail problems for the rooftop mounting because each module contained 60 bolting connections. Like the Owens-Illinois "SunPak" itself, a conventional roof membrane is delicate and its water shedding capabilities depend on full continuity across its surface. Excess joints, interruptions, irregularities in design, or careless installation can disrupt this continuity and/or the principal causes of leaks through the roof. Similarly, any intentional punctures in the roof to receive anchoring hardware devices are potential leaks and must be protected from water intrusion. Damming of water by equipment attached to the

roof can also cause leaks and should be avoided.

Since each MED home has 10 collector modules, the array attached directly to the roof membrane would need 600 connections if every available bolt hole provided was used. One proposal for protecting these openings was the use of bolts with neoprene washers. When drawn snugly, the washers provide a waterproof seal around the holes in the roof. If 99% of the roof penetrations were adequately protected, there would still be six leaks in the roof of the MED home. Even one leak is unacceptable. The chances of leaks have been reduced because the new end support design uses only eight bolts which is 80% fewer connection points.

Figures (17) and (28) illustrate the final solution conceived for the MED homes. It is a hybrid version of the original intention of using a reflective roof membrane and the consequent need for reducing the amount of connections to the roof. The three main lines of connection, the two end angles and a manifold, find bearing in 2" x 8" pressure treated wood beams laid flat against the roof. They are connected less often than the original end angle design and raised from the roof surface with several neoprene washers at each bolt. This allows free water runoff underneath and also protects each bolt hole through the membrane. With this detail, the collector remains close enough to the reflective roof surface and doesn't reduce performance appreciably. It uses inexpensive wood materials as an intermediary between roof and collector to reduce connecting holes and the chances of roof leaks. However, with the new improvements, this additional structure may be eliminated and the Owens-Illinois "SunPak" may be mounted with confidence directly to a conventional roof surface with little fear of leaks.

(28) Collector Manifold As Mounted On The MED Home

(29) Location Of Collector On MED Roof

The Location On The Roof

Placing the Owens-Illinois Collector array within the available roof area of each MED house was a four-fold task:

- Fitting all ten modules across the roof.
- Detailing the jointure of the two roof types--reflective one-ply and tile roof.
- Displaying the collector array within the roof area to feature it as an important aspect of the MED houses.
- Integrating the collector architecturally to maintain a uniform character to the exterior of the house.

(29) The ten Owens-Illinois modules stretch in one line across the entire length of the house roof to completely fit within the eave boundaries and is placed high on its surface near the ridge. (30) The fascia boards at the gable ends do not hang in a conventional manner underneath the roof's edge but are set above its surface and built like a long box to give it stability. (31) At the garage end of the array, this box acts as an enclosure to protect and conceal the supply and return lines to and from the

storage tank and the pipes to and (32) from the heat dump located at the ridge line and also trimmed in wood. Another wood piece, a single 2" x 8" board, stretches between the two sloping box-like fascia and is attached along the bottom of the collector array to trim off the tube ends. This entire arrangement of wood requires additional cost in labor and materials, but it functions to snugly surround the collector to set it more neatly within the roof and integrated visually with the rest of the house. Placing the collector near the ridge gives the collector prominence and the roof a look of greater substance. It also allows the necessary two-part division in the roof materials.

The roof membrane, used as the reflector to enhance the "SunPak" heat production is Allied Chemical's Chem-Ply Roofing System. This membrane is a white one-ply system with high reflectivity. It extends from the ridge down along the slope underneath the width of the array until it meets the tile roof at a point determined by the tile modules. This point of jointure is illustrated in Figure (33). Metal flashing between the one-ply system and the tile roof seals their edges to lock out water penetration, while the wood blocking underneath is a transition device that prevents damming at the top edge of

(30) Section Through Eave

(31) Section Through Pipe Enclosure

(32) Section Through Roof Ridge With Heat Dump

(33) Flashing At Tile Roof

the tile-it allows the water to shed from the reflective roof onto the tile to carry it down the roof and off its edge.

An improvement by the collector manufacturer, however, has eliminated the need for a white reflective surface on the building. Owens-Illinois has manufactured a parabolic reflector which easily slips underneath each of the twenty-four evacuated tubes in a module. The parabolic reflector sheet attaches easily to the collector module. Besides eliminating a reflective roof membrane, the parabolic reflector has been measured to increase the collector production by 25 percent. The MED home was built with the reflector membrane, but it was eventually replaced by the parabolic reflector.

In conclusion, the Owens-Illinois collector was selected for the Minimum Energy Dwelling because of the requirement of high performance needed for space cooling. The Owens-Illinois collector is one of the easiest collector modules to integrate with the building structure, but, with refinements, can be improved still further. The requirement for space cooling was given from the beginning of the project. However, with the sophisticated construction of the dwelling, mechanical and solar cooling may not be required, and the system may be replaced with a solar Domestic Hot Water heating system in future designs. Performance testing will be performed to validate this concept.

MECHANICAL SYSTEMS

Solar cooling requires the use of advanced system engineering. Although the Minimum Energy Dwelling's cooling system is not presently economically feasible, the information gathered by testing the equipment will lead to a wealth of new information upon which future designs can be based. A prime direction will be the packaging of different equipment requiring extra and unnecessary piping for interconnections within one sellable and compact unit.

Mechanical systems have evolved rapidly in the past 50 years, providing automatic comfort at a reasonable cost. Mechanical systems, like the automobile, have given the individual and society a new sense of freedom. Freedom from discomfort and worry can be provided by today's mechanical systems by sensing heating and cooling requirements, turning on required equipment, and then automatically shutting off. Freedom of design has been attained with mechanical systems which allow for more time to be devoted in other areas because the mechanical system can be sized to handle any problem areas which might occur. Freedom in building construction with mechanical systems which allow for the substitution of less costly building components provides the consumer with more building at less cost.

The basis of this freedom has been the inexpensive supply of energy needed to

operate mechanical systems. For a small portion of the total yearly operating expenses of a family, mechanical space conditioning could be supplied. This condition is changing, and for many individuals, the cost of energy has become a shackle rather than a freedom.

As the cost of energy has gone up, the use of mechanical systems is being increasingly scrutinized for possible energy savings. Three avenues of approaching the problem have been determined:

- Decreasing the amount of energy required from a mechanical system through building design or a changing of comfort expectations.
- The use of on-site renewable energy resources, such as solar energy, to provide a replacement fuel for the more conventional mechanical systems using costly forms of primary energy, such as oil or gas.
- Increasing the efficiency with which costly energy is used within the mechanical system.

All three approaches were used in the design of the Minimum Energy Dwelling.

Throughout the design stages, cost effective techniques of meeting the comfort requirements of the occupants must be researched and met by the use of one or a combination of the three approaches.

As an example, consider a south-facing window in a house. During the day, sunshine enters through the window and heats up the space. In the winter, this is a positive contribution and can reduce heating requirements. On the other hand, during the summer, the heat will build up within the space requiring cooling. The current building practice is to install a standard window, disregarding its impact on building loads. Typical heating and cooling equipment would be installed, keeping the occupants comfortable. Using the three approaches to energy conscious design, a variety of different methods could be used to reduce energy consumption.

Using the first approach might involve the use of a shading overhang, properly designed to allow the winter sun to enter the space while preventing summer entry.

The second approach involves the use of renewable energy resources for auxiliary fuel for the mechanical system. Using this approach, the window would remain as in standard construction. Solar energy could be converted to air conditioning by the use of sophisticated mechanical equipment. Although the same amount of cooling is required, some of it could be supplied with solar energy, thus saving the use of primary energy.

The third approach involves improvement of the efficiency of the mechanical equipment. In this example, only the replacement of the typical heating and cooling equipment with a more efficient model, leaving the window the same and not trying to employ renewable energy sources within the mechanical system may be involved.

"If someone's body is using energy rapidly to maintain a fever, the first order of business is to cure the fever not to feed it."

Steve Baer

The primary method of deciding which approach to use is made by comparing costs. If one method will reduce energy consumption, by one-half the cost, it should be selected for use. The costs can be broken down into two areas--initial cost and operating cost. A particular item may cost more initially, but save more over the life of the system, resulting in a life-cycle-cost advantage.

The analysis of various energy-saving techniques can become tedious if a thorough analysis is required for every design option considered. The ability to predict energy usage, fuel and interest rates is usually less than the desired accuracy needed to differentiate between the performance of different energy-saving techniques. Presently, the method of selection is more of an art than a science and requires a thorough knowledge of the implications of use. A useful methodology is to select subjectively with a minimum of calculation those approaches or items which appear to offer the greatest potential savings. They can be studied in greater depth using detailed energy estimation procedures.

Of the three approaches, reducing energy consumption through building design has been thoroughly explained in earlier chapters.

The second item, dealing with the substitution of costly energy sources with "free" renewable resources is the area of considerable research in this project. Two methods of substitution are used--solar energy and cool outside air.

The use of solar energy has gained increasing importance in recent years. The use of an abundant and free source of energy has become intriguing to a large segment of society. The use of solar energy in housing can presently be broken down into three primary methods:

- Hot water heating for domestic use
- Space Heating
- Space Cooling

Each method involves an increasing amount of complexity and cost. Because of the dynamic concept of solar energy, it is difficult to make generalizations as to the areas in which it can or cannot be used. Although solar cooling for a particular project may not be economical, this does not necessarily imply that domestic hot water heating is not feasible. Domestic hot water heating requires a lower technology level at a lower cost. A study of each particular case must be investigated on its own merits.

Another important factor in the use of solar energy is the type of fuel used if solar energy was not considered. For example, a life-cycle cost comparison between an electric and solar installation for domestic hot water heating will usually show a cost advantage in all areas of the country in favor of the solar system. A substitution of gas rather than electricity, however, will not show the same results. Gas is generally about half as expensive as electricity and, therefore, a much harder fuel to show a cost advantage by the use of a solar system.

The status of the solar industry is such that active competition is underway in many of the lower technological applications and is no longer in need of intensive solar application research. The same cannot be said for solar cooling.

One of the original goals of the Minimum Energy Dwelling was to provide solar cooling at a reasonable cost for small single-family homes,--a goal which is very difficult to meet with present technologies. Even though the final solution does not meet the original low cost objectives, valuable information has been gained, which is presented in this chapter, and which may eventually lead to the realization of this goal.

(1) Cooling Methods

Presently, of the two methods commonly available for residential space cooling (absorption and compression), only absorption has been thoroughly tested for use with solar energy.

A simple analogy to explain the two methods may be of use. Imagine a dry sponge. As such, it has the ability to absorb water. When a dry sponge is placed within a wet environment, it will absorb water from the air, lowering the humidity and improving potential evaporation. Cooling by evaporation is a common technique. After the sponge becomes saturated with water, cooling will cease. The wet sponge is replaced with a dry sponge and cooling begins again. The method by which the excess water is extracted from the sponge is the difference in the two methods of cooling. (1) In compression cooling, the water is squeezed out, again giving it the ability to absorb water. In absorption cooling, the sponge is placed in a hot environment where the water is evaporated.

A common compression cooling cycle is a heat pump, or an air conditioner. Research is now underway to use the sun to run the compressor by the use of a solar engine, but this concept appears to be in the future and was not thoroughly investigated in this project.

One of the important advantages of absorption cooling is in its ability to use fairly low temperature heat, in the neighborhood of 200°F., to extract moisture from a salt solution. The relatively low temperature required is an ideal application of solar energy for cooling.

Over 90% of the Minimum Energy Dwelling's space conditioning requirements are for cooling, therefore, requiring a system design primarily for peak cooling conditions. The Owens-Illinois evacuated tube solar collectors are an integral part of a cooling system design methodology. The evacuated tube collector has a greater efficiency in the collection

of solar energy at high water inlet temperatures (high in relation to water temperature expected from solar collectors) than the standard flat-plate collector required by the absorption chiller. Therefore, fewer collectors are needed to meet cooling demands, reducing collector substructure and installation costs.

Details of the collector and its operation and sizing are enumerated in greater detail in the "Solar Collector" chapter. The storage tank into which the collected solar energy is delivered is a pressurized 460 gallon tank. Analysis revealed a good correlation of timing between the maximum collector production and the maximum cooling required. The greatest solar cooling requirements tend to occur in the early evening, a few hours after maximum solar collection. The storage tank, therefore, is only sized to store energy for these few hours. A storage tank with greater capacity would be increasingly hard to justify as additional cost is greater than the benefit of increased storage. Therefore, a minimal amount of storage has been incorporated within the design.

From the storage tank, heat is supplied to the mechanical system components of the domestic hot water system and the heating and cooling system.

(2) Hot water can be used directly for building load by piping to a heating coil, or hot water can be diverted to the drive of the absorption chiller supplying chilled water to a cooling coil. At times, the collected solar energy will not be able to supply the needed energy, and the gas-fired boiler will supply the needed energy to operate the heating and cooling system.

The other source of substitution of costly primary energy sources is in the use of cool outside air for cooling rather than expensive mechanically-generated cool air. The method is described as an economizer cycle. An indoor thermostat senses the indoor temperature, and when it reaches an

(2) Solar System Schematic

"Night time cooling. . . poor man's air conditioning system."

350 Ways to Save Energy

elevated temperature, signals the need for cooling. At this point, an outdoor sensor known as an "enthalpy controller" reports the outside temperature and humidity, which together define a certain "enthalpy condition". If both the temperature and humidity are below the upper limit of the comfort zone; i.e., low enthalpy conditions exist, outside air will be used to supply cooling rather than the mechanical equipment.

The outside measuring device, when sensing the air temperature and humidity, integrates the two variables to determine the total energy content of the air, or enthalpy. The enthalpy can be the same for different air conditions. The enthalpy of air at 67°F. and a 90% relative humidity is the same as air at 87°F. with a 30% relative humidity.

The use of an economizer cycle in a mild climate such as Mission Viejo, California, can have a great effect on energy consumption. Studies have indicated an energy savings of up to 60% for space cooling conditions.

The ability to sense humidity with the enthalpy sensors can enable the wider use of outside air for free cooling. The humidity sensor in the control guards against the entrance of humid air. When the economizer is controlled from outdoor temperature alone, the controller set point must be reduced to prevent intake of humid air. In fact, the range of outdoor temperatures available for free cooling is approximately doubled when an enthalpy controller is used.

The economizer is composed of four essential elements:

- . Sensing Device
- . Air Ducts
- . Air Mixing Box
- . Air Handler

The sensing device or enthalpy controller consists of two elements--a nylon humidity sensor and a bulb-type

temperature sensor, which interact to open and close an electrical circuit when the enthalpy of the outdoor air is below the dial setting of the thermostat.

The air ducts consist of an outside air intake duct, interior return air duct, blended supply air duct and an indoor air outlet. The purpose of the air ducts is to provide for the movement of air from one location to another. Outdoor air for the economizer cycle is brought from an outside opening to the suction side of the furnace fan. Air entry is controlled by a motorized damper located at the air mixing box. In the Minimum Energy Dwelling, the outside air intake is located above the entryway into the house. This is a particularly good location as the air intake is located on the shaded northeast side of the home. The coolest outside air available should occur at this location permitting optimum operation. The interior return air duct returns soiled air from the living spaces to the mechanical system for reconditioning. When the economizer is not in operation, large amounts of energy can be saved by the reconditioning of the interior air rather than introducing outside air having a high energy content. Once outside air has been conditioned and soiled, the energy required to recondition is minimal. The air return grille for the return air duct is located in the hallway drawing air from the entire house. The air return grille is connected to the suction side of the mixing box, and the amount of return air recycling is controlled by a motor actuating damper connected in tandem with the outside air inlet dampers. The blended supply air duct distributes conditioned air from the mechanical system to the living spaces. The system is designed to supply 120 cfm to the small bedrooms, and 160 cfm to the master bedroom. The living room and the kitchen are supplied with 300 and 240 cfm respectively. The master bath is supplied with 60 cfm. At the same time, cool outdoor air is brought in

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(A) OUTSIDE AIR INTAKE DUCT	(G) INTERIOR RETURN AIR DAMPERS
(B) INTERIOR RETURN AIR DUCT	(H) ELECTRONIC AIR FILTER
(C) BLENDED SUPPLY AIR DUCT	(I) AIR HANDLER COIL
(D) MIXING BOX	(J) CENTRIFUGAL FAN
(E) DAMPER ACTUATING MOTOR	(K) AIR HANDLER FAN MOTOR
(F) OUTSIDE AIR INLET DAMPERS	

(3) Economizer Cycle

handler heat transfer coil at which heat can be added or withdrawn for heating and cooling requirements. The air is then blown by a centrifugal fan to the supply air duct and on to the house.

The operation of the economizer begins with the enthalpy control sensing the energy content of the air to determine if the energy content is below the energy content of the inside air. If it is, the economizer cycle begins operation. The return air is closed and cool outside air is brought through the mixing box, air filter and centrifugal fan, and delivered to the house. No heating or cooling is added by the air handler heat exchanger coil. The only energy required to cool a house during the economizer cycle is the energy used to run the centrifugal fan. At times, 100% outside air is not required for cooling. At those times, the dampers from the return air and outside air can be modulated to take air from both outside and return air sources.

The economizer cycle appears to offer particular advantages if the house is well insulated and tightly built and located in a mild moderately cool climate. These conditions are met with the Minimum Energy Dwelling in Mission Viejo, California. As was brought out in the "Comfort and Climate" chapter, the temperature range in Mission Viejo, California is between 34°F. and 84°F. nearly all the time. The mean monthly average temperatures fall between 48°F. and 80°F., an ideal zone for the use of an economizer. The house is well constructed and with normal heat inputs from the occupants and the appliances and lights, does not require heating until the outside air temperature is below 45°F. A glance at the yearly percentage frequency of occurrence (Figure 29 in the "Comfort and Climate" chapter) can give a rough indication of the probable performance of an economizer cycle. As can be seen, the majority of times are between 65°F. and 80°F., the

effective area for the economizer cycle.

The economizer appears to be one of the most cost-effective additions to the Minimum Energy Dwelling. The addition of an economizer alone can be an effective substitute for an air conditioner in this climate. Although the home may become uncomfortable for certain summer days, this discomfort may be acceptable to a homeowner if there are significant cost savings by not adding air conditioning equipment. If no air conditioning equipment is incorporated, the use of mass and time lag characteristics of the building materials becomes of increased importance.

A very appropriate future design philosophy for the Mission Viejo region may be a heavy and massive wall construction with a high degree of insulation and light colored walls and roof. The only mechanical system may be an economizer with no heating or cooling backup. The only energy required would be that to run the centrifugal fan in the economizer, if it appears for a home so designed to remain within the comfort zone 95% of the time. The key to the system is the incorporation of the time delaying attributes of mass. Even during the hot summer months, the temperature on average nighttime conditions 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 precooling with the use of the economizer cycle. The heavy materials could absorb the heat of the day and prevent penetration. At night, the economizer would begin operation and remove the heat buildup and prepare for the same cycle the following day.

In the winter, the mass of the house can also help the performance. The sun during the day can be stored by the mass to heat the building at night. If the house is well insulated and weatherstripped, the appliances,

(4) Minimum Energy Dwelling Flow Diagram

lights, and people could supply the needed amounts of energy for heat.

The solar system and the economizer cycle have been combined and developed into an integrated mechanical system. The following is a detailed description of the major mechanical system components and operational procedures between them.

Mechanical System Operation

The mechanical system for the MED is a basic loop design incorporating a gas-fired boiler, an absorption water chiller with attendant cooling tower, and an air handling unit equipped with a dual temperature water coil and two-speed centrifugal fan. (4) Hot water for heating or for driving the absorption chiller is supplied from either the storage tank, heated by a 320 square foot evacuated tube collector array, the gas-fired boiler or a combination of both depending on the mode of operation and the temperature of the water in the storage tank. In situations demanding a modulated supply from both the storage tank and the boiler, or when the need is for 100% boiler-heated water, the boiler loop acts as a thermal storage bypass. The system also has the capability of

utilizing outside air through an economizer cycle to assist in cooling when outside ambient temperatures and enthalpy conditions are favorable. A description of system components is included for the purposes of familiarization.

Solar Collectors

The "SunPak" evacuated tube solar collectors as manufactured by Owens-Illinois were selected for the MED Project. The system utilizes an effective collector area of 275 square feet comprised of ten 24-tube modules. A discussion of collector performance, installation details, orientation considerations, etc., may be found in the "Solar Collector" chapter.

Storage Tank

The storage tank is a heavily-galvanized steel vessel of 460 gallon capacity manufactured to A.S.M.E. 100 lb. standards. The collector loop operates at 25 psig with automatic pressure vents in the tank and collector feed line which maintains that setting. The tank is surrounded by loose mineral wool insulation installed at 7 pounds per cubic foot density. The side walls and lid of the storage tank

<p>(A) ABSORPTION CHILLER
 A₁ GENERATOR, INLET
 A₂ GENERATOR, OUTLET
 A₃ CONDENSER, INLET
 A₄ CONDENSER, OUTLET
 A₅ CHILLED WATER, INLET
 A₆ CHILLED WATER, OUTLET
 A₇ CHILLED WATER PUMP</p> <p>(B) COOLING TOWER
 B₁ COOLING TOWER, INLET
 B₂ COOLING TOWER, OUTLET
 B₃ OUTSIDE AIR, INLET
 B₄ EXHAUST AIR, OUTLET
 B₅ COOLING TOWER PUMP
 B₆ CONDENSER, BLOWDOWN FROM OUTLET A₄</p> <p>(C) GAS FIRED BOILER
 C₁ BOILER, INLET
 C₂ BOILER, OUTLET
 C₃ BOILER, VENT STACK
 C₄ HOT WATER, PUMP</p> | <p>(D) AIR HANDLER
 D₁ FAN MOTOR
 D₂ OUTSIDE AIR DUCT
 D₃ SUPPLY AIR, DUCT
 D₄ SUPPLY AIR, VENT
 D₅ RETURN AIR DUCT
 D₆ MIXING BOX
 D₇ ELECTRONIC FILTER
 D₈ COIL, OUTLET
 D₉ COIL, INLET</p> <p>(E) GAS FIRED DOMESTIC HOT WATER HEATER
 E₁ HOT WATER, SUPPLY
 E₂ COLD WATER, SUPPLY
 E₃ TEMPERATURE VALVE
 E₄ ULTRAFLO VALVE UNIT
 E₅ ULTRAFLO LINE FITTINGS
 E₆ HOT WATER TO STORAGE TANK, HEAT EXCHANGER
 E₇ HOT WATER FROM STORAGE TANK, HEAT EXCHANGER
 E₈ DOMESTIC HOT WATER HEATER, VENT STACK</p> | <p>(F) CITY WATER, SUPPLY TO COLLECTOR, ARRAY
 F₁ QUICK FILL BYPASS LINE
 F₂ PRESSURE REDUCING VALVE
 F₃ PRESSURE GAUGE
 F₄ PRESSURE RELIEF VALVE</p> <p>(G) COLLECTOR, ARRAY PUMP
 G₁ COLLECTOR, SUPPLY
 G₂ COLLECTOR, RETURN
 G₃ COLLECTOR, DRAIN LINE</p> <p>(H) MODULATING AUTO VALVE
 I (2) POSITION AUTO VALVE
 J GATE VALVE (TYPICAL)
 K CHECK VALVE (TYPICAL)
 L STRAINERS (TYPICAL)
 M THERMOMETER (TYPICAL)</p> |
|---|--|---|

(5) Minimum Energy Dwelling Mechanical Room

pit act to contain the fiberglass, creating an insulated cavity which minimizes heat losses.

Inserted through one end of the storage tank and running the full length of the central horizontal axis is an 8" O.D. Type "L" copper tube. The tube acts as an open cavity heat exchanger providing for the preheating of potable water for the domestic hot water system. The domestic hot water system is discussed in greater detail in the "Plumbing" chapter.

Heat Dissipator

Included on the collector feed side of the thermal storage loop is a 24' length of Vulcan Radiator Company bare fin tube consisting of 1-1/4" O.D. copper pipe with 4-1/4" square copper fins spaced at 40 per foot. It is installed on the roof level along the ridge vent above the solar collector array. When water enroute to the collector is above approximately 180°F., it is diverted through the heat dissipator. Assuming a 20°F. temperature rise through the collectors, this insures a thermal storage water temperature below the boiling point. The heat dissipator's position before the collector array permits maximum control of storage water temperature and minimizes the possibility of stagnation temperatures in the collectors.

Boiler

The boiler is included to assist the thermal storage component of the system in maintaining 90°F. water for heating and 195°F. water for cooling. For MED, a Peerless size G-360-W cast iron boiler was chosen with an output of 72 MBTUH when fired at a rate of 90 cubic feet per hour (1000 BTUH/ cubic foot) with natural gas. The boiler is designed to operate at 50 psig and is fitted with a relief valve to maintain the same. The boiler is fitted with two-stage firing for reduced capacity. The boiler is fitted with an electric

ignition rather than a standard continuously burning pilot light.

Absorption Water Chiller

Cooling is accomplished through the use of an Arkla Absorption Water Chiller with a rated output of 36 MBTUH when cooling 7.2 gpm of chilled water from 55°F. to 45°F. with an internal pressure drop of 5 feet of water. Hot water input required is 55 MBTUH with 11 gpm of hot water entering at 195°F. and leaving at 185°F. with an internal pressure drop of 7.0 feet of water. The heat rejected is 91.0 MBTUH with condenser water at 13 gpm entering at 85°F. and leaving at 95°F. The internal pressure drop across the condenser is 11.5 feet of water. The resultant internal energy consumption of the unit operating under these conditions is 250 watts using 115V-1-60 Hz current.

This unit, rated at 36 MBTUH (36,000 BTUH) has a 3-ton capacity. This is approximately three times that which will be required by the MED. A better match with the load would occur if the unit were operated at a 1-ton capacity. This could be accomplished by supplying the chiller with 179°F. water. However, there is a question concerning the level of dehumidification that would occur if the resultant 55°F. chilled water were supplied to the heating coil.

Cooling Tower

Heat rejection from the absorption chiller is accomplished through a Marley Size 6305 indoor "Aqua Cooler". Its rejection capacity of 99 MBH at 19.8 gpm is assuming condenser water entering at 95°F. and leaving at 85°F. under outdoor wet bulb temperatures of 75°F. The resultant pressure drop is 18 feet of water measured from the base of the tower. The fan circulates 1700 cfm of air against 25 inches of external static pressure. The fan is driven through an adjustable V-belt arrangement by a 1/2 HP motor wired for a 230V-1-60 Hz service.

Air Handling Unit

A Trane size 3 vertical draw-through "Climate Master" was chosen for the MED. It includes a mixing box, dual temperature water coil and blower. Economizer capabilities are achieved by modulating outdoor and indoor air dampers actuated by a single operator supplying or prohibiting air to the coil through the mixing box. A Honeywell electronic air filter precedes the coil. The coil is a 3 square foot (18" x 24") type "W", six row, fin series 15 with turbulators. Water friction is 2 square feet of water, and air friction is .42 inches of water. The forward curved wheel fan delivers 1000 cfm of air against a total static pressure of 7/8" at 1090 RPM. The drive is supplied by a 1/2 HP, two-speed motor wired from 230V-1-60 Hz linked by an adjustable V-belt.

Pumps

All pumps were selected from the current TACO catalog. They are all "in-line" and floor supported. The construction is iron body, brass-trimmed, except for the domestic water pump which is all bronze. The shaft seals on each pump are the mechanical type.

P₁ is solely responsible for the thermal storage loop, supplying the collector array with water from the storage tanks. Its 1/2 HP motor operates on 115V-1-60 Hz supply providing a constant 3 gpm against 17 feet of head pressure at 1725 RPM.

P₃ circulates space conditioning water from both the storage tank and boiler to the absorption chiller or air handling unit, depending on the mode of operation. It has a 1/8 HP motor which operates on a 115V-1-60 Hz supply providing 11 gpm against a 15 foot head at 1725 RPM.

P₄ functions only when the absorption chiller is in operation. It circulates water from the chiller condenser coil to the water tower where it is

dissipated. Operating on a 230V-1-60 Hz power supply, it circulates water at 20 gpm against a 32 foot head at 2750 RPM.

P₅ circulates chilled water between the absorption chiller's evaporator coil and the air handler's coil. Like P₄, it operates only during cooling modes. It provides chilled water to the air handler's coil at 8 gpm against a 13 foot head pressure with a 1/8 HP motor at 1725 RPM. It requires a 115V-1-60 Hz power supply.

Valves

The three main valves responsible for routing water through the system are listed in Figure (4) as V₂, V₃, and V₄. Valve 2 (V₂) consists of an electronic modutrol motor with an auxiliary switching package. It is a 1-1/4" mixing valve responsible for modulating hot water supplied to the chiller or air handling unit from the thermal storage tank, the boiler or a combination of both. The switching attachment is responsible for regulating the gas supplied to the boiler through gas valve V₅, not shown on the schematic. By doing so, it controls the temperature of the water coming from the boiler. The two-stage operation of gas valve V₅ is discussed in the appropriate mode diagrams.

V₃ is a standard 3/4" diverting valve which channels circulating water either to the collector or to be passed through the heat dissipator, or both. Water above 180°F. is expected to be diverted through the heat dissipator. Water below 180°F. will be allowed to flow uninterrupted into the collector. (See 'Heat Dissipator' this chapter)

V₄, like V₂, is driven by a modutrol motor. In the MED system, it acts as a diverting valve, that is, with one input and two outputs. During heating modes, it allows 90°F. hot water to bypass the absorption chiller enroute to the air handling coil. During cooling modes, it supplies 195°F.

(6) Storage I Heating - Heating From Storage

water to the absorption chiller for use in the generator.

A variety of other service components such as gate valves, strainers, check valves, etc., are necessary for proper operation and servicing of the system. Their passive role in the system's function does not warrant an in depth discussion of each.

System Operation

The temperature of the house is controlled by a T872D four-stage thermostat with a switching sub-base. The sub-base works in conjunction with a time clock to provide a daytime and nighttime consideration in the control logic. The four-stage aspect of the thermostat allows for Stage I and II heating and cooling in both daytime and nighttime operation, depending on the season. The thermostat settings are discussed individually within each mode description.

Stage I Heating - Heating From Storage

When the sub-base switch of the thermostat is set for heating and the time clock indicates day operation, the system's functions are as follows. (6)

When the room temperature drops below 68°F. and the first stage of the thermostat calls for heat, the temperature of the storage water is checked. If it is below 90°F. in Stage I, no pumps are activated and no water is circulated with the possible exception of Pump P₁ which may be circulating water to the collector array. The inside temperature will continue to drift downward until it reaches 65°F. At this point, a Stage II heating situation exists. (See Stage II Heating) If the temperature of the storage water is above 90°F., Pump P₃ begins to operate circulating water from the storage tank at 11 gpm to the air handling unit's coil. The air handler's fan begins low speed operation delivering warm air to the dwelling at 1200 cfm. If the water temperature in the storage tank is sufficiently high, the possibility exists that water returning from the air handler coil will be above 90°F. In this case, V₂ will mix water from storage tanks with return water from the air handler coil by routing it through the boiler. This reduces the demand on the thermal storage while maintaining a 90°F. supply to the air handling coil. Operating in a heating mode indicates low outside ambient tempera-

tures. Therefore, the outside supply air is cut off by the enthalpy control logic, and only return air is allowed to circulate over the heating coil.

Stage II Heating - Heating By Auxiliary

If the house requires more heat than Stage I is able to supply, the temperature continues to fall until it reaches 67°F. and (7) Stage II will then activate. In Stage II heating, the control logic calls for the continued operation of Pump P₃ while swinging modulating valve V₂ into a position where it accepts water from the boiler loop only, cutting off the supply from the thermal storage tank. In this mode, V₂ actuates boiler gas valve V₅ (not shown) which supplies enough gas for the "low fire" boiler setting in order to maintain 90°F. water while the system is operating 100% off the boiler supply. The air handler fan continues to operate at low speed and the outside air dampers remain closed.

When the time clock indicates nighttime, control is switched over to the night thermostat setting which is "set back" below that of Stage II daytime heating. If heating is still required, the same sequence of events takes place as that occurring for Stage I and II daytime heating. However, the lower nighttime set back dictates lower "cut-out" and "cut-in" temperatures, reducing the heating demand and associated energy consumption.

Stage I Cooling With Economizer Cycle

If the thermostat sub-base setting is switched to cooling and the time clock indicates daytime operation, the system functions as follows. (8) When the inside temperature rises above 73°F., the system's logic first checks the condition of the outside air through an "enthalpy controller." If the enthalpy is low, indicating outside air is low in humidity and cool enough to be used for space conditioning, the economizer motor activates the dampers on the air handler's mixing

(7) Stage II Heating - Heating From Auxiliary

(8) Stage I Cooling - Economizer Cycle

box, taking in outside air, and modulating the return air to the coil. When only outside air is being used for cooling, no water in the load side of the system is being circulated, and the air handler's fan is operating in the high position, delivering 1800 cfm of cool, outside air to the interior.

It is possible that the solar collector loop will operate simultaneously with the economizer cycle despite low enthalpy conditions. Collector Pump P_1 responds only to a 10°F. Δt between the collector and the storage tank water temperature. (See 'Periods of Collector Operation', this Section)

Stage I Cooling From Storage Without Economizer Cycle

If the outside air is too warm or moist for cooling, conditions of high enthalpy exist. (9) When this occurs, the enthalpy control senses the situation and closes the outside air dampers. The temperature of the storage water is again checked. If it is too low for solar cooling, below 190°F. , the system goes on standby. No pumps are activated and no water is circulated except for solar collector Pump P_1 , which may be circulating water to the collector array. During Stage I cooling, the air handler fan will circulate return air at 1800 cfm whether the units coil is receiving the chilled water or not. However, if the temperature of the storage water is sufficiently high to run the absorption chiller, 190°F. or above, V_2 is put into a modulating position by the control logic and system Pump P_3 , cooling tower Pump P_4 , and the chilled water circulating Pump P_5 all begin to operate. (10) The system fan begins operating on high, delivering cool air to the interior at 1800 cfm. The system modulation is similar to that which occurs during Stage II heating, with return water circulating through the boiler. The reason for mixing is that any excess heat put into the Arkla Unit is dissipated through the cooling tower, lowering the efficiency of the unit.

(9) Stage I Cooling - Cooling From Storage

(10) Stage II Cooling - Cooling From Auxiliary

Stage II Cooling - Cooling From Auxiliary

If the room temperature rises to 80°F. and Stage I operation cannot handle the cooling, the following occurs. The enthalpy condition of the outside air is again checked. If enthalpy is low, the economizer will be used for cooling. If enthalpy conditions are high, the outside air dampers will remain closed. As in Stage II heating, valve V₂ shifts 100% into the boiler loop, refusing water from storage. In this mode, V₂ switching circuitry calls for the boiler gas supply valve V₅ (not shown) to operate on "high fire", maintaining a 195°F. supply to the absorption chiller. Again, system Pump P₃, winter-summer cooling tower Pump P₄, and chilled water Pump P₅ all operate. The air handler fan goes on high, delivering cool air to the interior at 1800 cfm.

The sequence of enthalpy checking, Stage I and Stage II cooling, is the same for nighttime operation except that the requirement is lowered by less stringent temperature control demands.

Shown in Figure (11) are the thermostat control settings which are being used. The control system must determine if the economizer should be applied rather than the standard mechanical system. During the winter, the economizer, as shown by the settings, is not used for precooling. This is accomplished by a nighttime cooling thermostat setting of 70°F. If the setting during the winter was the same as in the summer (60°F.), the economizer would cool the home at night only to have to heat the home in early morning when the thermostat is set up to 68°F. Also, the logic of the control system will precool the house to 60°F. at night during the summer months only if the economizer can be used. If not, the standard mechanical system will operate when the temperature rises to 70°F.

		HEATING	COOLING
Winter Season			
Night	Stage 1	60°	70°
	Stage 2	60°	None
Day	Stage 1	68°	70°
	Stage 2	65°	80°
Summer Season			
Night	Stage 1	60°	60°
	Stage 2	60°	None
Day	Stage 1	68°	70°
	Stage 2	65°	80°

(11) Thermostat Setting In The MED Home

(12) Enthalpy Control Setting

The enthalpy setting for the economizer is 31 BTU/lb. of dry air. (12) The broad curving line shown is the setting used for the economizer on the MED home. Any time the outside air temperature or humidity rises below or to the left of the curve, the economizer will operate when required. When the temperature and humidity falls to the other side of the line, the standard mechanical system will be operated. The other similar lines are settings available on the enthalpy controller for different comfort requirements.

Periods of Collector Operation

In the MED mechanical system, the collector loop is independent of the space conditioning and domestic hot water supply components. This enables heat to be collected and stored whether the system is heating, cooling, or dormant.

Collector circulation Pump P_1 is programmed to circulate water to the collector array any time a $10^\circ\text{F. } \Delta t$ exists between the collector and the storage water temperature. The collector temperature sensing devices are located in the collector distribution manifolds, exposed to the return water stream at the end of the module. In this position, they sense the temperature of the water leaving the module. An additional temperature sensor is located in a circulation tube. This may be considered the return water temperature which, when compared to the supply water temperature from storage, results in the widest temperature range in the collector loop. By keeping the collector loop separate from the rest of the system, the collectors are freed from responding directly to the absorption chiller or air handling unit for cooling or heating. The collectors are used solely for maintaining the desired storage tank temperatures of 90°F. for heating and 195°F. for cooling. The boiler provides supply water at these temperatures if thermal storage cannot.

It is probable, given Mission Viejo's micro-climate and the evacuated tube

solar collector performance capabilities, that the storage water temperature will average well above 90°F. during the winter months. Because only 90°F. is required for heating, it is anticipated that most heating requirements will be satisfied primarily in the Stage I heating mode. Assuming 120°F. supply water and a 10°F. temperature drop across the heating coil, the resulting return water temperature from the heating coil will be approximately 110°F. However, the system is designed to recirculate return water through the boiler bypass loop until it drops to 90°F. This would indicate significant periods of modulation as described in Stage I Heating, Figure (6), until the heat originally supplied by the thermal storage water is dissipated through the heating coil. As a result, the demand on thermal storage is reduced.

In the summer, the production and storage capabilities of the collector loop are expected to meet between 60% and 80% of the total seasonal cooling load. During the spring and fall months, when cooling loads are moderate and insolation is adequate, 100% of the cooling provided by the collectors would not be unexpected. This, of course, depends on the intensity and duration of the demand, as excessive cooling requirements will result in the lowering of the tank temperature in spite of collector production.

The three-hour time lag inherent in the structure's design will result in periods of over production during early afternoon requiring the use of the heat dissipator. In the evening, the combined effect of this temperature lag, peak internal loads, and reduced collection rates will result in the need for a boiler assist in cooling if the thermal storage is inadequate.

In Mission Viejo, it may generally be assumed that in periods requiring heating, collection rates will be below those achieved during the time

of year when cooling is required. This appears not to be a problem since cooling is the dominant load by a factor of 10. Also, the difference between the 90°F. required for heating and the 195°F. water needed for cooling is such that the heating demand will be supplied nearly 100% of the time while cooling will be supplied only 60% to 80% of the time without assistance from the boiler. The system will supply 100% of the cooling load at any time with gas-fired boiler water.

System Concepts

Early design efforts for the Minimum Energy Dwelling involved the use of completely different heating and cooling concepts and equipment. The concepts of system design began with more exotic solar heating and cooling systems, which are still in the experimental stage. Unresolved technical problems forestalled their incorporation in the MED home. Absorption cooling was selected as the best candidate for immediate widespread application of solar cooling.

Absorption cooling is the only proven cooling concept for the use of solar energy which has extensive testing at the present time. Using present methods and technologies, absorption cooling requires the use of many separate components such as an absorption chiller for cooling, a boiler for heating, an air handler for air movement, an electronic air filter and a cooling tower. Presently, all of these components are separate and must be sized and connected to be compatible with each other. In the Minimum Energy Dwelling, the space required to fit all the components together is about 80 square feet. At present building costs, the space for the mechanical space alone can cost over \$2000.

Improvements of residential heating and cooling systems has been under study at the Institute of Gas Technology for more than 25 years. One

concept which has been developed appears to hold promise for the future--the Munters' Environmental Control (MEC) heating and cooling technique. The technique combines in one unit the functions which were previously performed by separate pieces of equipment. Heating, cooling, humidification and dehumidification can be confined within one piece of equipment.

The basis of the MEC unit and its operation is based on a fundamental property of air. As explained earlier in the economizer section, air which is cool and humid can have the same energy content as air which is hot and dry. This property is known as enthalpy. Both air conditions can have the same enthalpy.

On the interior of the MEC unit are two energy exchangers. (13) One is an enthalpy exchanger. This means it can transfer both heat and moisture from one area to another. The other energy exchanger is just a heat exchanger. With the addition of an air humidifying water saturation pad, the components for complete conditioning of the air are in place.

(14) For cooling, warm, moist outside air is brought across the enthalpy exchanger. The exchanger extracts moisture by the addition of heat. In other words, the enthalpy of the air remains the same, but the condition of the air changes from warm and moist to hot and dry. The air is then passed through the heat exchanger which extracts heat from the hot and dry air and converts it to cool and dry. Finally, a small amount of moisture is re-introduced by the water saturation pad extracting heat. The same process that occurred at the enthalpy exchanger again happens. The enthalpy, or energy content of the air remains the same, but the condition of the air changes. The cool dry air becomes cold and moist, and is then supplied to the occupants of the building.

(13) System Schematic Of MEC Unit

(14) MEC System Operation - Cooling Season

During the heating season, cold, dry outside air is brought across the enthalpy exchanger. (15) Because of the low energy content of the air, both heat and moisture is transferred to the cold dry air, becoming warm and moist. The heat exchanger is stopped completely, and the air is passed through unchanged. Humidity is adjusted to the desired level as the air passes through the saturator pads and is delivered to the house ducts.

Solar energy and/or a direct fired gas burners is used to supply heat to the MED unit. The heat is used to extract moisture from the enthalpy exchanger to regenerate its moisture carrying capacity for moisture removal during the summer and heat input during the winter.

Besides the reduction in size and the ability to use solar energy, the MEC offers other distinct advantages.

- The efficiency of the Solar-MEC system during heating rates high when compared with that of a conventional gas furnace. When supplemental gas energy is required because of insufficient solar energy, the system has a heating efficiency of 80%, including humidification. A conventional gas furnace is hardpressed to attain an efficiency of 70% in seasonal use, without humidification.
- There are no metal heat exchangers that operate at high temperature in the Solar-MEC system to burn through or corrode. In fact, no parts operate above 320°F.
- During the rainy season when temperatures are 70°F. to 75°F. but the air is too humid, the system can easily adjust the humidity of incoming air without cooling it. A conventional air conditioner cannot do this. A separate dehumidifier is required.
- Fresh, outdoor air is delivered to the living space at fan capacity during all seasons. No stale air is recirculated. The heat (or

(15) MEC System Operation - Heating Season

DESIGN SPECIFICATIONS

for a typical 1400 sq ft house

Heating/Cooling System

Cooling capacity	3 tons: 36,000 Btu/hr
Heating capacity (delivered air)	100,000 Btu/hr
Humidity control (year round)	completely adjustable
Electrical requirement (includes air circulation)	1 HP (total)
Dimensions (approximate)	50 in. L x 42 in. W x 42 in. H
Weight (includes solar heat exchanger and blowers)	660 lb
Auxiliary fuel	natural gas

Solar Collector/Storage System

Area*	800 sq ft
Collector fluid temperature (out)*	230° F
Temperature drop in solar heat exchanger	10° F
Collector fluid storage	insulated, under- ground tank

PERFORMANCE

Cooling coefficient of performance (COP) [†]	0.7
Heating efficiency (including humidification) ^{††}	80%
Estimated annual energy savings, when coupled with solar energy for:	
Chicago	30%
Los Angeles	43%
Washington, D.C.	29%

* Based on high capacity, selective coating
and/or vacuum type flat collector

† At American Refrigeration Institute standard base
conditions: outdoors 95° F, 75° W.B.; indoors 80° F,
50% RH, and based on gas heat only.

†† Based on gas input only as energy source.

cold) and moisture in it are re-
moved and re-used. Because of
this--and unlike any other system--
Solar-MEC delivers 100% fresh makeup
air without sacrificing operating
economy.

- No chimney or flue connection is
required because the gas is burned
in the exhaust air leaving the MEC
unit.

MEC also is unique from a mechanical
standpoint. It has no compressors or
high speed machinery that require
close manufacturing tolerances. It
has no sealed fluid system that must
be operated under pressure or vacuum.
It contains no surfaces whose tempera-
tures exceed a few hundred degrees,
even for heating. Finally, MEC has
demonstrated its ability to use effi-
ciently the low temperatures produced
by currently available flat solar
collectors supplement, when necessary,
by natural gas heat.

(16) The MEC unit appears to offer
many advantages not available with
standard cooling equipment.

Early in the MED Project, the MEC unit
was seriously considered as the pri-
mary method of space conditioning.

The problem in its use was unforeseen
laboratory difficulties delaying field
testing. After continued experimental
testing, an estimated two to three
years of field testing will be re-
quired before the system can move into
commercial production.

As buildings become better insulated
and more properly designed, peak load
energy requirements can easily be
reduced in the neighborhood of 50%.
Since mechanical equipment is sized to
meet peak energy demands, a well
constructed home may need half the
standard sized mechanical system.
This condition has occurred with MED.

MED is a small house, and even if
built with standard techniques, re-
quires the smallest commercially avail-

(16) Characteristics Of MEC Unit

mechanical system components. To reduce building loads still further may not create a significant drop in energy supplied by a standard mechanical system. If the average load is significantly below the design conditions of the equipment, the system will run more inefficiently, partially offsetting any gross energy savings.

In normal circumstances, a reduction of peak energy usage would allow the use of smaller equipment offering a saving in the initial cost of mechanical equipment. But, since the smallest commercially available unit is being used, no saving is possible.

Also, because the MED mechanical system is a prototype, all the components are separate and require careful integration, adding to design time and initial cost.

The obvious direction of further research in solar heating and cooling absorption systems will be in the incorporation of the individual components within a single enclosure. Also, since the housing trend is toward the smaller, better thermally designed home, smaller capacities will be needed.

Areas of investigation will include small scale applications presently available. The most fruitful work may be the investigation of mobile home heating and cooling systems or work in other countries.

One of the more interesting approaches to solar cooling has been developed by the Yazaki Corporation of Japan. The company has developed a small 1.3 ton absorption unit having close to ideal compatibility with the Minimum Energy Dwelling building loads. The unit combines many of the separate components. Integral with the absorption chiller is the boiler, the domestic hot water heater, cooling tower, circulating pump from the storage tank, the cooling tower circulation pump, and a hydronic circulation pump to the air handling unit. Also

"Every great advance in science has issued from a new audacity of imagination."

John Dewey

included within the package is system instrumentation and automatic control valves. The prototype model is quoted at \$2,300.00 as of May, 1976. They are presently going into mass production with the unit and expect to lower the price.

The unit would have been an excellent replacement for a majority of the mechanical components within MED. At the time of design, it was not available for use. Also, in order to obtain government financing for research projects, American-made components must be used. On the whole, the Yazaki unit appears to offer an excellent package for a small scale cooling requirement.

A refinement of the present MED mechanical system would be the addition of chilled water storage. With chilled water storage, the present size of the hot water storage tank could be reduced from 460 gallons to a minimal size of 50 gallons. The hot water storage tank would be sized only as a buffer between the solar collectors and the absorption chiller to allow the continued operation of the chiller during short cloudy periods. The reduction in hot water storage capacity would show a definite savings in initial cost. As presently designed, the large 460 gallon tank needs to be pressurized adding to the initial cost.

The reduction of the hot water storage capacity can be accomplished through the addition of a chilled water storage tank. Rather than store hot (195°F.) water during off-peak conditions, the absorption chiller can produce chilled water for storage. Three advantages can be achieved by this strategy. The absorption chiller can be run more efficiently by the continuous operation when solar energy is available and diverting chilled water from what is not needed to meet a building cooling load to the chilled water storage. The chilled water does not need to be stored in a pressurized storage tank, thus allowing the

use of less expensive storage vessels. The third advantage is the decreased temperature difference between the inside and outside storage tank temperature of a 55°F. chilled water storage and a 195°F. hot water storage. The reduced temperature difference achieves less energy transfer between the ground and the tank, saving energy.

In conclusion, the MED mechanical system has evolved over a wide range of options. As presently designed and built, the mechanical system does not meet one of the basic goals of the project—that of low cost. This is not a requirement of a prototype building, but must be resolved for future designs. The mechanical system offers the greatest volatility of prices in the future. Advances in technology can rapidly change existing assumptions.

During the course of study, a great deal of information has been gathered on the building heating and cooling loads. Because of the highly insulated and energy-conscious design, heating is rarely required. Again, because of the well-built construction, cooling is required more frequently due to energy retention from people, lights and appliances. Thus, many times during the year, outside air can be used for cooling. Southern California has a mild climate, and does not need extensive mechanical equipment.

A few likely directions for the future, knowing the given characteristics of the climate, the building and the customer are explained in the following paragraphs.

The cost-effective design element to add would be the economizer with a standard heating and cooling system. The economizer has been calculated to save approximately 60% of cooling energy, with no exotic equipment. The economizer requires larger fan motors and duct sizing, but increasing the energy savings.

"Long Life, Loose Fit, Low Energy."

Alex Gordon

The second item having a good life cycle potential is solar domestic hot water heating. Because of the good solar radiation in Southern California, and the continuous requirement of low temperature heat throughout the year, a solar domestic hot water heating system returns the most on the initial investment of any type of solar system. Also, the addition of a solar system will add marketability to a developer's line. Since the public as yet is not aware of the difference between solar domestic hot water heating, and solar heating and cooling, solar domestic hot water heating adds the most marketability with the least amount of expenditure. The public is sold on the idea of using the free source of the sun for energy requirements. Solar collectors have acquired a prestige going beyond just how much money or energy can be saved. It has even been predicted that imitation collectors may appear for sale to give an impression of having an exotic item, much in the same way plastic wooden shutters are applied to the side of windows today. The serious developer is aware of these trends.

Another option might involve the elimination of mechanical equipment, except for the solar domestic hot water heating and the economizer cycle. The climate in Mission Viejo is one of the mildest in the country and the elimination of the heating and cooling equipment can be accomplished with relative ease. The house would rely totally on good energy conserving design, and the economizer cycle. Preliminary design indicates such a house could easily maintain itself within the common expectations of comfort. Only infrequent record highs and lows occurring less than 2-1/2% of the time during the year would cause the dwelling to possibly become uncomfortable. Detailed design would determine if the cost benefit of the elimination of mechanical equipment and the attendant energy consumption would compensate for the added initial cost for a better thermally-designed skin over the life of the structure.

(17) Mechanical System Comparison

The development in equipment design should be watched closely for technological innovations or availability. The MEC or the Yazaki Absorption Units may be refined to be easily incorporated at a reasonable cost.

(17) Shown in the accompanying diagrams is a rough rating between different combinations of various types of mechanical equipment.

The types of systems shown are labeled 1 through 7 and run horizontally in Figure (17). The following is a short description of each:

1. This is the system installed in the MED home with the Arkla Chiller. Although the system can save a large amount of fossil fuel energy, the ease of installation and mechanical integration leaves something to be improved.
2. A heat pump combined with an economizer is commonly available. Although not the best in energy savings, the installation and service is backed with proven dealer organizations.
3. A simple solution which may work in climates similar to Mission Viejo would be where all air conditioning requirements are met with the economizer. Building design plays an important role in obtaining good performance.
4. The solar driven Munters Environmental Control offers important advantages if after thorough testing, MED becomes available at reasonable cost.
5. The system shown is generically the same as the Arkla system shown in column 1. The difference in

ratings is due to the pre-packaged unit marketed by the Yasaki Corporation.

6. A solar driven engine to run standard vapor compression machinery is not commonly available. Testing is presently being performed to determine its operational characteristics.
7. Heat pumps using a solar heated source can obtain more usable heat from solar collectors than standard systems. They are a good choice in climates where space heating is a dominant load.

The first type of mechanical equipment, as indicated on the chart, is the system which was designed for the Minimum Energy Dwelling. A solar assisted absorption chiller with an economizer is the system cooling description. The heating system as indicated is a boiler with solar. The system is rated on the basis of eight features.

- Availability of the product on a local level.
- Cost comparison of relative costs of the total system.
- Mechanical integration is the degree with which the various components of the system have been combined into a single saleable item.
- Serviceability is the ease of maintenance required. The less maintenance required, the more desirable.
- Energy savings is the savings of primarily energy over a standard system. The comparison is for systems in Southern California and are not necessarily valid in other areas of the country.
- Flexibility is the ease with which the system can handle simultaneous loads of heating and cooling in different areas of the building.

- Ease of installation is a measure of installation simplicity as compared with other techniques.
- Residential sizing is a measure of the availability of small residential size units, allowing for economy of scale.

The mechanical techniques shown include:

- Absorption--Solar is an absorption chiller with hot water solar input.
- Compression-Solar is a solar-operated heat engine to run a standard heat pump compressor.
- The MEC Solar is the Munter's Environmental Control Unit as explained earlier in the chapter.
- Economizer is the use of cool outside air for cooling.
- Compression-Standard is a standard electrically run heat pump.
- Compression-Standard-Solar is a standard electrically run heat pump but with a solar assisted heat pump to augment heat production.
- Boiler-Solar is a solar augmented boiler to supply heating for the building loads.

The future is by no means being narrowed to only one choice in system design. The fields of solar energy are just beginning to open up and offer many possibilities.

"Innumerable confusions and a feeling of despair invariably emerge in periods of great technological and cultural transition."

Marshall McLuhan

PLUMBING

The Minimum Energy Dwelling incorporates the use of a push-button plumbing system. The system is designed to save both energy and water by reducing flow and premixing at the hot water heater of the hot and cold water. Other water-saving fixtures included in the design of the building include a flow reducer on the shower head and a water-saving toilet. Although water is not an expensive item in most areas of the country, it is becoming a scarce commodity which must be carefully managed.

Pure, potable water is one of man's most critical needs. It is more essential on a short-term basis than food. (1) The saying "You are what you eat (and drink!)" takes on an even more startling significance when we acknowledge the fact that our bodies are 75% water.

As an inherent part of the biosphere, water exists simultaneously as a liquid, a solid, and a gas. Collectively, they represent different states of a substance unique in many ways. With the exception of mercury (Hg), water has the greatest thermal conductivity, or ability to transfer heat from molecule to molecule of any other liquid. Water also has the greatest specific heat among liquids. Simply stated, this means that water will store the greatest amount of heat for a given volume, for any increase in temperature. Water is also an extremely stable substance which reacts

predictably under a given set of temperatures, pressures, etc. It is these properties which account for its ability to store and transfer heat well.

In nature, water exists in its purest form as cloud water. (2) This is because evaporation, the process which enables cloud formation, is a distilling action. As cloud water travels to the earth, it becomes acidic through reactions with gases in the atmosphere. Water in this state is usually found in surface pools or water tables which are very close to the surface of the earth. A strong acidic water solution is capable of corroding some piping materials. Precautions must be taken to neutralize this situation before the water is introduced into the domestic water piping system.

As surface water is pulled by gravity to lower levels, it is usually altered chemically. Depending on the soil through which it sinks, it may remain acidic or impure. More often, however, water becomes basic as it dissolves more of the earth's minerals. Water in this state is alkaline, the opposite of acidic. This is a result of water reacting with the available chemical compounds in the earth and creating in the process an abundance of hydrogen

(1) 75% Of The Human Body Is Water

(2) Water Cycle In The Biosphere

(3) World Water Supply

(4) Mean Average Temperature For Ground Water

SOURCE: William J. McGuinness and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Fifth Edition, 1971.

(5) Average Temperatures For Surface Water

SOURCE: William J. McGuinness and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Fifth Edition, 1971.

ions not normally found in water. Hydrogen ions (H_3O^+) are water molecules with an extra hydrogen atom which gives the molecule a net positive charge. Hydrogen ions are aggressive molecules which actively seek other electrons to neutralize their positive charge. Hence, water dissolves and reacts readily with an abundance of other chemical compounds. Alkaline water will not corrode pipes, but may deposit its mineral content on the inside walls of the pipe regardless of material, effectively stopping water flow. (3) Water which reaches the sea reacts with the minerals in the salt-water, becoming increasingly alkaline.

Only desalination can purify water once this occurs. However, as water travels continually deeper, it will in some cases deposit its dissolved mineral content, precipitating it into different rock and soil makeups. For this reason, water extracted from deep in the soil has usually been filtered clean naturally, and requires no chlorine purification. Also, water from deep in the earth is usually very cool and, therefore, highly desirable for drinking.

Figures (4) and (5) show the mean average temperature for ground water and surface water respectively. Of interest in Figure (4) is the fact that the ground water temperatures fall in a fairly even gradient from north to south, disturbed only by the presence of the Rocky Mountains in the western half of the United States. Temperatures are much more stable throughout the year, but have a wider range ($30^\circ F.$) than that of the surface waters in Figure (5). Although the average mean temperature of the surface waters varies only $20^\circ F.$, the change is in response to the seasons with fluctuations occurring much more readily due to surface exposures. Again, the Rocky Mountains having cooler yearly temperatures and large snowfalls are responsible for disrupting the natural continental temperature gradients, and dictating lower average surface water temperatures.

Ground water and surface water temperatures have a direct bearing on energy consumption as they apply to domestic, commercial and industrial needs. In applications requiring hot water, warmer supply temperatures are desirable as less energy is needed to heat the water. The opposite is true of applications using cold water as the colder the supply water temperatures, the less energy needed to chill the water.

In spite of the earth's ability to filter and purify, the bulk of the water found in the biosphere is not chemically pure. Water is an ionic solution because of the hydrogen ions.¹ It supplies itself from its own "chemical reservoir". Hence, it can react readily with or dissolve an enormous number of different chemical compounds, making it the "universal solvent". The concentration of hydrogen ions provides chemists with a numerical index with which they can classify a given water sample. The degree of solution is known as pH. It is a logarithm scale to the base 10 between 0 and 14. Water usually ranges from very acid at pH₃ to very alkaline at pH₁₀. A neutral pH in the neighborhood of 7 is desirable in order to provide a supply for consumption which is easy on both pipes and people.

Water may also have varying degrees of "hardness" in addition to its pH rating. Hardness refers to the amount of calcium carbonate (CaCO_3) in the solution. As mentioned previously, water in vapor form, as found in the clouds, is the purest water in the biosphere's water cycle. Calcium carbonate is introduced as a mineral when water sifts through the earth by gravity. The amount of calcium carbonate in a given water sample is indicative of the degree of mineral content in the water. The minerals present determine the extent to which

¹Hydrogen ions, H_3O^+ are water molecules with an extra hydrogen atom. The resultant net positive charge results in an aggressive molecule which reacts readily with other compounds.

the water deviates from the pure or distilled state. The mineral content and pH rating determine the corrosiveness of the water.

Figure (6) is included to show the varying hardness conditions found throughout the continental United States. Designers and engineers must secure this type of information to insure total consideration and conditioning of potable water supplies, and to assist themselves in selecting the proper materials for water distribution systems. Water having above 65 parts per million is considered "hard" and should be softened before it is used. Water having less than 65 parts per million is, of course, considered soft. Water which is "rain water soft" is naturally more desirable for most home uses.

Organic impurities injurious to health are not usually tested as part of the general chemical analysis, and must be accounted for separately. Local government officials have jurisdiction over the biological qualities of water. This is because water quality can vary greatly between districts and because treatment facilities and distribution networks are subject to municipal or county maintenance and monetary bases. Also, contamination from defective cesspools, septic tanks, disposal systems, animals, detergents, and industrial wastes constitute problems which are most effectively dealt with on a local level.

Man is ultimately responsible for the way water as a resource is treated and consumed. If man were absent, the natural water cycle in the biosphere would continue unaffected except for natural disturbances. It is our responsibility, therefore, to interact within this natural process to assure nature's balance and a continual supply of pure water for ourselves.

In an effort to foster an attitude of conservation, the Minimum Energy Dwelling Project has engaged the problem of residential water usage. The purpose

(6) Average Water Hardness

SOURCE: William J. McGuinness and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Fifth Edition, 1971.

of this chapter is not to deal with the mechanical aspects of plumbing, but rather to examine water usage from the standpoint of its conservation. As we shall see, this will automatically reduce energy consumption, the central goal of the MED Project.

Residential Water Usage and MED

In discussing residential water usage, it is necessary to establish an arbitrary norm from which we can draw conclusions and make comparisons. Most technical sources use a family of four as the basis of determining residential water consumption. Therefore, immediate comparisons with these surveys can be made as the Minimum Energy Dwelling, for statistical purposes, is comprised of a four-member family of two adults, and two children--one school age and one pre-school age. However, the family finally selected to live in the MED home differs slightly in that they have only one pre-school child.

In the MED Project, water conservation is not an academic exercise, but a real problem. Water is scarce in Southern California. The Mission Viejo Development is supplied a blend of water from Northern California and the Colorado River. Both sources are quite remote. The construction of expensive, large scale supply lines was forced by Southern California's own lack of surface waters and significant underground basins. The consequences of this arrangement are twofold for the Mission Viejo Development:

- The Mission Viejo Development will have a noticeable impact on the available water supply.
- The Mission Viejo Development will present a significant sewage disposal problem.

These problems are standard to all developments in the Southern California area. A positive attribute is Mission Viejo's awareness of the problem which is recorded in their environmental impact statement and their willingness and investigation of alternatives.

"The flush toilet is the basis of Western civilization."

Alan Coult

(7) Typical Residential Water Usage For A Family of Four

The environmental impact statement written for the Mission Viejo tract states that a total of 282,500 gallons a day will be required to supply prospective residents. The estimate is based on 178 gallons a day for 1587 persons and includes all water uses, public and private. A 178 gallons/person/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 means of procuring water are developed. The increase in population and the alteration of the landscape will have an additional impact on the area due to nuisance runoff. This will affect nearby Tiabaro Creek, the attendant water basin and the river bank life associated with it.

The Mission Viejo Development will also generate approximately 175,000 gallons of sewage a day, all of which will be treated at the San Juan Capistrano Treatment Plant and discharged into the Pacific Ocean. The 107,500 gallons difference between this figure and the 202,500 gallons a day figure stated in the previous paragraph represent water which for some reason is not discharged into the sewage system. This includes water in public and private pools, fire prevention systems, and lawn and garden watering. It is the judgment of this report that the waste of potable water in the conventional sewage removal and treatment process is most unfortunate and certainly deserving of further study.

(7) 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 712 gallons a day representing 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. This excludes lawn irrigation, car washing, etc., which would add to the consumption figure. The breakdown of water consumption for an average residence is as follows:

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

From the above breakdown, it is apparent that most of our potable water is used not for drinking, but for hygiene. Nearly 100% of the total potable water used in our "typical" residence is not for personal consumption, but for waste removal and cleaning. In most instances this water, some of which is only partially soiled, is discharged into the public sewage or septic systems and lost. This constitutes a potable water waste that could be drastically reduced by more efficient fixtures and a 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. Included is a manufacturer's list and matrix of various fixtures as a reference for the reader.

Waste disposal systems are classified in a number of ways. Some references discuss water-borne versus privy methods. That is, the difference between waste which is carried away by water or retained in a pit or container. Other groups are classified as fixed or portable. Another approach is to consider aerobic or fermentation as opposed to the anaerobic or putrefaction methods. Aerobic processes break down wastes by oxidation processes. Anaerobic processes do not require oxygen. (8) The approach chosen for this discussion is

NAME	PRICE	WATER PER USE	POWER REQUIRED	CHEMICALS REQUIRED	WATER MAINS CONNECT	TYPE
	50 - 525	up to 1 quart	up to 21 quarts	up to 11 quarts		
BICOQUE	•	•	•	•	•	INFILTRATION
SQUATTING PLATE	•	•	•	•	•	Pit Latrine
FLUSH-O-MATIC	•	•	•	•	•	Aqua Privy
HEAD-MATE	•	•	•	•	•	
MARINE HAND TOILET	•	•	•	•	•	
PORTA POTTI	•	•	•	•	•	MANUAL REM.
PERDISAN STANDARD MINOR	•	•	•	•	•	Bucket
RANCH	•	•	•	•	•	
IGLOO	•	•	•	•	•	Chemical
CLOSESSO PERFECTA	•	•	•	•	•	Toilet
MOBILCLOSET	•	•	•	•	•	
SANITAM STANDARD	•	•	•	•	•	
SANITAM SALUBRIS	•	•	•	•	•	
MARK T	•	•	•	•	•	Freeze
ELSTAR	•	•	•	•	•	Toilet
MINIHJARTAT	•	•	•	•	•	
TE-BE T-1970	•	•	•	•	•	
PACTO 101	•	•	•	•	•	Packing toilet
JETFLUSH MINOR	•	•	•	•	•	
MONOMATIC	•	•	•	•	•	Recirculating
PJTPOURRI	•	•	•	•	•	Chemical
CRAFT TOILET	•	•	•	•	•	Toilet
OJO 7000	•	•	•	•	•	MECHANICAL
OJO 7100	•	•	•	•	•	REMOVAL
TURQUO	•	•	•	•	•	Vacuum
MANOIR	•	•	•	•	•	Truck
CASTEL	•	•	•	•	•	
CAUSTICA 128	•	•	•	•	•	Chemical
CLOSENET STANDARD	•	•	•	•	•	Privy
MAGIC FLUSH	•	•	•	•	•	
BIO-FLO 512	•	•	•	•	•	Recirculating
BIOCYCLE MK 1	•	•	•	•	•	Fluid
TOTO 5	•	•	•	•	•	Toilet
M S U 2	•	•	•	•	•	
DUAL FLUSH CISTERN	•	•	•	•	•	Water-Borne
NIBO	•	•	•	•	•	Network
BRICK-IN-THE-TANK	•	•	•	•	•	
PEDAMATIC 2	•	•	•	•	•	
VACU-FLUSH	•	•	•	•	•	Vacuum
ELECTROLUX VACUUM SYSTEM	•	•	•	•	•	Network
DESTROILET	•	•	•	•	•	DESTRUCTION
ELONETTE	•	•	•	•	•	Incinerating
TOAREII	•	•	•	•	•	Toilet
ECETT	•	•	•	•	•	
ELECTRO STANDARD	•	•	•	•	•	
CLIVUS	•	•	•	•	•	DECOMPOSITION
MULL-TOA	•	•	•	•	•	
SANITERM	•	•	•	•	•	Compost Privy
MULLBANK	•	•	•	•	•	
MULTRUM	•	•	•	•	•	
FARALLONES PRIVY	•	•	•	•	•	
KERN COMPOST PRIVY	•	•	•	•	•	Cont. Aeration
ECOL SANITARY UNIT	•	•	•	•	•	Algae Digester
ECO-HOUSE	•	•	•	•	•	
WHO METHANE PLANT	•	•	•	•	•	HOUSEHOLD
METHANE DIGESTER	•	•	•	•	•	WASTE
FLO-THRU	•	•	•	•	•	TREATMENT
CROMAGLASS C-5	•	•	•	•	•	PLANT
BIO-DISC	•	•	•	•	•	
AQUAROBIC	•	•	•	•	•	

(8) Comparison Of Waste Disposal Systems

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop the Five Gallon Flush!, 1973.

(9) Infiltration

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop The Five Gallon Flush!, 1973.

to group disposal methods by the processes involved as found in Stop The Five Gallon Flush!², a publication by McGill University in response to a grant for Minimum Cost Housing. If an in-depth study of a particular fixture or method is desired, a copy of this publication will detail what this report does not include.

Five Waste Disposal Processes

• Infiltration--The oldest and most widespread method for waste treatment is infiltration. (9) 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 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, (10) 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

²The Minimum Cost Housing Group, Stop The Five Gallon Flush!, Minimum Cost Housing Studies of McGill University, Montreal, Canada, 1973.

PORTABLE
SYSTEM

OPEN & USE

AFTER 50
USES.....

CARRY WASTE
AWAY IN BIN

(PORTABLE SYSTEM)

(10) Manual Removal

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop the Five Gallon Flush!, 1973.

ELECTRIC INCINERATION

GAS FIRED INCINERATION

(11) Incinerating Toilets

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop the Five Gallon Flush!, 1973.

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.

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.

Freeze toilets are commercially available which do exactly that, retaining the waste in a frozen state until removal can be accomplished. Freeze toilets, like recirculating toilets, use power. In that regard, they are inferior to other types like the packing toilet in which the waste is wrapped in a continual plastic membrane and stored until the container is empty. The plastic bag is then replaced and the cycle is repeated.

• 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.

(11) 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 elec-

tricity are the other factors limiting their application.

• 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. (12) 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 soluble 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 evapotranspiration, 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 anaerobic 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 anaerobic 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 insoluble

(12) Decomposition Toilet

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop the Five Gallon Flush!, 1973.

WATER SAVER CADET

(13) Mechanical Removal

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 water-borne 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. (13) 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 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 of 1% 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 of 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.

In open treatment plants, nitrogen is not recycled quickly into the earth. This stems primarily from the fact that many of the organisms in sewage are large complicated molecules which are difficult to decompose. The oxygen dissolved in water satisfies a demand necessary to break down or oxidize these compounds. When this demand is not met (it can be supplied only with sufficiently large quantities of clean water), waste which is essentially untreated goes into open lakes, rivers and eventually oceans. The detrimental result of this is twofold. Pollution is one obvious result. The other is the further reduction in the oxygen level of the water bodies as oxidation slowly continues until the process is complete. This results in the suffocation of life forms and general destruction of the chemical makeup of the water.

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 efficiently each year. This would induce far better plant growth and better vapor-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 benefit would be an alternative system that is non-energy intensive and ecologically sound.

An example of the first solution would be a design like that illustrated in Figure (14). 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

(14) Grey Water Re-Use System

SOURCE: Septic Tank Practices: A Guide to the Conservation and Re-Use of Household Wastewaters by Peter Marshall (1977 Edition; Doubleday/Anchor).

recycling of that given day's potable water supply, none of which was used directly for sewage disposal.

The singular disadvantage 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. 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.

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 contamin-

ated wastes are concentrated and hygenically contained until removed. This facilitates the ultimate disposal of waste and eliminates on-site pollution problems. However, the Magic Flush system incorporates an electrical power source for recirculating the transportation fluid. This may be interpreted as an energy-intensive device when reviewed in reference to the MED Program's central theme of reducing energy consumption. The problem is compounded when coupled with the energy used by the collecting vehicle. The Magic Flush system also represents a significant investment financially when compared to alternatives and should be considered from that standpoint when choosing a waste disposal system. The problem of water consumption versus cost per installation is solved in the MED home through selection of the water-saver cadet. This particular fixture uses three gallons 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 the four family members, this would result in a potable water savings of between 24 and 50 gallons a day for the typical residence. In addition, the Water Saver Cadet needs no power source or special mechanical components for operation. Because it is indistinguishable from any other conventional toilet, it satisfies Western preferences. It is also less expensive than comparable units, lending itself to widespread development applications like the Mission Viejo Project.

(15) Magic Flush System Schematic

SOURCE: Witold Rybczynski & Alvaro Ortega, Stop the Five Gallon Flush!, 1973.

The use of the Water Saver Cadet can be interpreted as a less than perfect choice when considered with decomposition fixtures such as the Clivus Moltrum, or grey water and black waste segregating systems as detailed in Figure (15). In many respects, the pit-latrine is superior to many of the more sophisticated fixtures available in that it is energy-conserving, uses no water, and if well constructed, completely safe. Choosing between

	WASTE DISPOSAL PROCESS				
	INFILTRATION	DECOMPOSITION	MECHANICAL		DESTRUCTION
			ON SITE SEPTIC	REMOTE	
RELIABILITY	Aerobic & anaerobic composting with some infiltration. Very stable.	Mostly aerobic composting. Stable when proper carbon/nitrogen balance maintained.	Settling, floatation, & anaerobic digestion in tank. Aerobic & anaerobic filtration and digestion in drainfield. Very stable if not overloaded.	Subject to municipal problems. Good and convenient for home owner.	Complete elimination by combustion.
MAINTAINANCE	Very easy. Minimal labor.	Not so easy. Proper amounts of vegetable matter must be added to feces. Manual labor required weekly in some models.	Easy. Labor minimal. Needs checking for pumping about every two to four years. If dual-field, needs yearly manual switching.	Difficult and extremely expensive plants, lines, chemicals, sub-systems, etc.	Difficult. Complex construction requiring outside energy sources.
COSTS	INITIAL: Very inexpensive (\$50). Grey water system may be required. OPERATION: None MAINTENANCE: None	INITIAL: (a) Farallones model (about \$150). Home made. (b) Clivus (\$500 to \$1,700) (c) Mendocino (\$50 to \$100). Home made. Grey water system may be required. OPERATION: None MAINTENANCE: None	INITIAL: Pretty expensive (\$800 to \$2,000) depending on size, contractor, and materials. Grey water system used to advantage. OPERATION: Water costs. MAINTENANCE: Pumping every 3 to 10 years (\$40 to \$85).	Very expensive depending on size of sewage treatment plant. Complexity and manpower dictate high operating expenses. Inexpensive for home owner - paid for by taxes.	INITIAL: Expensive, (\$450 to over \$1,000). OPERATION: Approximately \$.05/use.
LIFESPAN	About 10 years for a family of four.	As long as materials last. (a) 20 years (b) 60 years (?) (c) 10 to 15 years	10 to 75 years depending on soils and design.	Varies with development of community, size of clientel.	As long as mechanical components last.
POLLUTION/SANITATION	If not near or in water, no pollution or sanitary problems. Problem may result with increased density or eventual saturation.	No pollution. No sanitation when composting is maintained.	Larger pollution & sanitation problems because of water-feces mix. Soils, groundwater slope and over-load can be problems. Negligible problems outside property line because of in-soil discharge.	Water pollution major problem. Chance of harm to ecosystem is eminent. Can be solved with secondary or auxiliary system.	Air pollution and stench unavoidable. No sanitation problems.
RECYCLING	Ultimately by burial & planting a tree. Adds nutrients & humus.	Great fertilizer for gardens, etc.	Sub-irrigation in drainfield ultimately: fertilizes plants & may re-charge water supplies.	Little or no chance for recycling.	Only ash remains for disposal.
COMMUNITY	Accommodated high-densities in cities if away from water. Politically, not available for city use. Discouraged even in rural areas.	Can accommodate high-densities in cities. Need pick-up of compost. Politically, new to city & rural Health Departments. Rarely accepted with ease.	Low densities only -- need green space for drainfield(s). Rural use. Accepted home-site system but many badly designed.	Grossly misunderstood by public. Consumes large quantities of energy, resources and materials.	Used only under severe circumstances. Arctic regions and some northern railway lines.

(16) Generic Comparison Of Waste Disposal Processes

disposal systems extends beyond the energy-conserving features of each. Economics, style preference, and sales pressure dictate the use of conventional fixtures. Because the MED Project is not immune to these considerations, the familiar, yet water-conserving Water Saver Cadet was chosen.

The reader should keep in mind the numerous alternatives available and the impact they have in reference to site conditions and water demands. Figure (16) has been included in this section to aid the reader in weighing the advantages and disadvantages of the various removal and distribution techniques. Conservation in sewage systems is a matter of habit, proper fixtures and water reuse. A change of attitude by consumers in favor of water conservation will automatically promote their use.

It may be seen from the previous figures that bathing and 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%. This total of 36% is substantial enough to warrant a study for conservation purposes. However, the proper use of bathroom fixtures is of particular interest here. 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 in 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.

There is no reason an enjoyable shower, shave or light washing has to be sacrificed for the sake of water or energy conservation. The key is to use low flow rates in combination with a wide spray pattern. (17) The best designed faucets and spray heads have

(17) Flow Reducing Shower Head

flow restrictors installed in the fixture body or spray heads. Hardware is also available which an owner can install in-line to reduce the flow to previously installed conventional fixtures. Incorporating flow restriction devices can reduce the flow rate to as little as one-half gallon per minute. This is in marked contrast to the normal two to three gallons per minute which services most residential outlets; yet the user is not that conscious of the contrast. 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.

As a matter of habit and hygiene, showers are superior to baths. Not only do showers use less water (when taken conscientiously), but they enable the person to stand erect and not recline in his or her soiled water. Also a ten-minute shower with a device restricting the flow to one-half gallon per minute will be half as expensive as a typical 30-gallon bath, costing 12 cents. An excellent device in this regard is the on-off shower nozzle. (18) Usually hand held, the on-off option allows the user to soak, lather and rinse. This would use an extremely small amount of water. A fixture of this type incorporating a flow restriction device which has a good, invigorating spray pattern would be the ultimate energy and water conservation shower fixture.

Lavatory use seems to be insignificant when viewed in contrast to the other major contributors to water consumption. This is one area where user habits are almost totally responsible for the quantities consumed. The simple act of turning off a faucet while brushing one's teeth may mean

**HAND HELD
SHOWER FIXTURE**
WITH FLOW REDUCER, ON/OFF
& SPRAY PATTERN CONTROLS

(18) Hand Held Shower Fixture

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 a day.

A running faucet during a "quick" shave or makeup application may drain five or ten gallons at a time for a task which actually requires only two or three quarts.

Running a tap to drain the room-temperature contents of a water line in order to get a cold drink may drain one or two gallons for an eight ounce glass -if one drinks the entire glass.

The problems of water and energy consumption are dealt with in the MED home through the utilization of the UltraFlo system of water distribution.

UltraFlo is a central water distribution system unique in many ways. Figure (19) is a basic schematic illustrating the main features of the system. The UltraFlo system is comprised of two major components:

- Valve Unit--The valve unit contains the initial electrical supply and water control components of the system. Solenoid valves, which are electrically operated modulating devices, work in conjunction with mixing tubes and flow restriction mechanisms to control the water flow.

The solenoid valves are remotely energized by the push-button panels at the fixtures to allow hot or cold water to combine resulting in a supply of water mixed to a predetermined temperature. This water then leaves the valve unit at a preset flow rate substantially lower than conventional plumbing systems. Typical flow rates for the UltraFlo system are 2.0 to 2.5 gpm to the kitchen sink and tub-shower, and a nominal 1.5 gpm to lavatory basins. Also of particular significance is the fact that water

(19) UltraFlo Schematic For Residential Use

SOURCE: UltraFlo Corporation, Sandusky, Ohio

delivery is facilitated through a single, flexible tube of a reduced diameter to each fixture. A substantial installation saving is realized through the elimination of dual hot and cold feed lines, and the substitution of compression fittings, eliminating the need for joints and elbows and the accompanying necessity of connecting a multitude of fittings. The single line and smaller tube diameter provide for ample pressure without excessive volume. The only hot water "standing" in a dormant system occurs between the water heater and the valve control mechanism. Losses in the line are substantially reduced. A 50 foot length of 1/2 O.D. Type "L" copper line will retain 2.4 quarts of fluid. A typical UltraFlo line of the same length contains only .75 quarts.

Additional water conservation is possible because the system reduces the demand time at the beginning of a fixture's use. Delivering the desired temperature water much faster without costly faucet adjustment eliminates two major causes of waste.

• Push-Button Control Panel--The second main component of the UltraFlo system is the control point. The residential installations typically employ three different panel displays as illustrated in Figures (20), (21), and (22).

Some of the advantages provided by the use of the control panel include the elimination of washers, packing and O-rings, traditional trouble sources of conventional faucets. The system uses pressure-positive, self-cleaning solenoid valves which are completely leakproof (another cause of water waste) and highly resistant to hard water and corrosion. The buttons themselves require only a 12 volt power supply, an extremely small load for the energy and water savings realized by the UltraFlo system. The manufacturer claims a 33% hot water reduction for a family of four. Using 20,800 gallons of hot water a year,

DISP	HOT	WARM	COLD	DRINK	HI FLO	LO FLO	OFF
------	-----	------	------	-------	--------	--------	-----

KITCHEN CONTROL PANEL

<u>SELECT BUTTON</u>	<u>RESULT PROVIDED</u>
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.

(20) Kitchen Control Panel

HOT	WARM	COLD	OFF
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LAVATORY CONTROL PANEL

<u>SELECT BUTTON</u>	<u>RESULT PROVIDED</u>
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.

(21) Lavatory Control Panel

WARM	WARM 2	WARM 3	OFF
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SHOWER/TUB CONTROL PANEL

<u>SELECT BUTTON</u>	<u>RESULT PROVIDED</u>
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.

(22) Tub/Shower Control Panel

SOURCE: UltraFlo Corporation, Sandusky, Ohio

(23) Domestic Hot Water Supply Schematic

this would result in a potable water savings of 8,500 heated gallons, and an energy reduction of 5.6 million BTU.

The UltraFlo system eliminates any possibility of accidentally scalding the user by virtue of preset temperatures. Panels are available which include red buttons for those controls which provide untempered hot water to fixtures.

Disadvantages in the UltraFlo system depend upon the type of installation. In a small home with lightly grouped fixtures close to the domestic hot water heater, many of UltraFlo's single tube advantages are nullified. Heat losses in such an arrangement are nil, and the water contained in the piping

distribution network is minimal. These factors must be weighed against the initial cost of the installation which is moderately high in relation to conventional components, unless compared against installations having widely distributed fixtures along piping runs.

Any fixture not using the UltraFlo system is not affected in any way by the installation of the unit. Water supplied to toilet fixtures or outside spigots is tapped off the supply lines before entering the domestic hot water heater or UltraFlo valving component. Hot water heating in the MED home is accomplished through its inclusion in the solar heating system. Figure (23) illustrates the relationship of the DWH (domestic hot water heater) tank to

the thermal storage tank. Solar heated water is drawn from the thermal storage tank and passed through a modulating valve on the way to the DHW tank. If the water from the storage tank is above 140°F., the modulating valve tempers it down to 140°F. with cold water from the city supply. If water from the thermal storage tank is below 140°F., it is allowed to pass through the modulating valve and into the DHW tank where it is boosted conventionally. Hot water is then either routed to the UltraFlo valving component or tapped directly from the DHW tank for use by the dishwasher and clothes washer.

It is estimated that the solar heating system will be able to satisfy the entire heating requirement of the DHW system most of the time. This represents a significant savings. Projected statistics reveal that water heating will comprise 20% of the users' yearly fuel bills. The chapter on "Solar Collectors" outlines the design considerations of the entire solar heating system in greater detail.

In order to examine the combined impact of water-conserving, energy-efficient fixtures and users' habits, the following study of two prototypical families is included. To avoid confusion, the families will be discussed individually.

Mr. and Mrs. A. Pathy and their two children live in a home equipped with conventional fixtures. As we shall see, their everyday habits, although totally believable, leave much to be desired from a conservation standpoint.

Mr. and Mrs. T. O. Gether and their two children have recently purchased a MED home. They are firm believers in conservation and practice it at every opportunity.

The following is a comparative study of water usage patterns resulting from their two distinctly different lifestyles.

On a typical weekday, the Pathy family generally rise together and use the master bath and family bath at the same time. Mr. A. Pathy and his two children elect to shower daily in preparation for work and school while Mrs. A. Pathy prepares breakfast. Being a man of leisure, Mr. A. Pathy enjoys a seven-minute hot shower. Both his children take five-minute showers with warm water. If we assume a shower head allowing a 5 gpm flow rate, the results are as follows:

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	7 min. hot shower @ 5 gpm @ 50% hot water for 95°F. mix (assume 140°F. & 50°F. supply)	35	17.5
(2)	5 min. warm showers @ 5 gpm @ 40% hot water for 77°F. mix	50	20.0

After showering, Mr. Pathy enjoys his usual hot shave. Between leaving the water running to reach maximum temperature and doing the actual shaving, the faucet runs hot for four minutes.

(1)	4 min. shave @ 2.5 gpm @ 50% hot water for 95°F. mix	10	5.0
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Meanwhile, Mrs. Pathy is busily preparing breakfast. Water used for food preparation includes one full coffee pot and that used for washing off fruit for the morning cereal.

(1)	Full coffee pot @ 1 qt./pot	.25	
(1)	1 min. food preparation task @ 2.5 gpm (assume 100% cold water)	2.50	

After breakfast, Mrs. Pathy stacks all the dishes into the dishwasher and calls for a full-cycle wash.

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	Dishwasher cycle @ 15 gal./cycle (assume 100% un- tempered hot water @ 140°F.)	15.00	15.00

As the morning progresses, everyone uses the toilet at least once, and everyone brushes their teeth. The Pathy's poor habits result in each member of the family leaving the faucet running while brushing their teeth.

(4)	Toilet uses @ 6 gal./flush	24.00	
(4)	1 min. lavatory uses @ 2.5 gpm (assume 100% cold water)	10.00	

With the family off to work and school, Mrs. Pathy settles into her daily bath, which she takes as much to relax as to cleanse herself. Also, Mrs. Pathy elects to wash her hair this day. She does this after her leisurely bath by using the shower nozzle.

(1)	Bath @ 30 gal. 42.5% hot water for 87.5°F. mix	30.00	12.75
(1)	3 min. shower use @ 6 gpm @ 42.5% hot water for 87.5°F. mix	18.00	7.65

Having taken care of her personal needs, Mrs. Pathy begins her daily homemaking chores. This day, the only chores involving a substantial amount of water are her laundry and washing her car. Unfortunately, she has a water intensive clothes washer, and does not use cold water cycles or

biodegradable detergents. She also lets the hose run as she washes her automobile. Thus, the total amount of water used during the car washing process was 205 gallons.

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	Typical clothes wash cycle	35.00	

assume:

(1)	140°F. wash cycle		17.50
(1)	95°F. rinse cycle @ 50% 140°F.		8.75
(1)	20 min. car wash @ 10 gpm	200.00	
(1)	5 gal. bucket of water (assume 40% hot water for 77°F. mix)	5.00	2.00

In the late afternoon, Mrs. Pathy decides to make another pot of coffee and a garden salad. Rather than wash the vegetables in a bowl or plastic container, she elects to let the water run, rinsing the vegetables and cutting them in sequence as she prepares the salad.

(1)	Full coffee pot @ 1 qt./pot	.25	
(1)	10 min. salad preparation task @ 2.5 gpm	25.00	
(2)	2 min. total use of the garbage disposal	5.00	

In the late afternoon, Mr. Pathy and the children arrive home. Pre-dinner use of the lavatory takes place and food preparation begins. Mr. Pathy mixes a drink for himself and Mrs. Pathy from the bar. The children decide to mix a half gallon of their

favorite fruit drink. The evening meal required two one-quart saucepans for boiling water. A salad is included in the evening meal which Mrs. Pathy prepares in a manner similar to the one she had for lunch. After dinner, Mrs. Pathy gives the kitchen a thorough cleaning during which she wipes the appliances and countertops and scours the double bowl kitchen sink.

Assume: The use of both master and children's bathroom.

Assume: First person using each lavatory runs hot water 15 seconds to reach hot water temperature before using.

No.	Purpose	Total Water Gal.	Hot Water Gal.
(2)	2 min. face & hand washing @ 2.5 gpm + 15 sec. @ 2.5 gpm @ 40% hot water for 77°F. mix	10.625	2.00
(2)	2 min. face & hand washing @ 2.5 gpm @ 40% hot water for 77°F. mix	10.000	4.00
(2)	4 oz. water mixed into 8 oz. drink (assume cold water runs for 15 sec. to reach 50°F. supply temp. @ 2.5 gpm)	.0625 .6250	
	2 drinks require	.6875	
(1)	1/2 gal. required for fruit drink	.5000	
	TOTAL	1.1875	
(1)	10 min. salad preparation @ 2.5 gpm	25.000	

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	2 min. total use of garbage dis posal @ 2.5 gpm	5.00	
(1)	Dishwashing cycle @ 15 gal./cycle assume 100% un tempered hot water @ 140°F.	15.00	15.000
(1)	Kitchen cleaning @ 1.5 gpm Assume water left running total of 6 min. @ 2.5 gpm Assume additional "on-off" usage of 1 gal. Assume 50% hot water for 95°F. mix	15.00 1.00	8.000

In the course of the evening, between arriving home and bedtime, we shall assume Mr. and Mrs. A. Pathy and family consume two gallons of water for drinking and miscellaneous purposes.

(2)	5 min. warm showers @ 5 gpm Assume 42.5% hot water for 87.5°F. mix	50.00	21.250
(2)	3 min. light washings @ 2.5 gpm Assume 42.5% hot water for 87.5°F. mix	15.00	6.375
(1)	Lavatory use re- quiring 2 gal. in bowl Assume 42.5% hot water for 87.5°F. mix	2.00	.850
(4)	1 min. lavatory uses @ 2.5 gpm	10.00	

(24) The water consumption totals for Mr. and Mrs. A. Pathy for this day would be as follows:

686.5 gals. total water consump.
 -205.0 gals. for "outside" use
 481.5 gals. total "inside" use
 163.875 gals. hot water
 = 34%

Toilets	72 gals.	15%
Lavatory	78 gals.	16%
Bathing	133 gals.	38%
Laundry	35 gals.	7%
Kitchen	111 gals.	23%
Miscellaneous	2 gals.	1%

For an accurate comparison, a study of Mr. and Mrs. T. O. Gether family will be undertaken using an identical format. The same sequence of daily chores and personal routines will be used so that only habits of the users and the more efficient fixtures will determine the consumption rates.

The Gether family, like the Pathys, usually rise together and begin their day by showering while Mrs. Gether prepares breakfast. All the family members shower conscientiously using the wet, lather, and rinse method. This is done with an on-off hand held shower fixture in conjunction with the UltraFlo system. In addition, in order to conserve hot water, all the family members have opted for warm showers.

No.	Purpose	Total Water Gal.	Hot Water Gal.
(3)	45 sec. wettings plus (3) 2 min. rinses @ 2.5 gpm @ 40% hot water for 77°F. mix	20.625	8.25

After showering, Mr. Gether takes his morning shave. Unlike Mr. Pathy, Mr. Gether wets his face with hot water and fills the lavatory bowl with approximately one quart of hot water with which he cleans his razor as he shaves. Rinsing his face afterward results in a total consumption of:

(24) Water Usage - Mr. & Mrs. A. Pathy Family

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	30 sec. wetting @ 1.5 gpm		
(1)	30 sec. rinse @ 1.5 gpm plus 1 qt. of water in lavatory bowl @ 50% hot water for 95°F. mix	1.75	.875

Meanwhile, Mrs. Gether prepares a breakfast of coffee, fruit and cereal identical to that of the Pathys:

(1)	Full coffee pot @ 1 qt./pot	.25	
(1)	1 min. food preparation task @ 1.5 gpm	1.50	

Unlike Mrs. Pathy, Mrs. Gether stacks the breakfast dishes into her dishwasher and elects to wait until dinner, realizing she does not have a full load.

As the family prepares to leave for the day, each member uses the toilet once, and they all brush their teeth. Again, the Gether's good conservation habits dictate that they rinse their mouths before and after brushing. They do not leave the faucet running.

(4)	Toilet uses @ 3 gal./flush Assume 1 qt./ person for brushing teeth	12.00 1.00	
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After the family has gone, Mrs. Gether takes her morning shower. Unlike Mrs. Pathy, she uses the wet, lather and rinse method. She also washes her hair while she showers, eliminating an extra task.

(1)	1 min. wetting @ 2.5 gpm	7.50	
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No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	2 min. rinse @ 2.5 gpm @ 40% hot water for 77°F. mix		3.00

After showering, Mrs. Gether proceeds with her household chores. Like Mrs. Pathy, she does her laundry and washes the family car. Her home is equipped with a suds-saving washer in which she uses a biodegradable detergent which works with cold water. Also, Mrs. Gether uses the wet, lather and rinse method on her automobile and decides not to use hot water. By doing so, the total amount of water used for washing the car is 40 gallons.

(1)	Clothes wash cycle with suds-saver Assume (1) cold water wash cycle (1) cold water rinse cycle	15.00	
(1)	Car wash @ 10 gpm Assume 2 min. wet- ting, 2 min, rinse	40.00	

For her afternoon meal, Mrs. Gether, like Mrs. Pathy, also has a pot of coffee and a garden salad. Mrs. Gether, however, scrubs her vegetables and rinses them all at once, not letting the faucet run.

(1)	Full coffe pot @ 1 qt./pot	.250	
(1)	Salad preparation Assume use of 2 qt. container for washing Assume 45 sec. rinse of vegeta- bles @ 1.5 gpm	1.125	
(1)	2 min. total use of garbage dis- posal @ 1.5 gpm	3.000	

As the family returns home, Mrs. Gether prepares dinner. The family uses the lavatory in anticipation of dinner. Mr. Gether mixes drinks for himself and Mrs. Gether, and the children mix a half gallon of fruit drink mix. The evening meal requires two one-quart saucepans for boiling water. Again, salad is included. Also, like Mrs. Pathy, Mrs. Gether habitually cleans the kitchen after the evening meal.

No.	Purpose	Total Water Gal.	Hot Water Gal.
(4)	2 min. face and hand washings @ 1.5 gpm @ 40% hot water for 77°F. mix	12.00	4.80
(2)	4 oz. quantities of water mixed into 9 oz. drink	.0625	
(1)	1/2 gal. required for fruit drink	.50	
(1)	10 min. salad preparation @ 1.5 gpm	1.50	
(1)	2 min. use of garbage disposal @ 1.5 gpm	3.00	
(1)	Dishwashing cycle @ 15 gals./cycle Assume 100% untempered hot water @ 140°F.	15.00	15.00

Mrs. Gether typically cleans her kitchen by filling a sink bowl 1/4 full and using the soapy water for the entire kitchen. The only time the water is left running is to rinse out the sink itself.

Assume 2 gal. total for task	2.00	
Assume 50% hot water for 95°F. mix		1.00

During the evening, the Gethers consume two additional gallons of water for drinking and miscellaneous use:

No.	Purpose	Total Water Gal.	Hot Water Gal.
(1)	2 gallon requirement	2.00	

After dinner, each member of the family brushes his teeth and uses the toilet one time. Again, the water is turned on and off as necessary and not permitted to run.

(4)	Toilet uses @ 3 gal./flush	12.00	
	Assume 1 qt./person for brushing teeth	1.00	

In preparing for bed, Mr. and Mrs. Gether both shower. Like the Pathys, the children elect to wash lightly, choosing to shower in the morning. Mrs. Gether removes her makeup and gives herself an evening facial. Once again, each member uses the toilet and each person brushes his teeth before retiring.

(2)	1 min. wettings @ 2.5 gpm		
(2)	2 min. rinses @ 2.5 gpm @ 42.5% hot water for 87.5°F. mix	15.00	6.375
(2)	2 min. face and hand washing @ 1.5 gpm @ 42.5% hot water for 87.5°F. mix	6.00	2.550
	Assume 1 qt. per person for brushing teeth	1.00	

(25) The water consumption totals for Mr. and Mrs. T. O. Gether for this day would be as follows:

(25) Water Usage - Mr. & Mrs. T. O. Gether Family

186.0625	gals. total water consump.
- 40.0000	gals. for "outside" use
146.0625	gals. total "inside" use
41.8500	gals. hot water
= 31%	

Toilets	36.000 gals.	25%
Lavatory	22.750 gals.	16%
Bathing	43.125 gals.	29%
Laundry	15.000 gals.	10%
Kitchen	28.180 gals.	19%
Misc.	2.000 gals.	1%

It must be realized that the previous discussion of the Pathys and the Gethers is included for comparison purposes only. It represents a typical day in which a common sequence of events takes place. It may be noted that the percentages tabulated are not in keeping with typical averages. This may be accounted for by the fact that different lifestyles, vacation schedules, the inclusion of weekends, etc. will result in averages much unlike those tabulated on a daily basis when many other "typical families" are considered. However, this much is certain--the difference in water consumption is a product of two considerations:

- User Habits
- Water-Conserving Fixtures

Obvious savings can be realized through comparisons such as this. First, water consumption has been reduced by 70% considering both indoor and outdoor use. Secondly, hot water use has been reduced by 75%. Projected throughout a given year, the energy savings realized through reductions such as these would be in keeping with the quantities saved.

It should be also 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. It can be assumed, therefore, that savings such as those realized by Mr. and Mrs. T. O. Gether are possible anywhere by anyone who is willing to

retrofit or install water-saving
equipment and formulate conscientious
habits.

CONSTRUCTION

The two Minimum Energy Dwellings which were built during a four-month period used a 2 x 6 framing dimension. One of the most interesting points about this project is the construction of the homes which are heavily instrumented in order that comparisons can be made with predicted results. The construction process revealed items which must be refined before they are accepted by the building industry.

The construction of the Minimum Energy Dwelling began in the spring of 1976. The homes were built by the Mission Viejo Company who let out the majority of the construction to local subcontractors. The basic approach was to use traditional construction practices which were being used in other areas of the Mission Viejo development. The work, if performed in as typical a manner as possible, will allow for easier integration into the building trades.

The small photos which run vertically down the side of the page reflect the construction process of the MED homes. To the left of the smaller pictures is a time line indicating the week the work was accomplished. The larger photographs placed in the right hand margin illustrate areas of particular interest.

The design of the Minimum Energy Dwelling for energy conservation, while not easy, is understandable from

a theoretical point of view. The application of these energy conservation techniques can become difficult when external constraints which are not related to energy use are integrated.

An important area for the designer and builder to understand is the effect on the cost of a particular technique. The total cost involves much more than just the cost of materials and the expected amount of time required for installation. The five areas identified in this particular project were the following:

- Codes
- Unforeseen Costs
- Method of Assembly
- Installation Jurisdiction
- Learning Process

The first area of concern is codes. Some potentially useful ideas were vetoed because of code restrictions. A case in point is slab insulation made of a compressible material. The building code prohibits the use of compressible materials underneath concrete slabs in order to prevent unwanted cracking.

Another easy area to overlook is the unforeseen addition in costs. The Pella wood windows were used rather

than the aluminum windows standard for Southern California tract homes. In comparing total costs between the two products, care must be taken to include all costs for installation and material. The Pella wood windows must be painted on the interior, whereas the aluminum window requires no painting, thus saving the builder the time and expense of an additional subcontractor on the job.

In the MED home, the difference for painting added \$60.00 to the cost of a home, which has little to do with energy conservation, but a price which must be paid to use an energy conserving wood window. Although \$60.00 does not appear an unreasonable amount to pay, it can make the difference between a reasonable and an unreasonable return on investment.

At Mission Viejo, the subcontractors and workmen are paid by the amount of work accomplished rather than the amount of time. This method of payment, however, has not led to a deterioration in construction quality. The homes are checked against the builder's requirements and any visible discrepancies must be corrected by the negligent subcontractors. Therefore, although the homes are built quickly, they are also built correctly.

Problems can arise, however, in any building technique requiring the need of two individuals working together. A faster man may be able to accomplish the work in six hours which may take a normal worker eight hours. If the two workers are placed together to accomplish a single task, the faster worker may become aggravated by the extra time required to complete a task. Therefore, care should be taken to install energy conserving techniques by involving a single individual working at his own pace, rather than two people working together or the teaming of individuals with similar ability. This procedure will eliminate any personal conflicts which can lower productivity.

March 29, 1976

Most energy conservation techniques involve better workmanship in construction. This commodity is harder to obtain in piece work tract-built projects. Unless the technique is simple and easy to accomplish, it will be difficult to assure proper workmanship without a daily or hourly inspection to insure compliance. The window caulking around the edge of the finished framing is to prevent air infiltration. In tract-built housing, checking every window to determine if properly caulked is difficult, especially after the exterior and interior wall surfaces have been installed. The energy consumption will increase when the home is completed, but probably not enough to be noticeable. The only proper way to ensure proper installation is with an infra-red scanner, with the ability to spot unusual heat loss or gain. The method would be expensive to conduct and would probably increase the cost from apprehensive subcontractors.

During the construction of the Minimum Energy Dwelling the determination of which subcontractor should install a given energy conserving technique can become a problem. A solar collector can be a good example. Who should install it? The mechanical contractor because it is a piece of mechanical equipment, the glazer because almost all flat-plate solar collectors are the size of window glass and are installed using the same techniques as a spandrel wall, or a carpenter because many collectors are integrated within the roof structure or how about a roofer since that's where they are usually installed and must be integrated with the rest of the roofing materials? Most jurisdictional problems have been easily solved during the infancy of the solar and energy conservation growth. But, as the work continues to increase, the various national organizations and spokesmen for the component installers will be more vocal.

In any new process, the amount of time spent understanding and developing a

rhythm or a procedure for performing the work efficiently is greater the first time through and decreases with each succeeding attempt. This concept is classified as the "learning curve". The more typical a new experience, the less is required for learning the new task, and the more efficiently performed.

The "learning curve" applies to the cost of instituting a new energy conservation technique. The more unusual the technique, the more a subcontractor will inflate his bid to cover the unknowns. The technique may be no more complicated and may, in fact, be easier, but because of unfamiliarity, the bid will be increased. No known cure will alleviate the apprehension except actually doing the work, and doing it as many times as possible. The contractor can suggest and show methods making the task easy to accomplish, but the subcontractor will not likely change his price until he has had the experience of doing the work himself.

(1) Trenching For Foundations

The construction of the Minimum Energy Dwelling began on March 29, 1976 with the trenching for the foundation footings as shown. (1) The views

April 5, 1976

shown in this picture are from the east looking at the entrance to the house toward the garage and bedroom. Excavation of the hot water storage tank pit is shown in this photograph. To the left of the tank pit is the area in which the mechanical system will ultimately be built. The addition of the storage tank pit added considerably to the cost of the house. The cost of the form work for the tank pit was \$1600 including pouring and \$100 for excavation.

(2) Concrete Forms For Foundations

(2) Two 1" pieces of rigid polystyrene insulation are tied together against which concrete was poured. The reason for two pieces of 1" insulation is that 2" rigid insulation was not available at the time of construction.

A problem was encountered in using the insulation as a form as shown in Figure (3). The pressure of the concrete would bow out the insulation creating an unsatisfactory foundation wall. Ways of preventing this kind of occurrence in the future have been detailed. The use of foundation insulation is a limited practice in California and would require considerable education about building trades in order that it become common prac-

(3) Pouring Concrete For Forms

tice. In the Minimum Energy Dwelling, the added cost for under slab insulation was \$245. This compares with \$386 for the total cost of adding insulation to the rest of the house which includes the roof and the walls. The addition of slab insulation, therefore, may not have a positive return on investment. Improved methods of installing slab insulation have been detailed but it is felt that the cost savings would be no greater than \$100. The house is instrumented to monitor the effectiveness of slab insulation. If the test home proves that slab insulation is beneficial in Southern California, the re-education of the building trade would be worthwhile.

Additional problems uncovered during the construction of the house included compliance and timing of installation. County codes do not permit the use of compressable materials. Therefore, if slab insulation were used on a wide scale, a change in County codes would be needed. The second problem in timing installation of slab insulation would require a rewriting of the contract between the Contractor and the Subcontractor. The party responsible for installation of slab edge

April 12, 1976

insulation in Southern California has not been determined. The logical trade to perform the work would be the Subcontractor who is pouring the concrete footings and slab, thus eliminating the need for the insulation contractor to come to the job site twice--once during slab pouring and then again when the insulation is installed throughout the rest of the house.

The slab insulation installed in the Minimum Energy Dwelling is not as effective as it could be. A complete thermal break was not achieved. As now constructed, heat flows from the floor slab to the outer wall without being halted by insulation. Various methods could be used to solve this problem. One would involve pouring the footing with a key for the slab concrete. Before pouring the concrete slab, insulation could be placed between it and the footing providing a thermal break. This method would involve more work than is presently being done and is, therefore, more expensive. The effectiveness of slab insulation is improved to compensate for the increased cost. A second method would be to pour the footing and concrete slab using present technology and place the slab insulation on the exterior of the structure. The insulation could be sprayed with Stucco at the same time the rest of the wall is sprayed. A complete description of the slab edge condition occurs in the "Insulation" chapter.

Figure (4) shows the insulation being installed for the pouring of the concrete footing. A sensor has been attached to the interior of the insulation. This will allow for accurate measurement of the heat flow from the exterior of the building through the concrete footing and insulation.

After the footing has been poured, a polyethylene sheet was laid over the ground and steel mesh for concrete reinforcement was placed over in preparation for the concrete slab.

(4) Slab Edge Sensor Location

(5) Storage Tank Pit

(5) Shown is the solar storage tank after it has been poured. The blocking in the side of the tank pit will be used later for a piping trench. The storage tank pit and the storage tank are expensive components in the system. In future solar designs, the design of economical storage must take added precedence.

Storage Containers

The solar storage tank in the MED home uses a 360 gallon ASME Rated Tank designed for 125 psi operating pressure. This is far in excess of the required operating pressure, however, it is the lowest point at which pressure rated tanks are available. Experience in using non-ASME rated tanks operating at a 30 psi indicates that a substantial cost saving is available when the tank is constructed for more realistic operating pressures. If incremental storage tanks were available to operate at low pressures (in a range of 30 psi) at reasonable costs, it would have the potential of lowering installed system costs. One option which might be investigated is the use of incremental storage tanks in perhaps 250 gallon increments. Steel cylindrical sections could be bolted together to achieve the desired tank volume, using perhaps a ceramic liner with gasket connections at the joints, or a self-contained flexible membrane internal liner.

If non-pressurized storage tanks can be used, a wide variety of readily available construction components could be adapted for use as tank containers. For example, pre-cast concrete pipe sections, transite pipe, culvert sections, corrugated metal pipe, and sonotube concrete forms are available in cylindrical shapes which could serve as the shell for a membrane liner of metal or a flexible hypalon material. Other techniques which merit investigation for non-pressurized storage containers include the use of all-weather wood foundations, swimming pool construction techniques, septic tank containers, and the use of durable membrane bladders which can be simply placed in an excavated, insulated space within the building.

Some investigation and use of flexible membrane liners in concrete block or poured concrete storage containers has indicated that a substantial cost savings is available in comparison to

steel tank storage. In a recent example, a reinforced hypalon flexible liner was placed as a solar storage container for a material cost of approximately 10¢/gallon.

(6) Instrumentation Wiring

By April 15th the floor slab has been poured and the plumbing vents have been installed. Shown in Figure (6) is a detail of the instrumentation wiring coming through the slab after the slab had been poured.

The instrumentation system for the Minimum Energy Dwelling is one of the most extensive in the country. The instrumentation includes a complete weather station which records the wind velocity, wind direction, total solar insolation perpendicular to solar collectors, solar direct insolation on a horizontal plane and solar diffuse insolation on a horizontal plane.

The majority of the instrumentation is connected to the mechanical system and monitors its performance. The monitoring is accomplished by the use of three types of sensors: Temperature, Flow, and Occurrence. The three measurements allow for a complete determination of the amount of energy

April 19, 1976

flowing through a given section of the mechanical system.

(7) Comparison of 2 x 4 and 2 x 6
Construction Of Exterior Walls

Figure (7) illustrates the use of 2 x 6 construction that was used in the Minimum Energy Dwelling. Preliminary cost information indicates that the use of 2 x 6 construction in lieu of regular 2 x 4 construction does not add significantly to the cost of the house. Savings are permitted by spacing the 2 x 6 on 24" centers rather than standard 2 x 4 on 16" centers.

The house as it appeared on April 29, 1976, is shown in Figure (8). This view shows the rear of the house at the east corner where the kitchen is located. At this point in construction the rear shading device covering the patio windows is finished. The wing walls located near the center of the house on both sides of the Pella windows have also been installed at this time. Figure (8) shows the shadow cast by the sun and shading device on the concrete patio. The effectiveness of the shading device on the patio sliding doors is apparent.

(8) Framing On Southeast Side

(9) Rough Framing Crack Insulation

All of the open cracks in the 2 x 6 construction were tamped with Fiberglas insulation. The corner details were filled with rigid polystyrene and any of the other large gaps were filled with the same. Throughout the early construction of the Minimum Energy Dwelling, extreme care was taken in the building of the house. This included placing a sill sealer

between the concrete slab and the sill plate of a mastic compound 1/4" thick. The use of a puttied material for wall was tamped in order to create a good seal. By tamping, the puttied material would be squeezed to the edges. This additional step of "stomping the studs" would be expensive in-line production and, therefore, would be difficult to justify. The procedure for installing a sill sealer is as follows:

- First, clean concrete to remove particles of dirt.
- Second, place the sill sealer on the slab edge where the outside wall will be installed.
- Finally, place the wall frame on top and attach to the slab with anchor bolts.

A few problems were encountered during this procedure. First, adequate cleaning of the concrete is difficult to do on a construction project. Therefore, when the sill sealer was placed, it did not adhere to the concrete. A second problem encountered was in placing the exterior wall over the sill sealer. If not done properly the first time, the sill sealer had a tendency to stick to the studs making adjustment and alignment difficult. An alternative to this problem may be the use of a sill sealer introduced by the insulation company consisting of a fiberglass batt which can be rolled on the slab, underneath the sill.

Figure (10) shows the installation of the outside air intake for the mechanical system. The intake was placed over the entry to the Minimum Energy Dwelling. Placing the outside air intake in the entry way offers the advantage of being on the northeast side of the house and, consequently, the coolest air. Locating the fresh air duct in this position was not determined until the house was under construction. Originally, the intake was to be placed in the garage side-

(10) Economizer Fresh Air Inlet

wall. The placement of the ductwork from the air handler to the point of use should be left as schematic as possible in the plans to allow the ductwork subcontractor the needed flexibility for on-site opportunities. The sizing and quality of workmanship required should be thoroughly detailed. As construction procedures improve, leakage through the ductwork becomes of greater significance.

Increasingly, the zoning of residence so that unused spaces can be maintained at a different temperature than occupied spaces is becoming a common technique in energy-conserving buildings. Most small residential packages, however, are single-zone and do not inherently afford the opportunity to control space temperature individually. It would seem advantageous to investigate some type of multi-zone damper system for individual room control or for zone control of portions of the residence. These dampers could be manually adjusted or thermostatically controlled; this would be similar in concept to the zone control hydronic valves used on larger HVAC systems.

It has been noted in the Minimum Energy Dwelling that the level of infiltration control achieved by the

house is probably in excess of the infiltration control achieved by the operable dampers, even though a high quality opposed blade damper with felt strip closures was chosen. If homes are developed to control infiltration, it is appropriate that more positive means of closure be developed to control leakage through dampers and louvers. It might be appropriate, for example, to provide a pneumatic system with bladders for positive closure in the ductwork system.

(11) Kitchen Wall Plumbing

Figure (11) illustrates the plumbing wall looking from the kitchen to the bathroom. Because of the uncertainties with the Ultra-Flo system, a standard piping system was included. Although not clearly evidenced in this photograph, the ease of installing the Ultra-Flo system is significant. The Ultra-Flo system consists of a $3/8$ " pipe going to the kitchen sink. This compares with a standard plumbing arrangement of both hot and cold being supplied to the kitchen sink, with two $1/2$ " lines and their accompanying joints which must be soldered. With the Ultra-Flo system, tubing can just be unrolled and no soldered connections are necessary between the Ultra-Flo valve unit and the fixture in the kitchen. The same advantages would accrue with other fixtures in the

house. The advantages of the Ultra-Flo system were hard to assess in the Minimum Energy Dwelling compared to the Standard Cordova. The Standard Cordova has integral plumbing within a plumbing wall through the center of the house from which the bathroom and kitchen fixtures are served. In the Standard Cordova, the water heater is placed close to this plumbing wall requiring little plumbing. This proximity of the hot water heater to the fixtures is an inherent energy saver. As presently installed, the Ultra-Flo system requires 12 seconds for water from the water heater located in the garage to get to the kitchen sink. The flow rate, however, can be improved by adjusting the flow of the Ultra-Flo mixing box.

(12) Interior Ductwork

Depicted in Figure (12) is the air distribution ductwork. The smaller line which first branches off the ductwork in the lower part of the picture goes to the bathroom. The large ductwork to the left of the picture serves the kitchen. The line from the upper part of the picture goes to the bedroom. The ductwork for the house was built of round Fibreglas insulation lined with metal connectors. The

May 3, 1976

metal connectors were wrapped with a 1" blanket of insulation. The ductwork installed for the Minimum Energy Dwelling is approximately twice the area which would normally be expected in Southern California. This is due to the use of the economizer.¹ The placement of the ductwork in the attic space is not the best position for maximum energy conservation. A preferred location would be within the conditioned space so that any energy losses from the ductwork would benefit the house. If placed in the attic space care must be taken to prevent air leaks and do a good job of insulation.

(13) Polyethylene Vapor Barrier

A polyethylene sheet was placed on the exterior of the Minimum Energy Dwelling to prevent vapor migration to the interior when cooling. (13) A vapor barrier on the exterior is rather unusual in construction. Since the home is in a cooling mode most of the year, this membrane will prevent moisture from migrating from the outside to the inside and saturating the Fiberglas insulation. Care must

¹Economizer refers to the use of cool and dry outside air, when available, rather than using the cooling equipment from the mechanical system.

(14) Vapor Barrier and Wire Mesh

be taken to prevent punctures in the polyethylene film during its installation. Any punctures in the film will result in a drastic reduction in its effectiveness in preventing moisture migration. Any punctures which occur should be taped.

Depicted in Figure (14) is a view from the inside of the house through the stud wall, polyethylene sheet, and wire mesh for Stucco bonding. The substitution of standard building paper with 6 mils of polyethylene requires no additional cost. An interesting problem was encountered by the plastering subcontractor. Normally, applying the vapor barrier is a one-day operation requiring one mechanic and installing the wiring takes an additional day by another mechanic. In the Minimum Energy Dwelling though, both procedures were done by both individuals at the same time, meaning they had to work together. Since the individuals are paid by how much they get done rather than the amount of time it takes, this can create tension between the two individuals. In this particular case, one could do the same amount of work in a six-hour day that it took the other eight hours. Thus, the six-hour-per-day man would be

reluctant to perform this kind of operation in the future.

(15) Installation Of Vapor Barrier

Depicted in Figure (15) is the installation of the polyethylene vapor barrier on the exterior face of the studs. During the rough framing of the Minimum Energy Dwelling, all cracks and voids were filled with putty. This care could not be expected in a line production home and as can be seen in this photograph may not be necessary if a polyeythlene vapor barrier is applied to the exterior. The polyethylene drapes from the top of the doubleheader down to the sill plate. The only problem areas are above the doubleheader, at the sill plate, and around windows and doors or any other interior to exterior projections. A home, properly constructed in this manner such as the Minimum Energy Dwelling, has been tested to have an infiltration rate of $1/3$ the Standard Cordova. Because infiltration of cold or hot air into the building's interior is a major portion of the energy load, this reduction can be significant.

The two Minimum Energy Dwellings that were built are heavily instrumented. Thermal and moisture indicators were

(16) Instrumentation Wiring

placed throughout the house. Some of the typical placements include: slab edge, between the vapor barrier and the insulation, in the wall construction, and in the attic space. All of the instrumentation wiring is brought to a central point as shown in Figure (16). Ultimately, these leads will be connected to a micro-computer and thermal analysis of the house can be monitored by others. In the background of the photograph are the air louvers for the intake and exhaust of the cooling tower which had not yet been installed.

(17) Shown is the Pella window as installed. Window installation is usually not well done, but in this case exceptional care was exercised to avoid openings between the finish frame and the rough opening and prevent infiltration. The wood window offers many advantages for energy savings. The typical window in Southern California is comprised of a metal window frame and single pane glass. The metal frame will permit substantial heat transfer. Wood is a much better insulator and, consequently, the thermal flow is reduced.

This Pella window is constructed to have tight weather sealing to prevent infiltration. Also included in the

May 10, 1976

(17) Living Room Window

design of the window is a controllable, thin slat venetian-type shade which fits between the two panes of glass. The slim shade is an excellent shading device.

To prevent unwanted infiltration, the opening between the rough opening and the finished frame must be filled. In this particular installation, Fiberglas was stuffed between the rough opening and finished frame. Another effective technique would be to use a polyurethane foam which is available in an aerosol can. By foaming the polyurethane in a crack, it expands to at least three times its original volume and fills any opening tightly. Also shown in Figure (17) is the installation of batt insulation in the stud cavity. The kraft vapor barrier has been stapled to the face of the stud walls. This procedure will allow for a better vapor barrier. Industrial officials have indicated that the performance advantage of the increased vapor barrier is outweighed by the problems that face stapling creates for the dry wall subcontractor. Because the outside face of the stud is only 1-1/2" wide and the stapling flange on the insulation batt is 1" wide, the flanges overlap. The overlap creates an uneven surface of the stud face

making it almost impossible for the drywall subcontractor to do a neat looking job. It also makes it difficult for him to even find the studs. Therefore, Mission Viejo does not intend to nail face insulation in the production of other housing. Additionally the installation of an interior vapor barrier may not be required in a cooling climate such as Southern California. In cold northern climates where a good integral vapor barrier is required on the interior studs, this problem could be alleviated by inset stapling and using a foil-backed gypsum board. This system would provide an unbroken vapor barrier and still allow easy installation for the drywall subcontractor. The increased cost for this kind of wall system should be considered in those cases.

(18) Installation of Ceiling Insulation

Figure (18) shows the installation of the ceiling insulation. The picture shows the proper way of installing insulation so that an air space is created between the insulation and the ceiling gypsum board. Care must be taken when installing the insulation to avoid compressing the material which would result in greater thermal conductivity. No other vapor barrier

was included in the roof other than that supplied with the insulation. Although a continuous vapor barrier would be preferred on the outside of the insulation, the framing prevented easy installation.

Early in construction, a blown cellulose insulation was preferred. The use of a blown insulation would fill any cracks that may develop in the use of conventional insulation. Ultimately, the blown insulation was not used for reasons of expediency and cost. Since, at the time of construction, the blown insulation did not have widespread distribution in Southern California, the installed cost was greater. Also, the use of Fiberglas is widely accepted in California making lower costs available.

(19) Mechanical Room

Figure (19) shows the mechanical room space before any mechanical equipment was installed. In the foreground is the tank pit in which the solar hot water storage tank will be placed. From the storage tank and running along the side of this picture is a trench in which the piping to and from the solar hot water storage tank and the rest of the mechanical equipment will be placed.

(20) Infiltration Protection At Electrical Boxes

All electrical boxes were wrapped with a sheet putty material to prevent infiltration. Shown in Figure (20) is a box wrapped with the material and a sample of the material laying on the floor. A refinement to the Minimum Energy Dwelling was the care in installing exterior wiring. Under normal conditions, a hole is drilled through the center of the stud construction and the wiring is fed through the hole. In the Minimum Energy Dwelling, a notch is placed in the interior stud face and the wiring is stapled inside the notch. This will prevent the compression of the insulation retaining the maximum in the Fiberglas thermal resistance.

Illustrated in Figure (21) is the rear shading device at the kitchen. The addition of the shading device was an expensive addition, although it may be totally justifiable. The concrete for the patio slab cost \$336. The framing and lumber required \$500 and an additional \$192 was needed for the cost of a hot-mop roof. Originally, the shading device was built with a 2 x 2 trellis. Unfortunately, proper spacing of the 2 x 2s was not obtained, and sunlight penetrated the trellis and struck the south wall and patio windows. To alleviate this problem a

May 17, 1976

(21) Patio Shading

solid roof was later installed, adding to the cost.

Impending California legislation may require the installation of permanent exterior shading devices for windows and sliding glass doors. This presents a problem for standard homes built on many different sites with different orientations such as the Cordova model homes. The legislation as now written would require that a given window receive no sunlight on a specific date, such as August 21st of each year. Presently, the working drawings for the Cordova model home are reduced to three or four floor plans and accompanying elevations allowing for cost savings by building identical houses. It is felt that the implementation of this legislation will demand a different elevation for each side of the house depending on its location within the plot plan. This could add substantially to the cost of plans and installation. At the moment, the most likely approach by the builder to shading devices would be to design a worst case and install it on all sides of the house consistently. This approach will also add to the cost of the home and does

not recognize the individual conditions on the different sides of a home.

Because of the problem of enforcement the way the law may be written, it would not allow for the use of temporary shading devices such as canvass awnings or the use of vegetation or landscaping. The reasoning has been that if the shading device is not permanent, the owner could at sometime in the future remove the shading device, nullifying the intent of the law. However, temporary shading can be the most cost effective.

(22) Stucco Application

By May 27th the exterior of the home is ready to have applied a Stucco finish material. An early concern was expressed for the ability of the Stucco to adhere to the exterior polyethylene vapor barrier. A solution to this problem was to consider the use of a wash coat by swinging a wet mortar brush at the polyethylene to help in giving the polyethethylene sheet some adhering qualities. The decision was made that if a wash coat was necessary, then the use of a polyethylene sheet would not be practical in line production. Therefore,

May 24, 1976

it was decided to use the standard technique for applying Stucco in Southern California. (22) This consists of six people applying a scratch coat, taking approximately two hours after which a brown coat is applied by the six people, also requiring two hours. Finally, the color coat is troweled on the surface by three people requiring four hours. The use of Stucco in Southern California is a widespread practice and, therefore, the use of other kinds of exterior wall techniques would add to the cost. In the final analysis, the use of Stucco over polyethylene posed no application problems.

(23) Ductwork

Figure (23) shows the ductwork as it enters the mechanical space. The two pieces of ductwork protruding from the wall are the supply and return for the air system. The fresh air intake can be seen on the side wall. These three air ducts will be connected to the economizer and air handler.

In buildings which have been designed to conserve energy, and hence require smaller mechanical conditioning equip-

ment, a common problem is a too limited choice of air handling capacity. The Minimum Energy Dwelling is a good example. To meet the requirements of the economizer and the mechanical system, a commercial size air handler was needed. In larger homes, for which units with a proper output capacity for heating or cooling may exist, the air flow quantity may be insufficient to insure a good movement of air throughout the occupied space, and hence an even distribution of temperature. In smaller homes, where units with an appropriate output capacity are frequently not available, the rates of air movement may be uncomfortably large. When these considerations are combined with the implementation of an economizer cycle package to utilize "free" cooling when ambient conditions permit, it begins to suggest the use of multiple speed or variable speed fan motors. For example, it may be desirable to use a significantly higher air flow rate when operating in an economizer cycle mode than when operating in a heating mode of operation. The increase in flow rate would permit the use of warmer ambient air to accomplish the cooling objective.

Presently there are no residential units available which provide a package consisting of a coil section, face and bypass dampers for economizer cycle operation, filters, fan and motor. If such a package were developed, it would be logical to include a control sub-package with multi-stage heating and cooling capacity. It is possible that such a distribution package might be included with the absorption chiller package mentioned previously.

The Owens-Illinois collector is shown in Figure (24) as it is being installed on the roof of the Minimum Energy Dwelling. A white-rolled roofing² was applied first and then

²A 1/4" hyplon material was used. The roofing is commonly used for institutional buildings.

(24) Installation Of Collectors

the supports for the collector. The main section of the supply and return header was applied next along with the end brackets, after which the tube bundles were inserted into the end bracket and slid forward until they could be installed into the piping header. Next an end cap is placed on the end bracket and the tube is tightened to withstand pressures up to 25 psi when operating. After the preliminary work of installing the frame upon which the collector will be mounted is finished, the actual installation of the Owens-Illinois collector goes rather rapidly.

The collector integrates well with the roofing materials, however the collector could be improved further for better performance. Each MED home has a solar array consisting of ten modules of Owens-Illinois solar collector, measuring 4' x 8'. The net area available for collection is approximately 27.5 square feet per module. The flow arrangement within each module is a series flow, with water entering the module and passing through all twenty-four tubes before exiting the module. The ten modules are piped in parallel. The total flow rate of water to the array is 2 gpm, in accor-

dance with the manufacturer's recommendations. Under normal operating conditions, the rise in temperature which has been experienced from the collector supply to collector return is in the order of 40° . This 40° rise is out of proportion with the normal temperature drop experienced through the Arkla Absorption Chiller, or the fan coil unit. If the flow rate through the collectors was increased to decrease the temperature difference experienced, it would be possible to take flow directly from the collectors to the mechanical distribution equipment. Furthermore, a lower temperature rise across the collectors would increase available storage options, since a 200° storage tank temperature could be approached using an atmospheric storage system (non-pressurized). Under the present operating conditions, it is not possible to store water in a non-pressurized tank over 170° without boiling water in the collectors. As the collectors are currently manufactured by Owens-Illinois, an increase in flow rate would significantly increase the velocity of flow through the tubing and a pressure drop would be experienced. For example, an increase in flow to 1 gpm per module would result in a velocity of 2.2 ft./sec. and a head loss of 7.75 ft./100 ft. in the $3/8$ " diameter tube used within the modules. While this would decrease the Delta T to approximately 8° to 10° , it would increase the velocity by 400% and the head loss by 1300%. The resulting velocity (2.2 ft./sec.) and head loss (7.75 ft./100 ft.) might be in the acceptable range per module. However, the major difficulty occurs in the headers which supply and link modules together. The tubing in the headers is $1/2$ " diameter, and an increase in flow rate to 1 gpm per module would result in a velocity of 13.8 ft./sec. and a head loss of 174 ft./100 ft. These are far beyond the range of acceptable velocity and pressure drops and would result in a rapid deterioration of the tubing by erosion and would require a tremendous increase in pumping horsepower. One

May 31, 1976

July 12, 1976

alternative would be to provide separate supply and return headers and connect each module into those individually. This seems to defeat the intent of inter-connectability inherent in the design. An increase in tubing size within the header should be investigated.

Another desirable feature to upgrade the operating characteristics of the distribution equipment would be to vary the flow rate through the collectors to maintain a constant temperature difference from supply to return. Various pumping and valving arrangements would permit this variation of flow rate, but investigation should be done to determine the most cost-effective means of varying flow rate within acceptable limits of tolerance.

Since the design of the Owens-Illinois collector module does not easily permit the draining of fluid from the tubes, a problem can exist when there is production of the collectors in excess of the heat requirement, and the storage tank is topped off. If the pump were merely shut down, the stagnant water in the collectors would boil causing over-pressurization and leakage. In systems where the collectors can be drained, this problem is avoided by designing the collector to undergo stagnation temperatures. In the MED houses, a heat dump is employed to reject excess heat to the atmosphere, using a fin tube radiator. When the return water temperature from the collectors reaches 240°, a portion of the collector supply water is circulated through the fin tube radiator to reject heat and maintain a 240° outlet temperature. Since this condition is likely to occur in most systems which are designed using the Owens-Illinois "SunPak" collectors, investigation could be done by Owens-Illinois to integrate a heat rejection feature into the basic module with internal controls to automatically dump heat as required.

One problem which has proven difficult to resolve is the placement of a

sensor in the collector array to act in conjunction with the differential temperature controllers. Placement of the sensor within the array in a manner which accurately represents the average array temperature is an area of recommended investigation for Owens-Illinois. Somewhat related to this problem has been the experience of a reverse thermo-syphon flow from the storage tank during periods of noncollection, which effectively prevented collector operation at some times when there was sufficient sun to exceed the threshold intensity. A positive means of preventing flow must be employed.

A consistent problem in the solar collector industry has been the integration of collector components with conventional construction. By its design, the Owens-Illinois "SunPak" is inherently an applied, rather than integrated, collector array. This has resulted in certain special detailing conditions which were necessary to make a successful integration with the roof. For example, spacers were required to separate the header and the bracket assemblies from the roof surface to permit the free flow of water down the roof's surface. Furthermore, to make a visually-accepted interface, a special detail for flashing and edge trim was developed for the MED project. While Owens-Illinois has continually improved and advanced the collector design which they have developed, these are areas which would certainly merit increased investigation if widespread acceptance in the building industry is to be a reality.

By August 26th, most of the mechanical equipment has been installed and piped. On the left side of Figure (25) is the air handler into which the return, supply and outside air intake are connected. In the center is the Arkla WF36 absorption water chiller. On the right is the cooling tower connected to the outside wall. Behind

August 2, 1976

August 16, 1976

(25) Mechanical Room

the absorption chiller is the boiler and behind the cooling tower is the domestic water heater. There is substantial room for investigation of packaging cooling systems into a factory-assembled, marketable component. This might logically include a control package with multi-stage heating and cooling capability, a common drive motor for the various pumps required in the system, perhaps using varying pulley ratios, variable speed pumping, or an electro-magnetic clutch similar to an automobile air conditioner. It would also be possible to package the auxiliary system internally in the absorption unit. For example, this might be a small fossil-fuel-fired water boiler. Distribution equipment such as coils, fans, pumps, etc. would be a logical inclusion in this package.

The energy-conserving features of the Minimum Energy Dwelling have resulted in peak loads of approximately 10,000 BTUH for space heating, and approximately 1.3 tons for space cooling. These very small design loads make it quite difficult to select auxiliary energy equipment in an appropriate size range. For example, the space heating, space cooling, and domestic water heating auxiliary loads could

probably have been met by a single unit with an input of approximately 50,000 BTUH. Under most circumstances, this unit would be operating significantly below this peak level and hence would be run on an intermittent basis. If space cooling were not a consideration, a unit in the range of 20,000 BTUH might have been an appropriate choice for space heating and the domestic water heating. There exists a shortage of equipment on the market which is designed for long-term, fairly continuous service in these output ranges. While a conventional domestic water heater might have been an appropriate choice to supply the auxiliary requirements for space heating and domestic water heating, its limited temperature range (approximately 140° to 150°F.) would not permit its use as an auxiliary source for the absorption chillers. Furthermore, fossil-fuel-fired water heaters are not necessarily designed to efficiently handle this combined load on a long-term basis.

All fossil-fuel-fired equipment operate at peak efficiency when meeting the design load. At part load conditions, the combustion efficiency drops substantially. Typically, for about 90% of the heating season, the actual heating load is less than 60% of the design heat load. The use of modular burners controlled by outdoor air temperature is an area for investigation. Even a two-stage burner has the potential for considerable savings of energy if it is controlled in this way. The technique of modular burners is already well accepted in larger scale HVAC applications.

Presently, the control packages for solar mechanical systems have been custom-built for each particular job including MED. Although there are packaged units available to control collector operation by many manufacturers, these differential temperature controllers do not normally include any controls for distributing the collected energy. There is room for considerable investigation into low

August 30, 1976

cost control packages, which would control all operational modes of the system. Such a package might include multi-stage heating and cooling thermostatic controls, enthalpy sensors for economizer cycle operation, appropriate collector and storage tank sensors, and signals for automatic control valves, fans, pumps and other components of the system.

It is conceivable that a type of micro-processor might be used to anticipate a cooling load, and pre-cool using outside air when ambient conditions permit. For example, if a thermostat was used which had a heating/cooling manual selection, the micro-processor could control economizer cycle operation to reduce the space temperature significantly below the thermostatic setpoint when ambient conditions permit economizer cycle operation.

(26) Front Entrance

By August 20th initial landscaping has begun and the house is rapidly nearing completion. A good overall view is shown in Figure (26).

(27) Refrigerator Venting

Shown in Figure (27) is the Pella window at the kitchen and living room. Underneath the Pella window are two air vents. These two vents are connected to the refrigerator condensing unit. This allows for the transfer of heat that is being rejected from the refrigerator to the outside. The lower vent is an intake and the upper vent is the exhaust. During the winter months a damper, which is installed in the ductwork, can be closed allowing for the refrigerator condensing heat to be rejected into the living room, supplementing the standard heating system.

The front door entrance to the Minimum Energy Dwelling is shown in Figure (28). The door installed is a metal clad polyurethane core door. Magnetic weatherstripping was installed to prevent infiltration. Beyond the front door is a second door which leads to the living room. This design provides an air lock. A particular advantage of the metal door is its ease of installation. The door will not warp which results in fewer call-backs in future years.

Illustrated in Figure (29) is the Ultra-Flo system for the kitchen. The

(28) Front Door Entry Lock

(29) Ultra-Flo

pushbutton valving unit is activated by a low voltage switch, thus eliminating the typical hot and cold spigots of a traditional sink.

The construction of the Minimum Energy Dwelling was accomplished by the use of fairly standard construction techniques. In the future, as in the past, the easiest method of implementing a new energy conservation technique is by doing. The building contractor or subcontractor cannot be expected to give a realistic cost for installing a new technique until he has obtained adequate experience. Experience will bring success, and the builder can then more accurately predict the construction cost of a new technique. The government and local utilities can provide the needed funding for demonstration projects and spend money to help the builder become acquainted with a new technique. Innovative builders can be expected to find the prospect of trying new techniques to be of little or no cost to themselves and will be rewarded by the development of a competitive edge on their competition.

Included on the following pages are the reduced construction documents used in the construction of the Minimum Energy Dwelling.

INDEX

A1 FLOOR 3 FOUNDATION PLAN
A2 ELEVATION
A3 FRAMING
A4 DETAILS

M-1 FLOW DIAGRAM & SPECIFICATIONS
M2 FLOOR PLAN & DETAILS
T-1 TANK PIT DETAILS
C-1 COLLECTOR & ROOF DETAILS
C2 ROOF DETAILS

MED

FOR

MISSION VIEJO COMPANY

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REVISIONS

NO.	DATE	UNIT	REMARKS
1	1-25-76		BUILDING DEPT. CORRECTION
2	3-10-76		BUILDING DEPT. CORRECTION
3	5-15-76		PLUMB DELEGATIONS WTS. C-2 & M-2
4			
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SOUTH ELEVATION

EAST ELEVATION

NOTE
 *SCALE OF ELEVATIONS = 1/4" = 1'-0"
 *ALL WOOD TRIM TO BE ROUGH SAWN
 *ALL STUCCO TO BE ROUGH TEXTURED

NORTH ELEVATION

WEST ELEVATION

POT SHELF DETAIL (A)
 SCALE 1/2" = 1'-0"

ROOF PLAN
 SCALE 1/8" = 1'-0"

ELEVATION

MISSION VIEJO COMPANY
 26137 LA PAZ ROAD · MISSION VIEJO · PHONE 937-6050

MINIMUM ENERGY DWELLING
 CALIFORNIA - PLAN, 20 CONVERSION

DATE
 JUN 21, 1976
 SHEET
 A-2
 OF 4

FRAMING

MINIMUM ENERGY DWELLING
CORONA-PLAN 20 conversion

DATE
JUL 20 1968
SHEET
A. 4
OF 4

FLOW DIAGRAM

- WATER TEMPERATURE CONTROLLER** --- Shall be Symmons Engineering Company Temprol 5-200 3/4" size automatic temperature controller. Unit shall be adjustable for a temperature range of 85° to 145° F. and shall automatically compensate for supply line temperature and pressure changes. Unit shall incorporate the fail safe feature of shutting down if either the hot or cold water supply fails.
- PUMPS** --- See schedule on drawing.
- PIPE, FITTINGS AND HANGERS** --- All piping shown on flow diagram shall be hard type "L" copper with wrought copper fittings and sweated joints using 95/5 solder. Gas piping shall be black steel with screwed joints and suitable iron fittings. All water piping shall be pressure tested to 80 P.S.I.G. hydrostatic. Do not subject solar collector to more than 25 P.S.I.G. test pressure. Piping shall be supported at intervals not to exceed 10 feet by clevis or other appropriate hangers. Hangers shall not penetrate the insulation on covered piping.
- VALVES** --- Gate valves in copper piping to be 125 pound bronze body with solid taper wedge, union bonnet and solder joint connections. Check valves in copper piping to be 200 pound, bronze body, horizontal swing check type with renewable bronze disc, regrinding seats and sweated connections. Valves shall be Fairbanks, Jenkins, Walworth, Stockham or Crane.
- DIRT STRAINERS** --- To be "Y" pattern with non-ferrous baskets having .045" diameter perforations at 225 per square inch.
- HEAT DUMP** --- To reject excess solar heat provide and install a 24 foot length of Vulcan Radiant Confinery bare fin-tube radiator consisting of 1-1/4" copper pipe with 4-1/4" square copper fins spaced 40 per foot. Elements shall be installed on the roof, level and beneath the solar collector array.
- SHEETMETAL DUCTWORK AND ACoustICAL LINING** --- Sheetmetal duct construction shall conform to S.M.A.C.A. residential standards. Acoustical lining shall be 1" thickness N.F.P.A. approved resilient glass fiber blankets of 2 pound per cubic foot density held in place with adhesive applied over the complete metal surface. Black side shall face the air stream.

- GRILLES, REGISTERS, DIFFUSERS AND LOUVRES** --- To be Tuttle and Bailey. Supply air registers to be 4-84 double deflection type with opposed blade damper and of aluminum construction. Ceiling outlet air diffusers shall be type DME complete with damper No. 6 and Whitestone enamel finish. Ceiling return air grille to be CR-510 egg crate type of aluminum construction with Whitestone enamel finish. Louvers for intake and exhaust air through outside walls to be "Versaflex" (core only) of extruded aluminum construction with clear anodized finish and installed with blades deflected 15 degrees downward toward the outdoors.
- BACKSPLASH DAMPER** --- To be multi-leaf gravity type constructed of 28 gage hard aluminum blades with reinforced edges fitted with felt strips. Blades shall not be linked together or spring loaded.
- INSULATION COVERING** --- All piping shown on the flow diagram shall be insulated except condenser water piping, gas piping, and the tubing between the Ultra-Flo unit and the plumbing fixtures. Pipe insulation to be 1" thickness Owens Corning 25 ASF "Fiberglas" with integral all service jacket. Self-sealing longitudinal flaps and end joints shall be additionally secured with flame-retardant staples 4" O.C. Fittings to be insulated with fiberglass blankets with Zeston P.V.C. covers. The void between the solar water storage tank and the pit shall be filled with Johns-Manville "Baroc" loose mineral wool insulation installed at 7 pounds per cubic foot density. The body of the chilled water pump P-5 shall be coated to 1/4" thickness with 3-M brand EC-549 insulating compound to prevent condensation.
- THERMOMETERS** --- To be Tracerie series 4400 red reading mercury type with 6" scale and range of 30 to 240 degrees F. except water from the solar collector to be 100 to 600. Pipe line thermometers to have 2" long stems and 1/2" male screwed connections. Duct thermometers to have 4" long stems and 3" mounting flanges.
- PRESSURE GAGES** --- To be Tracerie series 600 with 3-1/2" dial size and gage cock. Pressure range C to 160 P.S.I.G. except downstream side of P.R.V. to be 0 to 50 P.S.I.G.
- AUTOMATIC TEMPERATURE CONTROL** --- All temperature controls, automatic valves and damper operators shall be furnished by Honeywell and installed by the contractor in strict accord with the manufacturer's instructions and the National Electric Code. Honeywell shall furnish a complete wiring diagram showing both control and power wiring including all required switchgear.
- WATER TREATMENT** --- A reliable local water treatment company shall make recommendations for a chemical program to prevent corrosion, scale and organic growth in the outdoor condenser water cooling tower piping system and the chilled water/piping conditioning system. Determine blowdown rate for the cooling tower. Provide instruction to the Owner, test apparatus, and approximately 3 years supply of chemicals.

REVISIONS
1/1/74 (1/1/74)

MINIMUM ENERGY DWELLING

BURT, HILL & ASSOCIATES • ARCHITECTS
SIXTH FLOOR, MELBON BANK BUILDING BUTLER, PA.
PITTSBURGH, PA. FORT MYERS, FLA.

FLOW DIAGRAM AND SPECIFICATIONS

DRAWN BY J.A.G.
CHECKED BY J.E.E. DATE ISSUED 10 FEB 74 SCALE

JOB NO.

SHEET NO.

M-1

OF 1

- NOTES: 1) T.R. DENOTES TOP REGISTER SUPPLY AIR OUTLET.
2) C.G. CEILING GRILLE FOR RETURN AIR.
3) C.O. CEILING OUTLET SUPPLY AIR DIFFUSER.
4) DENOTES ACoustically LINED DUCTWORK.
5) DIMENSIONS GIVEN ARE OUTSIDE DIMENSIONS METAL TO METAL.

FLOOR PLAN
SCALE 1/4" = 1'-0"

SECTION A-A
SCALE 1/4" = 1'-0"

SECTION B-B
SCALE 1/4" = 1'-0"

SECTION C-C
SCALE 1/4" = 1'-0"

PUMP SCHEDULE									
PUMP NO.	SERVICE	MANUFACTURER SIZE	CAPACITY G.P.M.	HEAD FT. WATER	PUMP SPEED S.P.M.	CONNECTION SIZE	MOTOR SIZE	ELECTRIC POWER	
P-1	SOLAR WATER	113	2	17	1725	3/4"	1/8 H.P.	115-1-60	
P-2	CHILLED								
P-3	SPACE CONDITIONING WATER	113	11	18	1725	1 1/4"	1/8 H.P.	115-1-60	
P-4	CONDENSER WATER	1612	20	32	1750	1 1/2"	1/8 H.P.	115-1-60	
P-5	CHILLED WATER	111	8	13	1725	1 1/4"	1/8 H.P.	115-1-60	

NOTE: PUMPS SELECTED FROM TACO CATALOG. TO BE IN LINE TYPE SUPPORTED BY RIGID TO WHICH THEY ARE CONNECTED. DOMESTIC WATER PUMP TO BE ALL BRONZE CONSTRUCTION; ALL OTHERS TO BE IRON BODY BRASS TRIMMED. SHAFT SEALS TO BE MECHANICAL TYPE.

SOLAR WATER STORAGE TANK
NOT TO SCALE

REVISIONS
1. 11/14/76
2. 1/14/77

MINIMUM ENERGY DWELLING		JOB NO.
BURT J. HILL & ASSOCIATES - ARCHITECTS SIXTH FLOOR, HILLMAN BANK BUILDING PITTSBURGH, PA.		SHEET NO.
FORT MYERS, FLA.		M-2
FLOOR PLAN AND DETAILS		OF 1
DRAWN BY J.A.C.F.P.	DATE ISSUED 10-10-76	SCALE
CHECKED BY J.E.E.

REVISIONS	MINIMUM ENERGY DWELLING		JOB NO. 7562
	BURT, HILL & ASSOCIATES - ARCHITECTS SIXTH FLOOR, MELLON BANK BUILDING PITTSBURGH, PA.		SHEET NO. M.3
	MECHANICAL ROOM PIPING ISOMETRIC		SP
	DRAWN BY LUCAS, JR.	DATE ISSUED 5/12/76	SCALE

REVISIONS	MINIMUM ENERGY DWELLING			JOB NO.
	SOUTHERN CALIFORNIA GAS COMPANY			
	BURT, HILL & ASSOCIATES ARCHITECTS			SHEET NO.
	SIXTH FLOOR MELLON BANK BUILDING BUTLER, PA.			2
	PITTSBURGH, PA. FORT MYERS, FLA.			OF 3
	ROOF DETAILS			
	DRAWN BY	CHECKED BY	DATE ISSUED	SCALE

TRANSVERSE SECTION 4
SCALE 1/4" = 1'-0"

DETAIL - ROOF OPENINGS FOR COLLECTOR PIPING
SCALE 3/8" = 1'-0"

DETAIL - FLASHING @ TILE ROOF
SCALE 3/8" = 1'-0"

NOTE: GENERAL CONTRACTOR AND PLUMBING CONTRACTOR SHALL COORDINATE TO ENSURE THAT ALL CHASE OPENINGS BE SIZED AND LOCATED TO ALLOW CLEAR PASSAGE OF PIPING AND DUCTWORK AND THE PROPER ASSEMBLY OF VALVES AND INSTRUMENTS.

COLLECTOR / ROOF INTERFACE
SCALE HALF SIZE

REVISIONS	MINIMUM ENERGY DWELLING			JOB NO.
	SOUTHEAST CALIFORNIA GAS COMPANY			
	BURT, HILL & ASSOCIATES - ARCHITECTS			SHEET NO.
	SIXTH FLOOR, MELLON BANK BUILDING			3
	PITTSBURGH, PA.			OF 3
	FORT MYERS, FLA.			
	COLLECTOR / ROOF DETAILS			
	DRAWN BY P.H.	DATE ISSUED	SCALE	
	CHECKED BY P.H.			

GLOSSARY

Absorption--a process whereby heat extracts one or more substances present in an atmosphere or mixture of gases or liquids; accompanied by physical change, chemical change, or both of the material.

Absorption Chiller--a refrigeration unit based upon 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 the mechanical movement of energy by the use of an external force of energy.

Aerobic--requiring the presence of oxygen.

Air Change--the movement of a volume of air in a given period of time; if a house has one air change per hour, it means that all the air in the house will be replaced in a one-hour period. Air changes are expressed in cubic feet per minute.

Air Conditioning--the process of treating air to control its temperature, humidity, flow, and odor.

Alkaline--having properties containing more than average alkali (K_2O and Na_2O); having a greater pH than 7.

Altitude--the measurement in degrees of the difference in vertical direction on perpendicular to the earth's surface and a given object.

Ambient Temperature--temperature of the outside air.

Anaerobic--the absence of oxygen, preventing normal life for organisms that depend on oxygen.

ASME--abbreviated notation for American Society of Mechanical Engineers.

Attic Ventilation--in houses, screened openings provided to ventilate an attic space. They are located in the soffit area as inlet ventilators and in the gable end or along the ridge as outlet ventilators. They can also consist of power-driven fans used as an exhaust system.

Azimuth--the measurement in degrees of the difference in the south horizontal direction on the earth's surface and a given object.

Berm--a mound or small hill of earth, man-made.

Black Water--highly contaminated sewage.

Boiler--a device used to heat water or produce steam. It includes burner, heat exchanger, flue, and container and controls; may be fueled by oil, gas, or electricity.

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 equal to the amount of heat given off by burning a kitchen match.

Building Skin--the physical structure which encloses a building.

Bypass Loop--a piping arrangement which bypasses or circles the flow of a heat absorbing medium around rather than through a piece of mechanical equipment.

c.f.m.--an abbreviation for cubic feet per minute.

Capacity--the usable output of a system.

Centrifugal Fan--a machine for moving a gas, such as air, by accelerating it rapidly outward in an impeller to a surrounding casing, generally of a scroll shape.

Change of State(phase change)--the change from solid, liquid, or gas to either of the other two.

Chimney Effect--the tendency of air or gas in a duct or other vertical passage to rise when heated due to its lower density compared with that of the surrounding air or gas. In buildings, the tendency toward displacement (caused by the difference in temperature) of internal heated air by unheated outside air due to the difference in density of outside and inside air.

Coil--a cooling or heating element made of pipe or tubing.

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

Compression--in a compression refrigeration system, a process by which the pressure and temperature of the refrigerant is increased to allow for greater heat transfer.

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

Control Logic--the sequence of steps required to perform a specific function.

Convection--transfer of heat by movement of a fluid or gas.

Crack Method--a method used in the calculation of air movement from the outside into an enclosed space. The method is based on the rate through one foot of crack between sash and frame or between door and frame.

Cursor--a movable, clear scale which can be used to accurately read a value on a stationary scale.

DHW Tank--abbreviated form for "Domestic Hot Water" Tank.

Damper--a device used to vary the volume of air passing through an air outlet, inlet or duct.

Dehumidification--the condensation of water vapor from air by cooling below the dew point or removal of water vapor from air by chemical or physical methods.

Density--the weight per unit volume.

Desalination--removal of salt, as from water or soil.

Dew Point--the temperature at which water vapor begins to condense.

Diurnal Cycle--the day-to-night change or cycle of natural phenomenon. An example is the variation of outdoor temperature throughout a twenty-four-hour period.

Dry Bulb Temperature--a measure of the sensible temperature of air (the one with which we are most familiar).

Economizer Cycle--a cooling mode which uses cool outdoor air to offset heat gains in buildings rather than using an energy consuming cooling device.

Electronic Air Filter--the use of electricity to set up a static charge which can remove dust and other particulate matter.

Emissivity--the ratio of the radiation emitted by a surface to the radiation emitted by a perfect black-body radiator at the same temperature. The lower the ratio, the less energy re-admitted to the atmosphere.

Energy--the capacity for doing work; taking a number of forms which may be transformed from one into

another, such as thermal (heat), mechanical (work), electrical and chemical; in customary units, measured in kilowatt hours (KWH) or British Thermal Units (BTU); in SI units, measured in joules (J), where 1 joule = 1 watt-second.

Energy Mountain--a graph, representing in three dimensions, the scale of energy use over a period of time.

Enthalpy--a measurement of the total energy content of the air. The total energy content is composed of both sensible and latent heat as measured by the dry bulb and wet bulb temperature.

Equinox--the fall and spring equinoxes occurring about September 23rd and March 21st are the times at which light falls equally on the Northern and Southern Hemispheres, day and night are of equal duration everywhere on earth.

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

Evaporative Cooling--lowering the temperature of a large mass of liquid by utilizing the latent heat of vaporization of a portion of the liquid; cooling air by evaporating water into it.

Flame Spread--the rate at which combustion will occur.

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

Flow Rate--velocity at which a fluid travels, usually through an opening or duct.

Frequency of Occurrence--the number of times a given event will occur during a given period of time.

gpm--an abbreviation for gallons per minute.

Grey Water--lightly polluted bathing and washing water.

Greenhouse Effect--the effect of the earth's atmosphere in trapping heat from the sun; the atmosphere acts like a greenhouse by admitting the sun's shortwave radiation but blocking the exit of long wavelength radiation re-emitted by the earth or other warmed objects.

H--the monthly average daily total radiation on a horizontal surface, expressed in BTU/(day) (Ft.²).

Heat Capacity--sometimes called the thermal capacity; a measure of how much heat is required to raise the temperature of a specific quantity of material by a given amount.

Heat Dissipator--the method of transmitting energy or power out of a system in the form of heat.

Heat Exchanger--a device used to transfer heat from one medium to the other.

Heat Gain--an increase in the amount of heat contained in a space, resulting from direct solar radiation and the heat given off by people, lights, equipment, machinery, and other sources.

Heat Loss--a decrease in the amount of heat contained in a space, resulting from heat flow through walls, windows, roof, and other building envelope components.

Heat Pump--a reversible refrigeration system that delivers more heat energy to the end use than is input to the compressor; the additional energy input results from the absorption of heat from

a low temperature source--combination heating and cooling unit; operates like a normal air conditioner in summer, and in winter operates in reverse, ejecting warm air indoors and cool air (or water) outdoors.

Heat Wheel--a device used in ventilating systems which tends to bring incoming air into thermal equilibrium with exiting air; as a result, hot summer air is cooled and cold winter air is warmed.

Humidifier--a device to add moisture to air.

In-line Pump--a pump which is supported by the piping system.

Incident--usually used in the term "incident radiation" which is the amount of energy striking a collector surface before entering the collector.

Infiltration--the uncontrolled flow of air into and out of a building through cracks, openings, doors, or other areas which allow air to penetrate.

Initial Cost--the original price of an item or system.

Insolation--the exposure of an object to the sun; solar energy received, often expressed as a rate of energy per unit horizontal surface.

Insulation, Thermal--any material high in resistance to heat transmission that, when placed in the walls, ceilings, or floors of a structure, will reduce the rate of heat flow.

Ions--an isolated electron or positron, or an atom or molecule which by loss or gain of one or more electrons has acquired a net electric charge.

$\bar{K}_d$ --the monthly average daily diffuse radiation which strikes a horizontal surface.

Kilowatt Hour(KWH)--unit of electrical energy consumption; equals about 3,400 BTU.

Latent Heat--a change in heat content that occurs without a corresponding change in temperature, usually accompanied by a change of state.

Latitude--the measurement in degrees of a given position on the earth perpendicular to the equator.

Life-cycle Cost--the total cost of a system calculated over its anticipated operational life span.

Longitude--the measurement in degrees of a given position on the earth and perpendicular with the meridian of Greenwich, England.

Longwave Radiation--energy radiation in the infra-red portion of the spectrum; normal window glass is opaque to longwave radiation, hence forming a heat trap.

MBTU--a thousand British Thermal Units.

Masonry--stone, brick, concrete, hollow tile, concrete block, gypsum block, or other similar building units or materials, or a combination of the same, bonded together with mortar to form a wall, piers, buttress, or similar mass.

Mass--the property of density of a material; the use of mass by itself or in combination with insulation gives building structures the capacity to store energy or heat.

Mean--the average or expected value.

Mechanical System--the use of mechanical methods operated with not directly usable forms of energy to provide comfort for occupants.

MED--abbreviation for "Minimum Energy Dwelling."

Micro-Computer--a small desk-top computer or programmable calculator with a limited capacity to store information for calculations.

Mode--one of several alternative conditions or methods of operation of a device or system.

Moisture Content--the quantity of water in a volume of air expressed in grains of moisture; a grain of moisture is one seven thousandths of a pound.

Operating Cost--the cost in money to operate a system for a given period of time; its greatest use is in the comparison of different systems.

Overheated Period--the times during a day, or year, in which the interior of an enclosure is above the comfort zone.

pH--a term used to describe the hydrogen-ion activity of a system.

psig--abbreviation for "Pounds Per Square Inch Gauge".

Passive--the use of the natural movements of energy such as convection or conduction through fluids and gases to provide human comfort.

Peak Load--maximum predicted energy demand of a system.

Perms-Permance--the ratio of water vapor flow to the vapor pressure difference of the surfaces; permance is expressed in perms or

(grains)/(Sq.Ft.)(Hr.) (and of mercury vapor pressure difference)

Potable Water--the drinking water for the house; in solar water heating systems where anti-freeze is used, this must be kept separate by use of a heat exchanger.

Psychrometric--pertaining to the device comprising two thermometers, one a dry bulb, the other a wet bulb or wick-covered bulb, used in determining the moisture content or relative humidity of air or other gases.

R-Value Resistance--the resistance of a material to the flow of heat or energy.

Reflectance--a property of a material indicating the percentage of light that is reflected when a certain amount of light strikes the surface of the material or is transmitted through it.

Relative Humidity--the ratio of the amount of water vapor at a given temperature to the maximum amount of water vapor that could be held as vapor.

Roll Roofing--roofing material, composed of fiber and saturated with asphalt, that is supplied in rolls, containing 108 square feet in 36-inch widths; it is generally furnished in weight of 45 to 90 pounds per roll.

Roof Sheathing--the boards or sheet material fastened to the roof rafters on which the shingle or other roof covering is laid.

SHW Tank--abbreviation for "Solar Hot Water" Tank.

Sensible Heat--heat that results in a temperature change.

Set Back--the lowering of the thermostat setting; the technique is used to reduce the amount of heat required to heat a space.

Set Up--the raising of the thermostat setting; the technique is used to reduce the amount of cooling required to cool a space.

Shading Coefficient--the effectiveness of any shading device can be expressed by its shading coefficient; this coefficient describes the fraction of the incident solar energy which is transmitted through a window.

Shading Device--a covering which blocks the passage of solar radiation; common shading devices consist of awnings, overhangs, or trees.

Shortwave Radiation--a term used loosely to distinguish radiation in the visible and near-visible portions of the electromagnetic spectrum (roughly 0.4 to 1.0 micrometers in wavelength) from longwave radiation (infra-red radiation).

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

Sling Psychrometer--a psychrometer in which the wet and dry bulb thermometers are mounted upon a frame and connected to a handle at one end by means of a bearing or a length of chain; the psychrometer may be whirled in the air for the simultaneous measurement of wet and dry bulb temperatures.

Solar Intensity--the amount of solar radiation.

Solenoid Valve--a valve actuated by a solenoid or an electronic impulse for controlling the flow of gases or liquids in pipes.

Solstice--the two days (actually instants) during the year when the earth is so located in its orbit

that the inclination (about $23\text{-}1/2^\circ$) of the polar axis is toward the sun; the days are June 21st for the North Pole and December 22nd for the South Pole; because of Leap Years, the dates vary slightly.

Space Heating--interior heating of a building or room.

Stagnation--the condition of a fluid or gas unstirred by a current or flow.

Thermal Comfort--the zone in which a majority of the human population would not feel too hot or too cold.

Thermal Lag--the ability of materials to delay the transmission of heat; can be used interchangeably with time lag.

Thermal Sensation--the ability of the body to sense the temperature as being too hot or too cold.

Time Lag--the time between a cause and a resultant effect, as between occurrence of heat input on an exterior surface of a wall and the time until the heat is transmitted to the interior wall surface.

Ton--(of air conditioning)--the thermal refrigeration energy required to melt one ton of ice (2,000 pounds); equals 12,000 BTU.

"U" Value--a coefficient which indicates the energy (BTU) which passes through a component for every degree (Fahrenheit) of temperature difference from one side to the other under steady state conditions.

Vapor Barrier--a component of construction which is impervious to the flow of moisture or air.

Vapor Pressure--the force exerted when moist air attempts to seek equilibrium by migrating to areas with less water vapor.

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

Ventilation Air--outside air that is intentionally allowed to enter an interior space.

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

Wet Bulb Temperature--the lowest temperature attainable by evaporating water into the air, without altering the energy content.

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Price: Paper Copy \$9.00

Microfiche \$3.00

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