# SUN SEEKING ARCHITECTURE

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SUN SEEKING ARCHITECTURE:

The Relationship Between
Passive Solar Energy and Form

by

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Submitted in Partial Fulfillment
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ABSTRACT

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This study considers passive solar design in several ways:

First, this piece of work looks at and evaluates how the human, thermally interacts with the natural environment. Simultaneously, it reviews the larger climatic forces which affect human comfort. The interaction of these two concerns especially for the architect can lead to the formulation of worthwhile thermal design tools.

Second, it develops a series of design tools which describe the climatic context and the thermal response of buildings to climate. Thermal measurement, mechanism and means, together provide the kind of solar information necessary to instigate thermal design decisions.

Third, it documents a partial formal vocabulary of passive solar design which provides not only the necessary thermal requirements but in addition contributes to a supportive human environment.

Personally, this thesis is an affirmation of a design philosophy which envisions a language of form where utility and beauty are compatible.

Thesis Supervisor: Timothy Johnson ______________________
Title: Research Associate

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| | |
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# INTRODUCTION

Although the precise nature of the life cycle remains a mystery, whatever the incremental measure of life's cyclic nature, we nevertheless exist as a part of an intricate network of rhythms, patterns and change.

The pulse of a heart beat from an anthropocentric point of view might define life's rhythms as the incremental measure of its cycles.

A different view of the fundamental time piece inherent to rhythmic life forces, and perhaps held by the molecular scientist, stretches beyond the microscopic level. The scientist focuses on the infinitesimally small increments of time counted by the vibrations of molecules in motion.

A macro view of the rhythmic movements of energy and matter looks to the larger motions of our planet around the sun, the accompanying seasons and recurring cycles which follow.

A recognition of these larger rhythms; the power and importance of the sun, its seasonal moods and impressive dialogue with the earth, has prompted this inquiry.

It is in recognition of these rhythms that the architectural language of passive solar design begins to take form. This thesis, then, is a study of an emerging language whereby the primary reference is the natural landscape and the sculpting tool is the rhythmic/cycle force(s) of nature.

Edaburi, a Japanese word, translates to mean "the formative arrangement of the branches of a tree." This definition is perhaps illustrative of a certain consciousness, intrinsic to the formal relationship in nature which permeate the Japanese language. Much of the Haiku poetry is written with seasonal imagery, denoting the cycles of nature. As evidenced by the architecture of Japanese tradition, that which is found in the spoken language is often expressed in the language of their buildings.

The tree may be regarded as the ultimate solar collector. Man's built analogue to nature's tree form is the frameworks and free standing structure of his buildings. These frameworks filter, repel and regulate the sun's impact in a manner not dissimilar to the canopy of leaves and branches. Frameworks are representative of tree form. As the tree is rooted in the earth, so is the vocabulary of frameworks and screens connected to ground form materials.

A vital connection exists between passive solar design and the time-honored principles of building with earth materials. The use of ground form, masonry, for example, is valued for its associative nature as well as for thermal reasons. It is not surprising that earth and water are the primary building materials giving thermal memory to passively designed buildings. These materials link us back to the landscape and provide a measure of stability in a world of change.

The vocabulary of frameworks and screens used in conjunction with the stability of ground form allow for a measure of flexibility which provides a range of built opportunities supportive of the human condition.

The element of stability offered by ground form encourages the construction of buildings which are durable and lasting.

The flexible nature of framework materials provides for the hand of human intervention which allows both growth and change.

The dichotomy between permanence and change allows an architectural regionalism to take hold. The dominance of one factor over the other is indicative of the overriding conditions which climatically and topographically differentiate one region from another.

Passive solar design rethinks certain traditional ways of building and in light of current energy needs has provided the rationale and incentive for its existence. Much of passive solar design simply reinterprets traditional ways of building and incorporates the new into the old.

Finally, there is adequate justification for the additional cost incurred by a rich and enlivened weatheredge. Brightly colored shuttered windows, adorned wrought iron terraces and balconies, ivy strewn trellices and undulating canopies --the reevaluation of priorities brought on by the energy shortage has created a scenario whereby utility and beauty are compatible. The result is an increased potential for embellishment which has established a more personal architecture.

The building's exterior comes to life and assumes an almost face-like quality. Its features are the additive elements that move out into the landscape and reach toward the sun. Seasonal moods corresponding to the larger earth-sun cycles are emphasized in the building's countenance. Not unlike the sunflower the building looks to the sun for light and warmth. Sunlit orientations change character in response to the daily and seasonal movements of sun across the sky vault.

The weatheredge becomes a loosely defined boundary which extends both out into the landscape and penetrates into the building volume. The trellis framework, for example, provides for plant form and solar protection on the outside and use levels in the inside. The expansion of the weatheredge becomes a sequential movement of additive pieces which generate overlapping physical and thermal zones.

Passive solar design provides the impetus to generate a formal vocabulary--a language which has the characteristics of a collage. This mosaic of building materials confronts the natural elements in an embracing manner. This design philosophy vigorously reacts to some of the more glaring insensitivities of modern architecture, i.e., that attitude which has chosen to isolate buildings from the natural environment. What emerges as the final precipitate from passive design is that a building's character is realized when the dialogue between shelter and site not only recognizes natural forces but is conscious of the visual and spiritual connection between its inhabitants and the surrounding landscape.

Perhaps an interesting connection can be drawn from Louis Sullivan's comment on the disparity between mindless stylistic imitation and truly modern architecture, a disparity similar to our own dilemma.

"The old idea, . . . is dying because it no longer satisfies the expansion of thought and feeling of which the impressive revelation of modern science are a primary factor, and especially because it is no longer at one with those instincts we call human; it does not recognize the heart as a motive power."

This thesis presents a view of passive solar architecture which lends itself to a specific design methodology. The first part of this process looks at and evaluates how the human body interacts with the natural environment. Simultaniously, it reviews the larger climatic forces which affect human comfort. The interaction of these two concerns especially for the architect can lead to the formulation of worthwhile thermal design tools.

On the one hand these tools serve as a simplified analytical basis for understanding solar phenomena from a design standpoint, and concurrently provide a means for prioritizing design issues.

The issues inherent in a passive solar approach constitute one set of constraints in the architectural design process.

"Thermal Aspects of the Solar Wall" is a potpourri of references and innovative examples which demonstrate a variety of solutions in the built environment cognizant of human comfort and climatic impact.

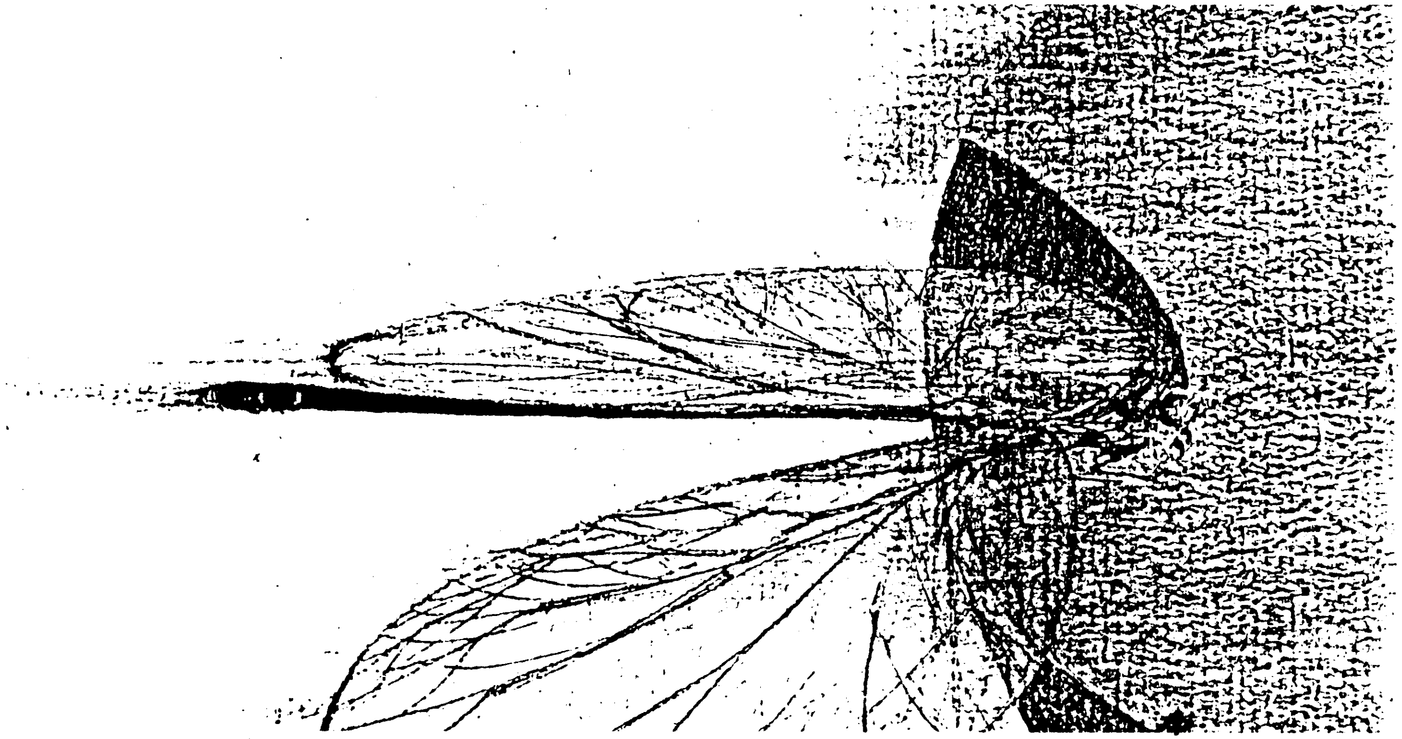
With regard to the scope of this exploration several ideas need to be clarified, in order to understand the use and application of this thesis. Whereas the main body of information pertinent to solar energy to date is concerned with reducing solar impact, the focus of this thesis is to take advantage of solar potential in a given region. This study, therefore, deals with northern climates where the demand for heating outweighs cooling loads.

An interest in passive solar design has prompted a closer look at the works of certain major figures in contemporary architecture who I have respected. Though the primary interest of architects like Wright, Le Corbusier, and Maybeck to mention a few, was not one of solar energy, nevertheless their work demonstrates an individual, conscious treatment of the building sympathetic to sun, natural lighting and indoor-outdoor connection.

In fact one begins to see that these tenets are basic to the understanding and implementation of passive solar design. More specifically, a passive approach presupposes an integration of building materials and the natural processes of thermal flow.

Clearly my attention has been devoted to the "thermal aspects of the solar wall." This work is divided into sections dealing with solar collection, protection and collection-storage. Hopefully, subsequent analyses will continue this exploration and evaluate "thermal aspects of the solar roof" and "assemblages of form."

Furthermore, it is assumed those reading this thesis will have a familiarity with fundamental principles of solar energy.



# SECTION 1

# THERMAL & VISUAL COMFORT

Thermal comfort is defined by the specialists in the field as "a condition of the mind that expresses satisfaction with the thermal environment." "Condition of the mind" is a vague and loosely defined statement of environmental indice. At the same time, it is an accurate statement of the range of subjective interpretations of the human condition. The thermal comfort statement suggests the difficulty of setting definitive standards. Thermal comfort criteria do not prescribe the optimum interior climate for all seasons and circumstances; rather they qualify a reasonable range of overlapping conditions that approximate a thermally comfortable environment.

It might prove helpful in assessing the standards of thermal comfort to consider briefly the larger context of human biometeorology which spans the range between atmospheric science and the biological basis of comfort.

The following graphic representation illustrates the fundamental relationship between:

EXTERNAL ENVIRONMENTAL FORCES

SHELTER ENVELOPE

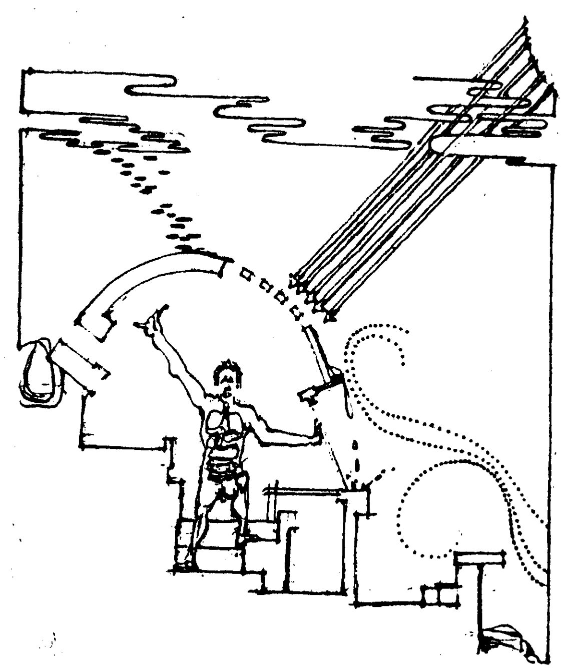
INTERIOR CLIMATE

and

INTERIOR CLIMATE

BODY SHELTER

INTERNAL PROCESSES



## BIOMETEOROLOGY

> Biometeorology is a branch of ecology which studies the interrelationships between chemical and physical factors of the atmospheric environment and living organisms. This environment ranges from the bottom of the root zone in the soil to the highest atmospheric levels involved in the dissemination of pollen and spores. Not only does biometeorology investigate in the natural atmosphere but also in man-made atmospheres such as those found in buildings, shelters, and in the close ecological systems of submarines and satellites.°

° World Meteorological Organization, No. 65: A Survey of Human Biometeorology

The subject of human biometeorology is touched upon in the most general way, primarily to inform the reader of this specialized field and to suggest its relevance to the larger context of thermal comfort.

### The Nature of Human Biometeorology

Human biometeorology is an interdisciplinary science joining together the biological sciences, particularly human ecology and atmospheric sciences, i.e., meteorology, in the study of the systems in which people and environment interact.

More specifically, human biometeorology investigates the effects of atmosphere on people and the reactions and adjustments made by people to changes in the atmosphere. The atmosphere is but one component of the total environment within which people function (sustain life processes). It is this component of the environment that bears most directly on human thermal comfort conditions. The study of human biometeorology sandwiches the indoor atmospheric elements of thermal comfort between the extremes of measuring weather -- unravelling the causes of atmospheric processes and human biology.

Because human biology is not merely an extension of the principles of animal biology to man, human biometeorology has a different orientation and content from general biometeorology. From a strictly biological viewpoint man possesses few characteristics which can be identified as unique. His conformation, size, upright stance, anatomical differences are distinguishing features. Functionally, however, human beings differ from other animals very little. How then is man unique? And what is the interrelationship between his uniqueness and the thermal regulation of built environments? "Man is unique among animals because of the tremendous weight that tradition has come to have in providing for the continuity, from generation to generation, of the properties to which he owes his biological fitness."° Biological fitness in this regard is some measure of human adaptability.

° WMO, p. 2.

In turn, human adaptability is not only gauged by the current cultural and biological milieu but moreover is dependent upon it. Both cultural changes, notably technological advances and human biology have exhibited evolution. Within the last one hundred years the forces of technology have outstripped biological change in human evolution. This is of fundamental importance in understanding the weight imposed by technology upon the range and quality of controlled indoor environments.

Health in general is sustained by preserving human capacity for adaptation. Furthermore, adaptive capacity is maintained by the repeated impact of environmental variation. Man exhibits a wide degree of plasticity and through adaptive capacity utilizes acclimatization. This chain of reactions, however, is suspended when environmental variations stabilize. Such is the case with mechanically tempered buildings. Cultural innovation has increasingly placed man outside the natural order of things.

> By changing the physical world to fit his requirements -- or wishes -- (man) has almost done away with the need for biological adaptation on his part. He has thus established biological precedent and is tempting fate...°

° WMO, p. 7.

# THE BIOLOGICAL BASIS OF COMFORT

## The Built Body

Because the human being is an open system fulfilling many of its needs for heat and nutrient energy from the raw materials of the immediate environment, the model for homeostatic mechanisms must include internal and external regulation.

The human body can be considered a piece of thermal software, capable of responding symbiotically to its surroundings. In looking at the human body one begins to understand human physiology in purely thermal terms. The human body can be described via a formalized definition, much in the same way that we consider buildings:

- Size
- Shape
- Orientation
- Radiation properties
- Surface temperatures

The sensing body can be further defined according to:

- Age
- Sex
- Body Type

and behavioral factors:

- Diet
- Clothing
- Activity -- exercise
- Behavioral responses (attitudinal)

## The Sensing Body

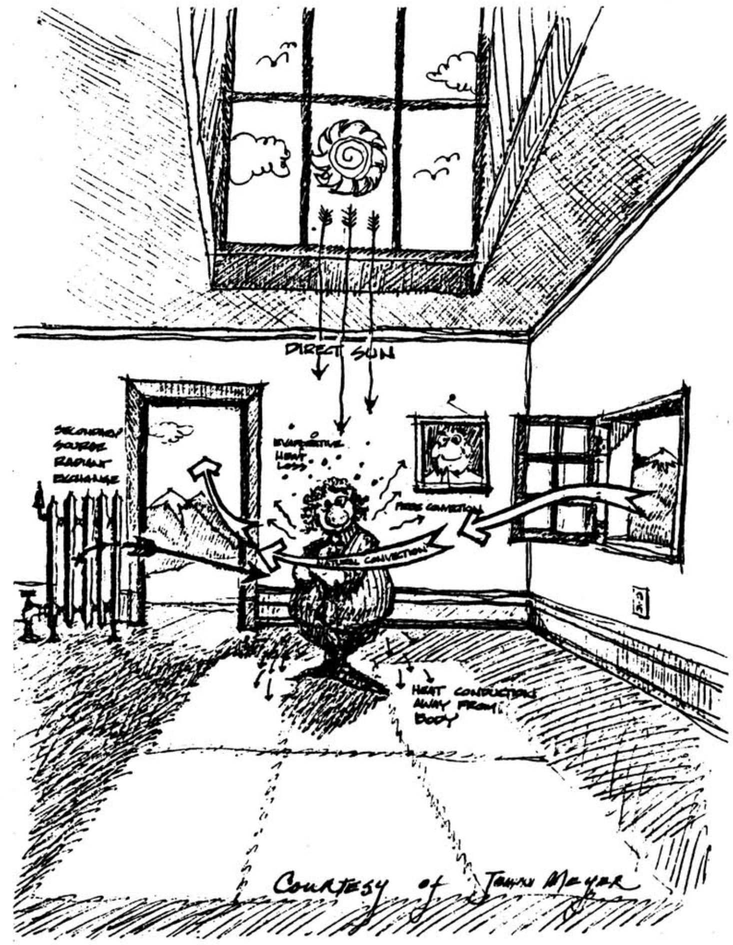
The outstanding feature of the human organism is its operational integration. Cells, tissues, and organs each perform specialized functions. Nonetheless, these parts are made to function holistically by integrating systems. These systems provide the guidance for the homeostatic mechanisms, and are responsible for a "steady state" being maintained in the internal environment (anatomical) amid the fluctuations of the externalized environment (indoor/outdoor climate).

People/man can make both immediate and extended adjustments to stressful conditions. With repeated exposure to stress or with continuous exposure to a variety of environmental circumstances, the zone of thermal comfort shifts.

The sensing body possesses exquisitely refined detectors which are specialized to respond to stimuli of certain kinds. These detectors-receptors react to light, sound, chemical change, pressure, thermal gradient, etc. How we integrate, respond to, and utilize the sense messages determines to a great extent the operational and behavioral characteristics of our sensing body.

In more concrete terms the human body is mobile architecture in thermal exchange with localized physical definition. Man alters this exchange, often in subtle ways, such as changing orientation and exposure, varying proximity relationships as well as through movement.

For example, the relative surface area of a person sitting down is 71% of a person standing; when this individual begins to move the whole range of thermal conditions shifts correspondingly. Not only are new thermal regimes encountered but certain factors such as convective currents begin to dominate, stripping away body heat. The thermal exchange is further complicated by the extent of architectural conditions offered. These range from purely open convective volumes, partial containment, to complex radiant surface relationships and configurations. The following diagram illustrates the fundamental exchanges between the sensing body and boundary conditions.



## THERMAL EQUILIBRIUM AND COMFORT

Thermal equilibrium and the resulting sense of comfort are achieved by physiological and behavioral responses that monitor the amount of metabolic heat generated by the body.

The ideal 'steady state' condition which strives to balance heat generation with heat loss can be understood by looking at four mechanisms of thermoregulation.

Heat Generated

metabolic rate

Heat Loss

conductive and convective heat exchange

radiant heat exchange

evaporative heat loss

### Metabolic Rate

In cold climates metabolic rate dominates thermal regulation. Man is fortunate enough to be equipped with his own heating plant. In contrast to cold blooded animals he exerts considerable control over his built-in thermostat. It is well known that people are capable of maintaining a heat balance even when the ambient temperature varies within wide limits. Within a relatively narrow zone, including the comfort zone, the heat balance is maintained by metabolic activity, under greater thermal loads, by sweating, shivering, or other means. Aspirants who have mastered certain forms of meditation, yogis in particular, are noted for their ability to alter their heart beat, respiration and metabolic functions by significant amounts.

Certain sects of the martial arts in Japan spend their pre-warmup meditation sitting in lotus position outside in snow-bound conditions, wearing only loosely fitted gi's. This demands a considerable rise in metabolic rate due to inactivity and the impact of ambient conditions. For those of us who are less serious in this regard and have not attained such levels of mind-body control, other means of stoking the furnace prevail. The primary means of regulation is control of the level of physical activity, specifically exercise. Metabolic rate (probably the most important parameter in coping with extremes) can range widely: 220 Btu/hr while sleeping, 325 Btu/hr while reading, 550 Btu/hr for light physical activity, and in the order of 1,500 or greater Btu/hr running the last stretch of the Boston Marathon.

If one moves from a certain set of environmental extremes to another or changes the level of activity drastically, the body will undergo pronounced physiological changes. (Blood flow rate and viscosity alter, heart rate varies, and blood circulation undergoes appropriate changes.) Frequent exposure to varied environmental conditions strengthens the body's ability to acclimatize quickly and effectively.

As well as changes of short term duration affecting body metabolism, more subtle seasonal changes override and alter metabolic rate a few degrees. The metabolic processes of the body are highly inefficient; 80 percent of the metabolic energy generated is rejected as heat. The inefficient nature of physiological processes is exactly what keeps us alive in adverse conditions. These processes, however, tend to work against us in overheated conditions. The body employs ingenious ways of dealing with high temperatures which will be discussed under the heading of Evaporative Heat Loss.

Conductive and Convective Heat Exchange

According to the first law of thermal dynamics, energy wants to flow from a hot to a cold body. Heat energy is lost by conduction through direct physical contact with surfaces or bodies of lower temperature. Heat is gained through reverse energy flow by directly contacting surfaces and bodies of higher temperature. The human body detects heat flow, that is to say, it does not exhibit temperature sensors. For example, a concrete bench feels much colder than a wood seat because the body senses the greater heat flow into concrete. Essentially the body is trying to warm up the concrete.

Convective heat exchange is based on the same fundamental principles as conduction, except that an additional mechanism of energy transfer is present. The most common heat transfer medium is air. Air molecules exchange energy with adjacent surfaces, by what is initially a conductive heat transfer process. The movement of air molecules speed the dynamic exchange through mass transfer and carry off larger amounts of energy. In this way the normal conduction process is enhanced. This effect can be dramatically felt firsthand when entering through a drafty doorway from the frigid outdoors. Forced convection is providing the chilling factor in this situation.

There are basically two types of convection: natural and forced. In forced convection, the air has some significant perceptible velocity in relationship to the surfaces encountered. Forced convection is brought about through either mechanical or natural means. Natural convection arises due to the heating or cooling of air when it contacts a surface. As the air changes temperature it changes density and rises or falls. This self-generated free convection operates in all indoor environments.

The heat loss by convection from the outer surface of the clothed body can be expressed by the following simplified equation:

$$Q_c^{Btu/hr/ft^2} = (1 + \frac{V}{5}^{ft/sec})\ (T^{\circ f}_{skin} - T^{\circ f}_{air})$$

where V is wind speed in ft/sec.

## Radiant Heat Exchange

Radiant heat transfer centers around wavelengths of electromagnetic energy in the infrared portion of the spectrum. Light is a form of electromagnetic energy in wave lengths which is visually recognized. Those wavelengths in the infrared portion of the spectrum escape our vision but not our other senses. The body will lose or gain energy depending on the temperature, texture and geometric arrangement of the surrounding surfaces. To exchange energy by radiant means, the objects need not be in contact. Rather, they must be in direct line of "sight" of each other.

A tightly sealed potbelly stove provides an excellent source of invisible radiant heat, while an open fire or the direct rays of the sun offer radiant heat transfer by the electromagnetic waves in both infrared and visible wave lengths. These waves operate under the same physical laws as do light phenomena, i.e., their ability to 'leap across interplanetary voids' or travel the short distance between source and receptor. These invisible waves permit the body to interact thermally with walls, windows, and other surfaces, comprising the total environment. Due to the complex arrangement and magnitudes of the radiating sources these surfaces provide subtle and often complex thermal regimes.

Heat loss due to radiant exchange is given by the following equation which is a helpful yet simplified version of a fourth order equation:

$$Q_r^{Btu/hr/ft^2} = 1\ (T_{skin} - T_{MRT})$$ where MRT is determined via a globe thermometer.

Comparing convection and radiant heat loss equations illustrates a fifty-fifty split contributing to thermal exchange when the air speed reduces to zero velocity and the MRT is the same as the air temperature.

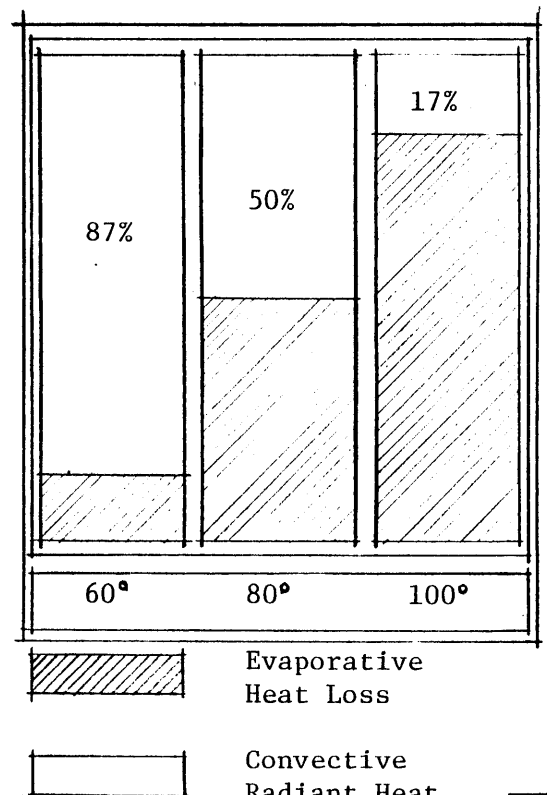
$$Q = (1 + \frac{0}{5})\ (T_{skin} - T_{air})$$
$$= \quad 1 \quad (T_{skin} - T_{air})$$

Evaporative Heat Loss

In moderate to high temperatures, sweating of the skin is a major source of evaporative heat loss. Respiratory passages and lungs are sites of continuous evaporative heat loss. Heat is lost in evaporation because it takes energy to turn liquid (water) into water vapor. For example, our canine friends utilize respiratory heat exchange exclusively.

As the activity level increases the metabolic rate in turn drives up the evaporative heat loss, depending upon the ambient conditions.° Assuming a constant relative humidity (RH) of 45 percent, the chart (Fig. 1 ) shows the interplay of evaporation, convection, and conduction at various room temperatures. The metabolic rate is nearly constant over the range from 60° to 100° F., but the evaporative heat loss rises rapidly to dominate at higher temperatures. On the other hand, at lower temperatures, convection and radiation play the dominant roles. Pure conduction usually has little effect on body heat loss.

°Jim Leckie, et al. Other Homes and Garbage.




1

INDICES OF THE INDOOR ENVIRONMENT

Four environmental indices (air temperature, relative humidity, mean radiant temperature, and air movement) provide a fairly complete thermal picture of the indoor environment when considered along with the behavioral indices of activity level and clothing.

Air temperature affects two methods of heat exchange which are essential to the energy balance of the body -- convection and evaporation. The control of air temperature is the principal means of affecting the state of comfort when the body is close to its optimal comfort zone. Conventional heating systems are designed with this in mind and in fact concentrate solely on air temperature control. Architecturally, the indoor air temperature is most directly influenced by the construction and selection of materials comprising the weather edge. Two distinct systems are utilized for heating purposes, radiant heating and forced air. Studies have shown that one system is not thermally favored over the other. However, radiant means of heating has certain advantages over forced air in buildings of large open volume. Radiant sources contribute less than forced air systems to the already pronounced movement of convective currents and increased infiltration rates.

Relative humidity is closely tied to air temperature, since warmer air can retain more moisture and consequently reduce the evaporative exchange between body and ambient environment. Relative humidity is an often overshadowed index of environmental comfort. Simply stated, it is a measure of the quantity of water vapor suspended in the air. It is measured in percent, with the percentage referenced to a "saturated" state in which the air retains all the moisture it can without some condensation occurring. Thus, if air with a fixed quantity of water vapor is heated, the relative humidity drops. Conversely, the lower the relative humidity, the higher the evaporation rate, and the greater the temperature depression. High relative humidity results in a muggy atmosphere and stifles the evaporative cooling mechanisms. On the other hand, low humidity conditions can be abrasive, causing chapping, making hair brittle and generally toughening the extremities.

While high humidity conditions are often more difficult and costly to rectify, low humidity situations are more manageable and at least partially relieved by the introduction of such things as greenhouse plants. The potential for plants to impact the interior environment and weather edge favorably is undisputed. The ways in which plants contribute to visual and atmospheric qualities will be discussed in a following section.

Of the four environmental indices, mean radiant temperature (MRT) and air movement (natural ventilation) contribute the most to the regulation of thermal comfort conditions through the complex arrangements of architectural elements and manipulation of form.

The mean radiant temperature (MRT) is a measure of radiative effects arising in a room. Simply stated, MRT is defined as that uniform temperature of black surroundings which will give the same radiant heat loss as that from the actual surroundings.

Depending on the temperature differential ($\Delta T$) between indoor and outdoor climates and the makeup of the weather edge mitigating the two regimes, inside surface temperatures often settle below the room air temperature. These cold surfaces can cause significant discomfort by actually drawing away body heat through radiation exchange. A classic example is that of a room with a large window area. On a cold day, occupants can feel distinctly uncomfortable depending on the proximity to the window surface, even though the air temperature in the room is upwards of 70°F. An understanding of the relative relationship between window area and interior volume to minimize the heat sink effect is crucial not only for energy reasons but for maintaining thermal comfort conditions.

Similarly, one can experience the opposite effect when bombarded indoors either by direct radiation of the sun or by exceedingly hot radiant sources, even if the air temperature is below 65°F. The architectural means of limiting these adverse effects is a concern elaborated in the body of this thesis.

Natural ventilation is important not only for comfort but also because air movement provides a means for air exchange. However, some restrictions on natural ventilation may be imposed by urban condition -- contaminants, etc. Reasonable air velocities in the range of 20 to 40 feet per minute increase convective and evaporative heat loss and eliminate stagnant conditions. Air speed is often translated into air flow or air exchange. A standard of 25 cubic feet per minute per person, or one complete exchange of room air every hour is not uncommon. In the exchange of air two main forces are at work: first, wind forces which produce pressure differences across the building; and second, buoyancy or stack forces which exist because of temperature differences between inside and outside air.

Buoyancy forces dominate at low wind velocities in squat buildings and in tall buildings at somewhat higher wind velocities. The actual rate of air change achieved will depend on infiltration rates, the type of windows and vents, their placement and size, and the way the occupants use them. These considerations will in turn affect the proper orientation and dictate minimum depths of buildings.°

°WMO, p. 82.

## MEASUREMENT FOR THERMAL COMFORT

Establishing thermal comfort criteria provides a procedure for organizing and adapting the design process of a building to encompass human requirements and climatic conditions. Recent work in the energy field has expanded this procedure and consequently the "Bio Climatic Chart" developed by the Olygay brothers (Design with Climate) and the standards of thermal comfort put forth by Ashrae (American Society of Heating Refrigeration and Air Conditioning Engineers). The "bioclimatic chart" is a graphic means of showing the zone of human comfort in relation to ambient air temperature, humidity, mean radiant temperature, and air speed. Ashrae standards summarize the range of conditions applicable to indoor thermal comfort.

Introduced here in its reprinted form is the work currently being undertaken by Vivian Loftness and the A.I.A. Research Corporation in conjunction with the National Oceanic and Atmospheric Administration's national climate center. This research provides not only an overview of thermal comfort criteria but more importantly assesses and identifies the impact of climatic factors on human thermal comfort and the design of energy conserving buildings.

## INTRODUCTION

It is the human requirement for comfort, associated with a building's functional use, that forms the basis for energy demand. As a result, an effective way of reducing energy consumption in residential buildings is to recognize the advantages of 'natural' comfort conditioning. In most cases, climate is not actually perceived as a pure temperature and humidity state. The effects of radiation, wind, moisture addition and diurnal temperature ranges can both improve or jeopardize individual and room comfort. To improve energy efficiency, and more importantly to reinstate man's communication with all forces in the environment, buildings should be designed to reflect a judicious balance between isolating the interior of a building from an 'alien' climate and opening the interior of a building to a 'friendly' climate. The design of shelter to provide this natural human comfort and to maximize energy efficiency demands the careful consideration of building form, placement, enclosure and opening, balanced to answer the challenge of a particular site and climate. This in turn demands a clear understanding of the climate forces which may improve, or jeopardize, comfort in that particular region, on that particular site. The purpose of this climate research, then, is to begin to characterize the broad climatic differences in this country which influence design decisions, and to establish a preliminary set of residential design regions for energy conservation.

## DEFINING A TEMPERATURE/HUMIDITY COMFORT ZONE

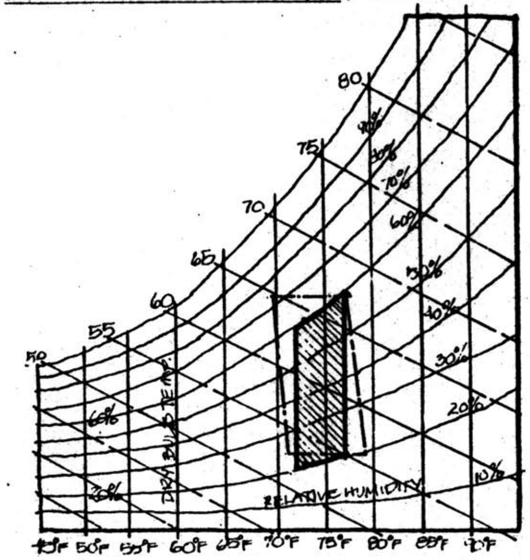
In all building design research for energy conservation, it is necessary to define the range of temperatures and humidities in which a majority of people engaged in normal activity would be thermally comfortable. This 'comfort zone' will in turn determine either the desirable or the potentially acceptable temperature and humidity conditions that the modern residential building must achieve for human occupancy.

A great deal of effort has been spent to determine a more accurate description of the comfort zone. Since the early 1920's, with the existence of the Effective Temperature Scale (ET) for thermal comfort, the lower limits of acceptable living temperatures have risen from 62 F to a present day design standard of 75 F.

In the 1950's, ASHRAE reexamined the Effective Temperature Scale and replaced it with a new comfort design scale which would better reflect modern living patterns, lighter clothing habits, and diet changes. A much smaller comfort zone resulted, which allowed a design temperature range of 72 F to 78 F, and established the stable indoor comfort standards of today.

Simultaneous to this comfort standard, the United Nations began research in comfort design standards for developing countries. This standard recognized an acclimatization factor (where it is assumed that individuals develop different tolerances due to length of time spent in cooler or hotter climates) and set up a comfort zone based on acceptable, not desirable, temperature and humidity conditions for human occupancy.

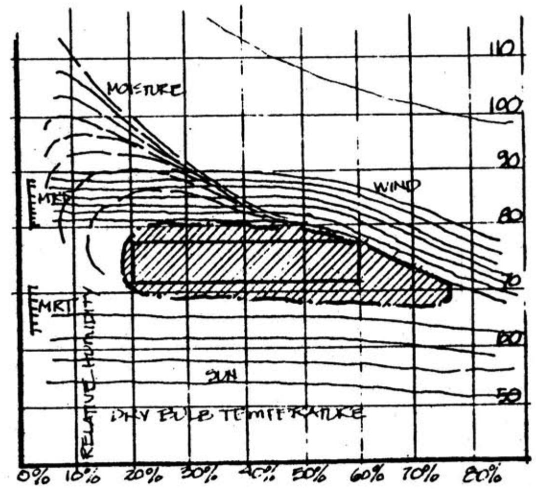
*the effective temperature scale,*
*Man Climate and Architecture, Givoni 1969.*




— *the ASHRAE comfort standard 55-66*
*Handbook of Fundamentals*

*U.N. study, Climate and House Design,*
*Volume 1, New York 1971.*

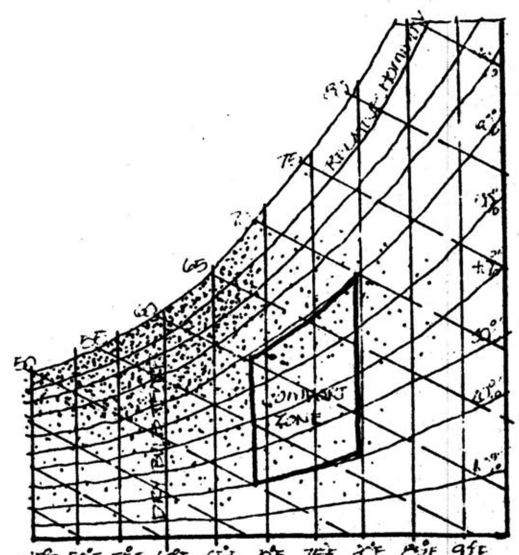
To address the conditions created by an energy shortage, it was decided for the purpose of this research to work with a comfort zone that was developed in the 1950's by Victor Olgyay, which makes certain demands on the individual in terms of clothing and tolerances. The assumptions made in setting the boundarles of the adapted temperature/humidity comfort zone were designed to: 1) reflect government policy by adopting a lower limit design temperature of 65 F; 2) expand the 6 degree maximum daily temperature range allowable by present design standards, to a 15 degree range; 3) set a 30% and 80% relative humidity health limitation on the design comfort zone; 4) acknowledge the effects of high relative humidities from 70% to 80% in diminishing human comfort potential in higher temperature conditions.




—Olgyay comfort scale, Design With Climate, Princeton University Press 1963

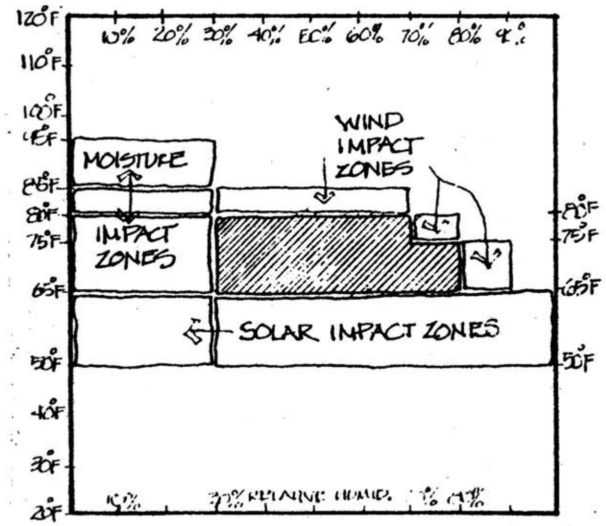
## REDEFINING THE COMFORT ZONE TO REFLECT OTHER CLIMATIC FORCES

The shortcomings of all of the preceding definitions for the comfort zone can be readily seen in the Minimum Energy Dwelling research that was conducted by Burt-Hill and Associates. By mapping daily temperature/humidity readings for El Toro, California onto a psychrometricchart, it was shown that the ASHRAE 90-75 energy standard's comfort zone misrepresented the actual comfort conditions of the town. What, then, is the definition of thermal comfort? Since the major properties of the environment that influence thermal comfort are air temperature, humidity, air velocity, and radiant temperature, the range in which an individual is comfortable cannot be described by ambient temperature and humidity alone. Wind speed and radiation, in combination with flexible tolerance levels in terms of activity and clothing, must also define the design comfort zone for building standards.




*yearly percent frequency of occurrence El Toro, California. Minimum Energy Dwelling, Burt-Hill & Associates 1976*

The task, therefore, lies in defining the influences of radiation, wind and moisture changes on the accepted temperature/humidity envelope. Based on graphs developed by ASHRAE, Kansas State University, Pierce Institute, and Olgyay, the impact of air movement for convective cooling, of moisture addition for evaporative cooling, and of mean radiant temperatures and solar radiation for radiant heating could be estimated. Although the estimates used will be further defined in the following section, the adjacent graph outlines the expanded envelope which represents the estimated impact of these climatic factors on the base comfort zone.




*comfort scale reflecting climatic impact research and computer input form. references: Olgyay, ASHRAE, Kansas State University, comfort research.*

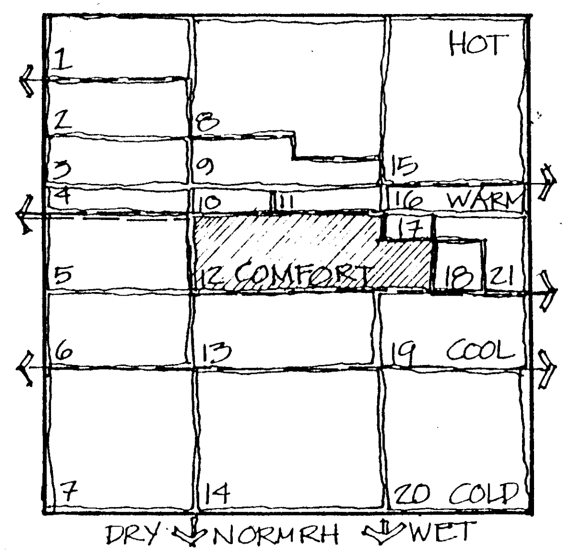
footnote: It was originally thought to assess the potential human contribution to expanding the comfort zone for energy conservation by creating a series of comfort charts to reflect three seasonal clothing changes (clo values for overheated, underheated and mild seasons) and two activity changes (sleeping and active). The weather data from the 130 test cities could then be analyzed by hour of the day and time of the year to describe the energy conservation available through human tolerance adaptations. However, the limited time and funds available for this first phase in assessing the climatic impact on building design precluded this detailed evaluation.

## CALCULATIONS OF THE IMPACT OF CLIMATIC FORCES ON THERMAL COMFORT

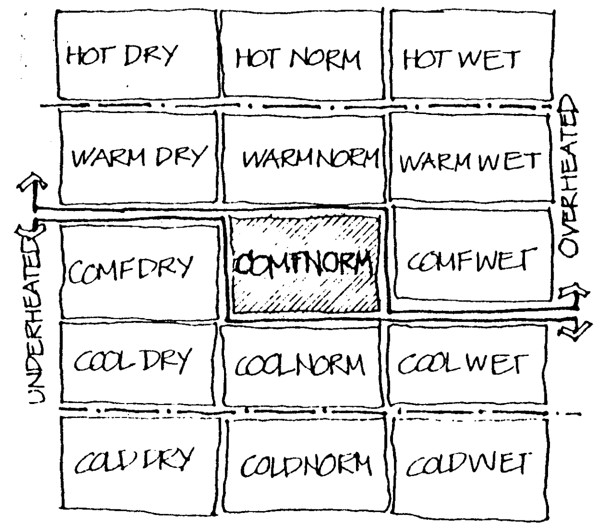
Once this base (temperature/humidity) comfort zone and a second all climate comfort zone (reflecting the impact of climatic forces) had been defined, a program could be written to assess basic predominant thermal design conditions and identifv regionally available climatic forces for increasing base comfort.

For each of the 130 primary National Weather Stations, the input for this climate analysis includes hourly mean temperature and humidity readings, hourly wind conditions associated with each temperature and humidity condition, and Air Force charts recording 3-hourly mean temperature and humidity conditions for each month to interpret the potential impact of daytime solar and diurnal conditions.

The superimposed graph of the base comfort zone and the all climate comfort zone has been combined with calculated 'stress' temperature and humidity conditions to establish the following 21 location breakdown for the climate analysis. The basic comfort zone itself has been defined by the temperature and humidity conditions discussed earlier. The areas of potential climatic impact for increasing base comfort surround this zone. Five temperature ranges have been recorded to separate 'stress' temperature conditions in which mechanical systems are necessary, from regions near the comfort zone in which there are clear passive heating and cooling potentials. To complete this breakdown for climatic representation , humidity has also been defined as wet (greater than 70%, above which man has difficulty evaporatively cooling), norm, and dry (less than 30%, below which dehydration becomes a health issue).



The output of all of these calculations conforms to a 15 point matrix, which was developed to incorporate the ordinates of both the temperature and humidity axes. A first count of temperature and humidity conditions falling in and around the base comfort zone reveals basic thermal design conditions in this country, which vary from overheated to comfortable to underheated. A recount of temperature and humidity conditions falling within the expanded all climate comfort zone reveals the potential for increasing natural comfort due to sun and wind availability, diurnal temperature range, and moisture availability.




footnote: The heat stress conditions in which man cannot actively survive without mechanical cooling assists (defined in research by the Department of Defense) divides the overheated conditions above the comfort zone into warm (tolerable) and hot (intolerable) design climates. Below the comfort envelope in the underheated temperature conditions, a 50 to 65 degree band was distinguished to show a feasible tolerance level as well as a conservative first estimate for passive solar heating potential in residential building design.

## VISUAL COMFORT

"... as the basis for music is the presence of silence, the world of light is dependent upon darkness to give it definition and form, and a quiet matrix within which to come alive."
Henry Plummer, Built Light.

The title of this section of criteria is perhaps misleading. Nevertheless, the notion of visual comfort introduced here is meant to qualify the range of daylighting conditions that serve the activities of people in practical-useful ways. Equally important is an understanding not only of natural light and the implications of form, i.e. depth, splaying details, geometry of openings, but also the soft line quantitative, often poetic boundaries of light that enliven the spirit and span as Plummer suggests from dark to light; the somberness of gloom to the spiked nature of glare.

Daylight comes to us in the same energy packets as solar heat. This raw material is as much a source of energy as it is a building material. "Light is as much a building material as stones, bricks." Derek Philips. Sculpted by the physical definition the thickness of light defines the edges and fills the architectural void. Sun seeking architecture characteristically incorporates the range of natural lighting conditions from dark to light and the gradations in between. Ideally each exposure has a differentiated light filtering built response.

The striking quantities and similarities of light associations among various people: the uplifting effects of a sparkling sunny day, the dreary overcast day..., the passion of color saturated sunsets (filling built spaces), or the delight of dancing water reflections, suggests the possibility of a language by which qualities of light evoke particular intellectual, emotional and physical experiences. If this language could be translated into an architectural vocabulary, we could begin to again rebuild into our environment the 'luminous food' which man has in past ages found essential to his daily nourishment and sustenance.°

°Plummer, H., Built Light.

GENERAL - THE DAYLIGHTING OF BUILDINGS

The amount and quality of daylight available in a building depends on the levels of illumination out-of-doors, the proportion of sunlight (direct insolation) to skylight (diffuse) and the spatial configuration of the room and light transmitting surfaces. On a clear, sunny day the 'warmth' of sunlight plus the 'coolness' of skylight give balanced color rendering. By consciously orienting a window or clearstory, allowance for the penetration of both elements of daylight are possible. Though natural light has dynamic qualities, due to the changing weather patterns, shifting clouds, the slowly setting sun, indoor illumination levels at the rear of typical rooms vary in the order of .5 percent to 3 percent of those values obtained outside, while adjacent to the weather edge the levels may range from 10 to 20 percent depending on the boundary conditions. The illumination climate also varies considerably from season to season. In higher latitudes it is customary to base design on typical overcast sky conditions for the winter half of the year. This could potentially create some glare and overheating problems the remainder of the year. In more temperate climates design is exclusively based on clear sky conditions depending on the region and some account is taken of reflected sunshine.°

°WMO, p. 83.

## Glare

One aspect of natural lighting, glare in particular, is responsible for visual comfort. One of the intrinsic problems often associated with passive solar design is high contrast glare. A basic understanding of this phenomenon may aid the designer in eliminating extreme and or unnecessary glare conditions.

Glare can be created principally by two factors, too much light or excessive contrast in the field of view. Disability glare is caused by a simple overload of the eye with too much light. Discomfort glare is determined by the contrast sensitivity-curve of the eye which varies from person to person. One often experiences discomfort glare when driving into the sun or opposing the bright reflections of sunlight bounced off highly reflective surfaces.

The size of window-wall openings and a person's proximity to this light source has an effect upon glare. Small windows often produce contrast glare, and larger windows can bring about an overload due to optical saturation of the eye's interior.

In passive solar design the materials chosen to reduce overheating and high back losses can also control excessive glare conditions. Through the use, arrangement and placement of glazing surfaces, a reasonable balance can be struck between excessive glare conditions, natural lighting and solar gain.

It is important to remember in certain circumstances, glare may be tolerable, in fact inspirational. The sparking reflections off water or the intense light of partially blocked sunrays under a canopy of evergreen trees may enliven the scenery and awaken the senses.

Thermal Analysis

Thermal analysis comprises three areas which describe the climatic context and thermophysical response of buildings to climate. Thermal measurement, mechanism and means, together provide the kind of solar information necessary to instigate thermal design decisions.

Thermal measurement is made up of four major elements of the climatic environment which affect human comfort and determine the thermal performance of buildings. They include:

-- Air temperature

-- Air movement

-- Humidity

-- Solar Radiation

Thermal mechanisms identify the fundamental thermo-physical process that underly energy flow in buildings. These architectural thermal mechanisms have developed into a sophisticated science in their own right, based on the fundamental exchanges between matter (earth materials), energy (sunlight) and the forces of gravity. A partial list of these architectural thermal mechanisms include:

- The greenhouse effect
  - -- convective heat trap
- Thermal mass storage
  - -- specific heat of material

-- density of material

- Natural air flow

  -- thermal chimney effect

  -- cross ventilation

  -- gravity convection

- Shading

  -- solar control

Thermal means describe the investigation and application of certain solar related principles that identify important relationships, for instance, earth-sun geometry, the nature of solar radiation (direct-diffuse) to collection and thermal flows and properties of materials.

The hope is that these solar related principles might begin to define thermal design tools that enrich our understanding of the relationship of the forces of nature to building form. These tools are meant to provide a starting point to bridge the gap between energy issues and adaptive form. Furthermore, these solar design tools are a way of identifying and prioritizing design issues that influence built form. They represent only one facet of design input that make up the whole range of parameters, constraints and ultimate trade-offs in building design. The tools presently make up a partial list which can be added to and expanded. A more extensive list of tools than those presented in this paper include:

-- Altitude-Azimuth (solar position)

-- Cloudiness or clearness factor

-- Aspect-orientation

-- Exposure-topography

-- Sol-air temperature

-- Angle of incident

-- $\Delta T$/openings

-- S/V ratio (surface to volume ratio)

-- MRT (mean radiant temperature)

-- Thermal storage sizing

-- Aperture effect

-- Wind modeling

-- Vegetation

-- Climatic region (Vivian Loftness)

-- Climatic envelope (Ralph Knowles)

-- Shading (Olgyay Brothers)

This is the makings of a framework for the development of a responsive design process that aligns itself with natural law and strives to provide a range of amenities for human habitation.

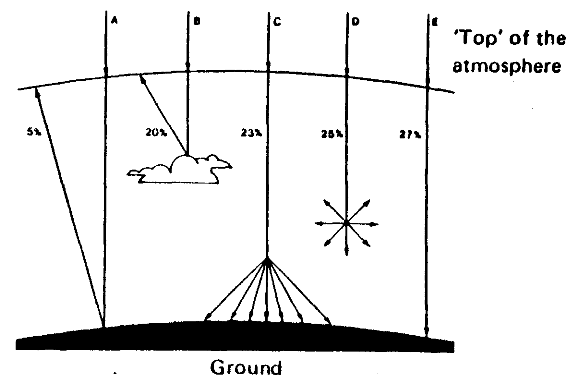
# SECTION 2

For millennia the sun's radiant energy has driven our solar system and provided heat and light inducing the life process on planet earth. The earth's orbiting path and relative distance to the sun is a favorable one for maintaining these conditions. Furthermore, the earth's atmosphere, composed of layers of dust, moisture, ozone and other gases held close to the earth's surface by the forces of gravity, shield spaceship earth from the full intensity of direct solar radiation.

This filtered radiation, our planet's whirling motion, and the effect of land and water bodies produce the variations and changes in the atmosphere that determine the overall weather patterns. The solar energy received by the earth is held for a time in the atmosphere, in land and water bodies (ocean masses) and over time is released to outer space as re-radiated heat. The atmosphere serves as the earth's weather edge, both tempering the effect of the sun's radiation and providing a transparent thermal blanket to hold in the warmth. The insulating atmospheric weather edge surrounding the sun-warmed earth's mass, together maintain a thermal balance.

The earth's journey around the sun contributes in a paradoxical way to the seasonal cycles of weather. This is due to our elliptical orbit altering the relative distance to the sun. Earth is closest to the sun during the winter and most distant during the summer in the northern hemisphere. Nevertheless, the tilt of the earth's axis dominates the seasonal weather cycle.

Total radiation arriving (solar constant) = 100%



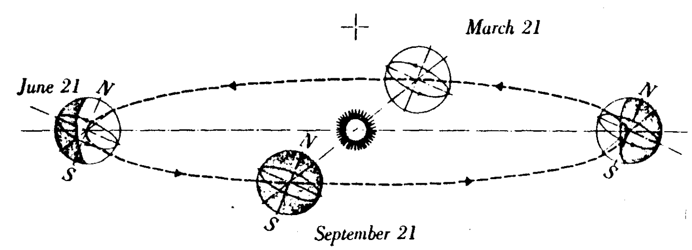

| | % |
|---|---|
| A = reflected from the ground | 5 |
| B = reflected from the clouds | 20 |
| C = diffuse, on the ground | 23 |
| D = absorbed in the atmosphere | 25 |
| E = direct, on the ground | 27 |

*Solar Radiation received at the Earth's surface.*

Watson, Donald, Designing and Building a Solar Home.

This axial tilt in fact produces the seasons of the year. The northern hemisphere tilts toward the sun in summer and away from the sun in winter. Correspondingly, we observe the sun higher in the sky in summer and closer to the horizon in winter. The sun's rays travel a great distance through the atmosphere in winter due to their low angle of incidence. Another summer-winter paradox is operating here. Although the sunbeams are transversing a larger atmospheric dimension in winter, the lower humidity in snow bound regions resulting in less atmospheric absorption, compensates for the longer path; consequently the winter solar intensity is not reduced.

The path of the earth around the sun.




°Olgyay Brothers, Solar Control and Shading Devices.

## CLOUDINESS FACTOR

The amount of heat received from solar energy input is directly related to atmospheric clarity. The relative importance of diffuse and direct radiation varies with the percentage of clear days over the year or the range of cloudiness in a given region. The overall heat received on a cloudy day (primarily, diffuse radiation) is much less than the overall radiation received on a clear day (direct plus diffuse radiation). Nevertheless, the diffuse component can contribute a significant amount of solar heat to a building depending on the climatic region and the associated ambient temperatures. The St. George's School° located in England is an excellent example of a building heated primarily by diffuse energy. Overcast, cloudy conditions prevail over a large portion of the heating season in this region of England.

°See drawing of St. George's School, "Solar Collection" section for reference.

The ratio of diffuse to direct (or spectral) radiation provides useful information to the designer. The ratio of diffuse to direct on clear days may be .85 (85 percent direct radiation) whereas on cloudy, overcast days it may be only .15 (15 percent direct). The largest portion of total solar radiation arrives during times when the ratio of diffuse to total radiation is smallest, which is on the clearest days. This relationship with regard to climatic setting and a given built condition begins to suggest design specifications.

For example, a prevalent ground fog during winter conditions on a south facing site in Mendocino, California, may suggest a design modification to the east exposure in response to the profuse amount of shattered light energy (diffuse light) during the early morning hours. The design response to this particular condition would include a range of built responses. For example, increased glass surface area with the application of heat mirror° on the east exposure; adjusted slope angle and geometry to optimize diffuse collection; type of glazing surfaces employed.

°Refer to section on heat mirror, Solar Collection.

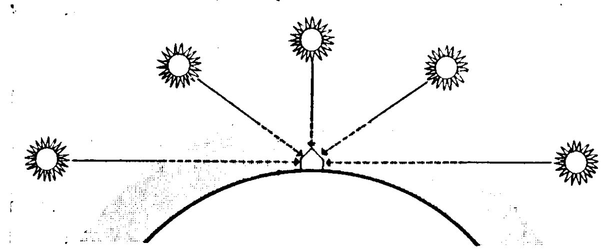
The consideration of increased glass surface area or shift in orientation depend entirely on the design temperatures and the particular micro-climatic features on a given site. Without the application of heat mirror to standard glazing surfaces the amount of diffuse energy during morning hours must be weighted against heat loss ($\Delta T$) over 24 hours. Also attention should be paid to glare or overheating conditions during the cooling season (summer).

If flat plate collector efficiencies are considered, orientations west or south, under morning haze conditions, can contribute a significant amount more energy due to increased insolation and higher afternoon air temperatures. In this case early morning collector heat up may suffer due to the westerly orientation, although passive direct gain on the east may be utilized to offset this.

ZENITH-AZIMUTH

A preceding section, The Source, serves as a brief introduction to general principles that apply on smaller scale to diurnal (daily) changes in micro-climate and are of primary interest to the architect. Of particular interest here is the daily fluctuations of thermal intensity relative to the zenith-azimuth of the sun and site features. The same solar-earth geometry that determines seasonal changes influences daily excursions.

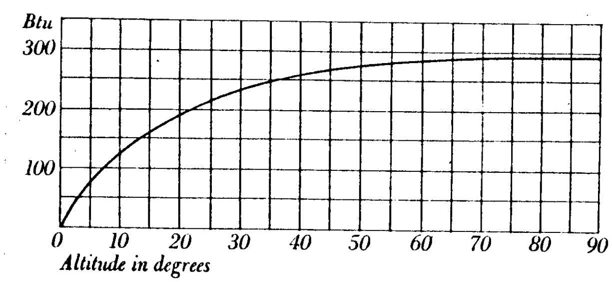
Diagram 2 illustrates the general path of sun light through the atmosphere over the course of the day. In the early morning or late evening hours a longer path through the atmosphere is transversed. Near the noon hour the sun is closest to the vertical and the atmospheric distance is shortest; the amount of energy received will be the greatest.



The path of sunbeams through the atmosphere.

2

Fig. 3 uses values representative of a clear summer day at sea-level and plots the intensities of the sun's energy received at normal incidence with respect to solar altitudes.




Solar energy in relation to the sun's altitude.

3

Olgyay Brothers, Solar Control and Shading Devices.

For design purposes it is helpful to distinguish the relative importance of zenith and azimuth. The zenith position of the sun or solar altitude is directly associated with the intensity of radiation, a quantitative measurement (in B.T.U.'s), while azimuth is the projected angular deviation from true south and combines with the altitude to describe the directional component of the source of energy (angle of incidence).

Solar altitude and azimuth can be calculated, using readily available charts,° for a particular time, day and latitude. Through the combined efforts of this solar tool and a general knowledge of site reconnaissance,° a more complete picture of the interaction of sun and shelter can be documented. A knowledge of the sun's position and sweep across the sky vault relative to particular site features, e.g. topography, off site obstructions, adjacent buildings, as well as the times of rising and setting sun influence a range of design decisions responsive to seasonal collection and protection.

°Libby-Owens Ford Glass Co. or Kool-Shade Corp.

°Vivian Loftness, Natural Forces and the Craft of Building. M.I.T. Thesis 1975. Highly recommended.

Such considerations include:

Configurative Factors

Building orientation

Layout

Window placement

Use areas

Surface to volume ratio

Roof types

Thermo-physical Factors

Sol-air temperature°

°Refer to subsequent section.

Thermal capacity and resistance of building materials relative to orientation

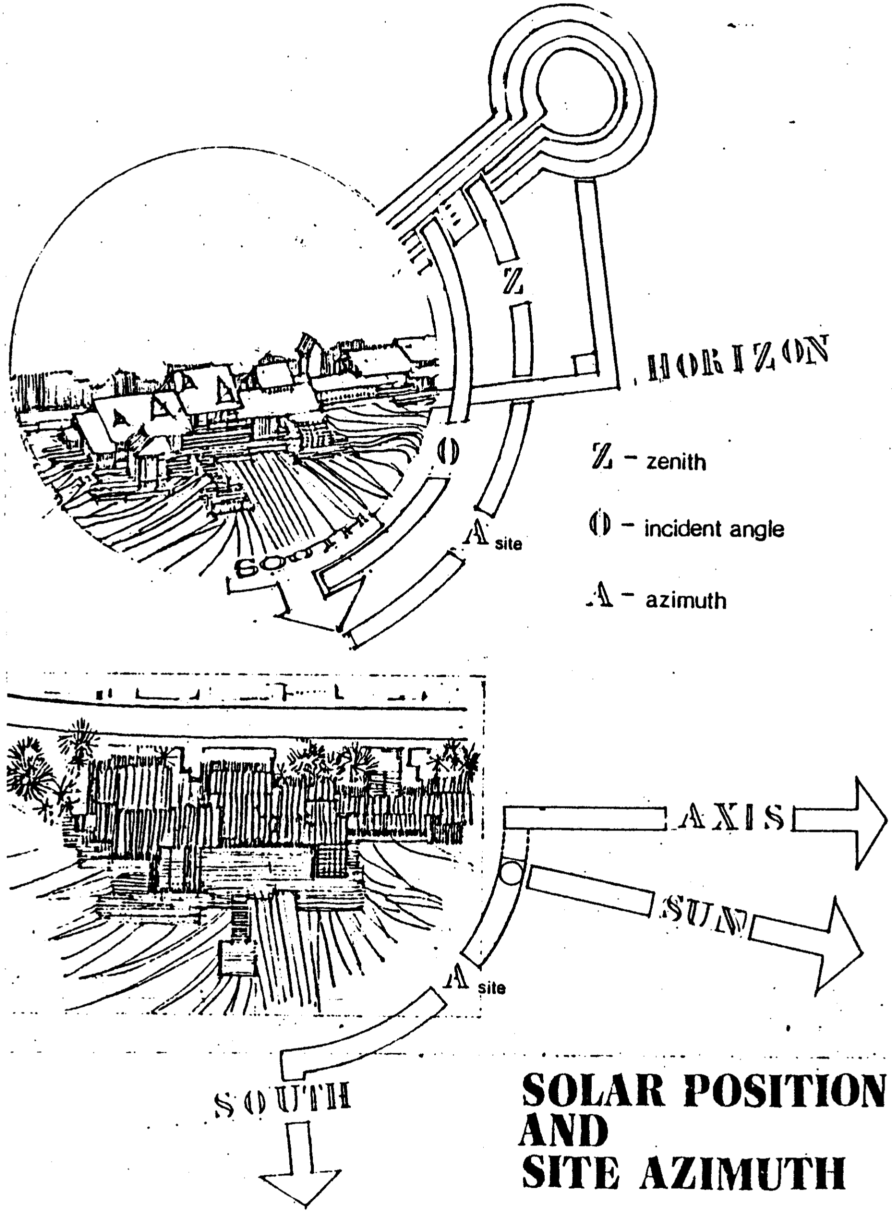
Shading

Solar position and building orientation can be viewed as a scaled relationship. The site orientation and long dimension of the building cluster can be described according to its site azimuth (see Diagram 4 ). At this level of planning the major orientation may be determined more by major definitions, streets, slopes, lot lines, topography, than adhering to true south, optimization of the sun. Clustering reduces the surface area of the weather edge reducing climatic impact and allowing greater flexibility of orientation. The larger surface to volume ratio gained by clustering is less susceptible to climatic variation and thus affords some measure of flexibility over the free standing building.

Solar position and building azimuth (see Diagram 5 ) may modify the major orientation for free standing structures or portions of the larger assemblage of buildings. The following diagram ( 6 ) for the Solar Home book illustrates that efficiency considerations of solar collection has a flexible design range. Although the percent deviations of the vertical collection surface from south are large this diagram takes into account incident radiation only. This information does not contradict the work of the Olygay brothers (next diagram 7 ); rather the "sol-air orientation"° balances a range of climatic impacts and responds accordingly by relatively precise deviations in building azimuth angles off due south.

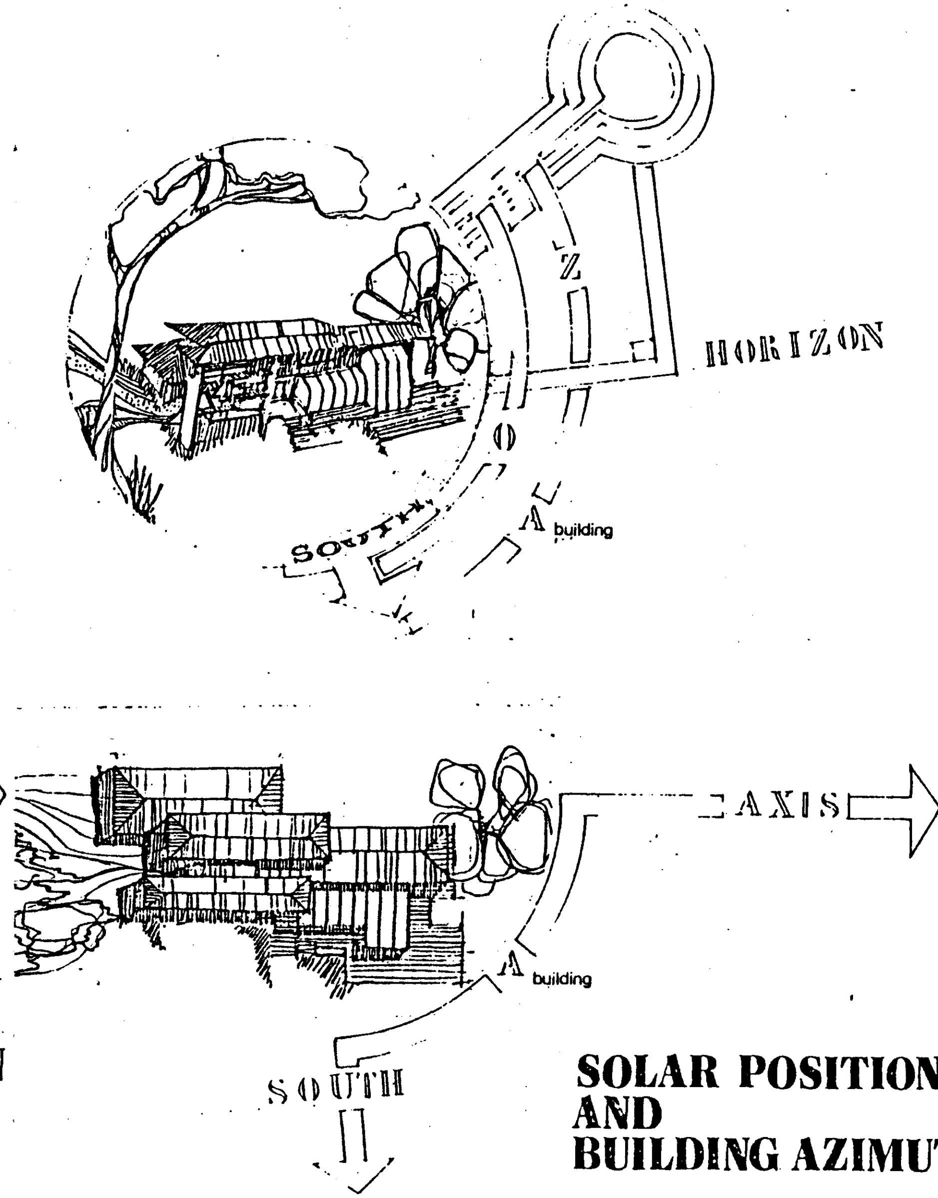
°Olygay Brothers in Design with Climate use "sol-air orientation" for orienting building east or west or south.

Micro-climatic forces (wind, air temperature, moisture, solar position), in effect, fine-tune the major orientation(s), which are site specific and further suggest built responses indicative of an architectural regional approach.



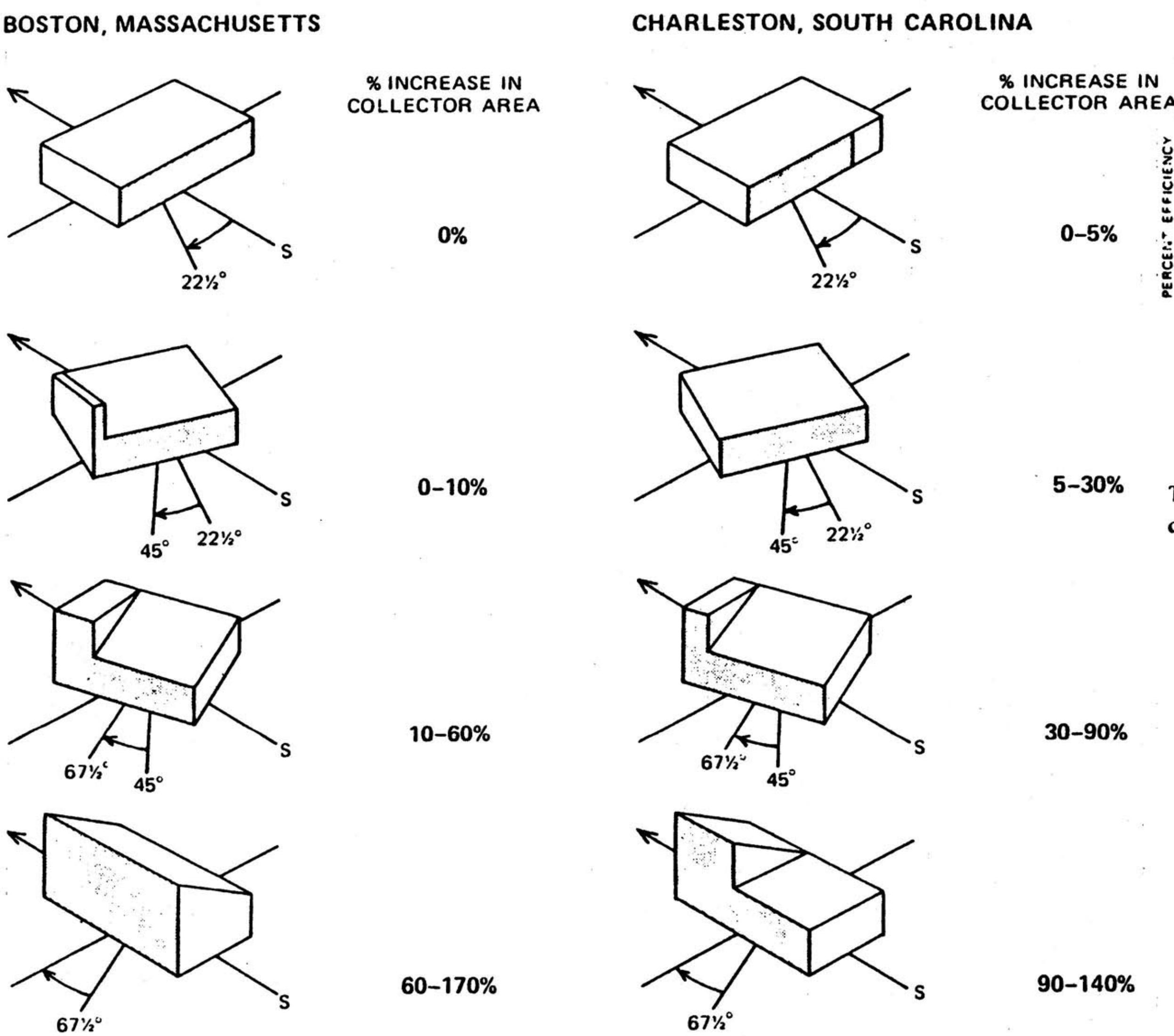

**SOLAR POSITION**
**AND**
**SITE AZIMUTH**

4

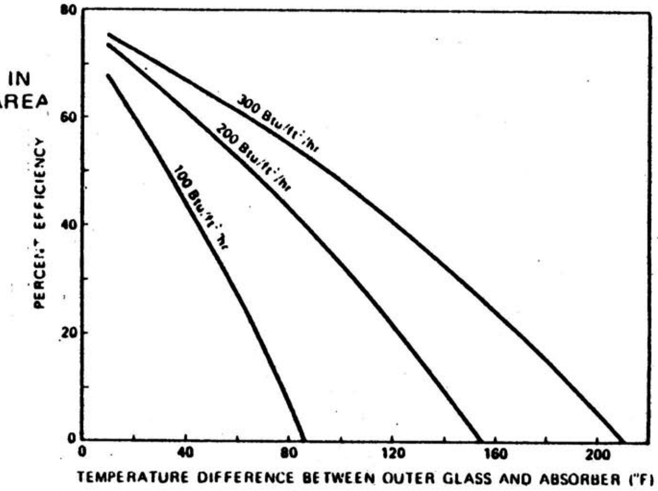



**SOLAR POSITION**
**AND**
**BUILDING AZIMUTH**

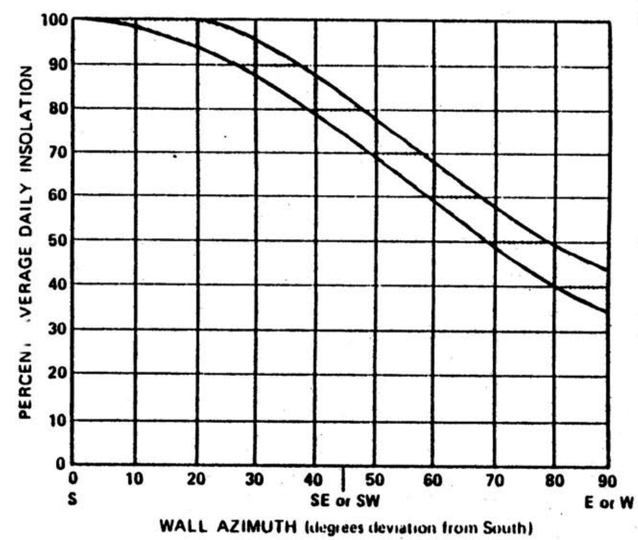
5




The change in area of a vertical wall collector with orientations away from true south. The collectors (shaded areas) have been sized to provide 50 percent of the winter heating needs of well-insulated homes in Boston and Charleston.



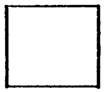
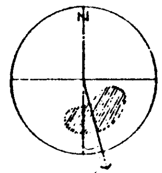
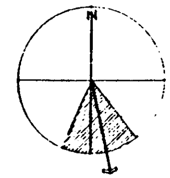
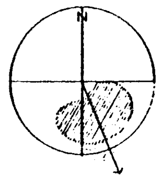
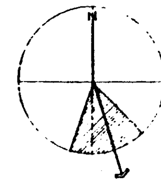
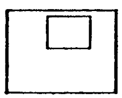
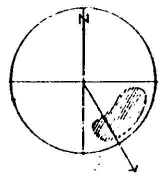
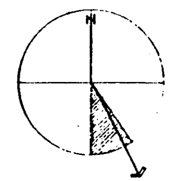
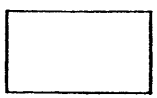
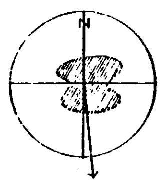
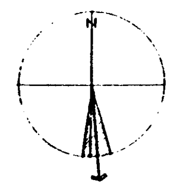

The effect of different insolation rates on collector efficiency. The outdoor air temperature is assumed constant.




The percentage of insolation on vertical walls for orientations away from true south.

The table below pertains primarily to isolated buildings. The information presented should be considered along with other contextural and programmatic requirements.

In determining a building's form, location, and orientation, the objective should be to maintain a balance between underheated periods when solar radiation is beneficial and overheated periods when radiation should be avoided. The long face of a building should normally face south if possible. East and west exposures are generally warmer in summer and cooler in winter than south, southeast, or southwest exposures.

| OPTIMUM SHAPE | LOCATION | GENERAL OBJECTIVES | ORIENTATION |
|---|---|---|---|
|  low temperatures encourage minimizing of form's surface area |  | COOL REGIONS<br>• increase solar radiation heat absorption<br>• reduce radiation, conduction, and evaporation heat loss<br>• provide wind protection |  |
|  temperate climate allows considerable along the east-west axis |  | TEMPERATE REGIONS<br>• solar heat gain should be balanced with shade protection on a seasonal basis<br>• wind: air movement desirable during hot periods; should be blocked during cold periods |  |
|  closed forms; building mass enclosing cool air ponds desirable |  | HOT-ARID REGIONS<br>• reduce solar radiation and conduction heat gain<br>• promote cooling by evaporation (using water and planting)<br>• shading desirable |  |
|  form may be freely elongated along the east-west axis to minimize east and west exposure |  | HOT-HUMID REGIONS<br>• reduce solar radiation heat gain<br>• utilize wind to promote cooling by evaporation<br>• shading desirable |  |

Building Construction Illustrated
Francis D. K. Ching

The overall climatic impact on a building is largely determined by the predominant orientation and shape. However, the building can respond to favorable climatic elements on smaller levels of built definition. This is a scaled relationship; the microclimatic forces impact differently small scale building elements (such as the window) than the overall structure. The thermal characteristics of specific use areas can be modified by orienting the associated collection surfaces to optimize incident radiation, for a given time of day.

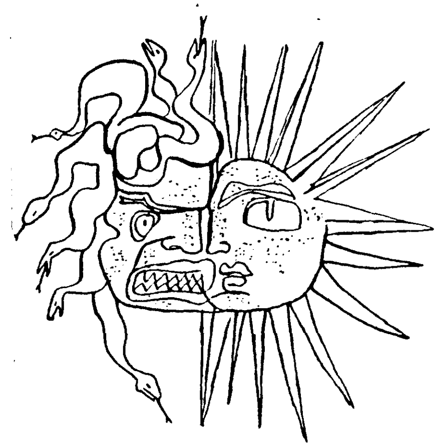
The determination of the sun's position relative to a given location is important to our understanding of the quantitative measure of the varying amounts of solar energy with which we are showered. Furthermore, familiarity with the sun's movement throughout the year encourages a realm of less quantitative concerns, which might direct design options.

Solar position recognizes the potentials and possibilities of the built dimensions of light, associated with sun geometry and building design responses. In this regard the built dimension of sun light responds as an architectural material which can be framed, shaped, sculpted by the building elements. The architectural medium of sunlight provides not only a heat component and natural light but serves as a design metaphor. The way in which sunlight enters a building through openings or casts its shadow from a designed overhang can mark the seasons. The structure becomes a kind of solar clock, a seasonal sundial.

Major directions of the building can respond to the rising and setting of the sun. The ritual celebrated through built form, the warmth, light, changing hues of color that penetrate into the building, igniting planes and surfaces with glowing energy. Equally important the design metaphor of sun geometry takes advantage of sunlight's gently rendered moods while it protects against its harsh character. The kind of reverence that is felt on special occasions when shafts of light become visible in a cathedral or in the mist laden forest is inspired recognition of the dimension of light. The building design can emphasize this dimensional character aligning itself at fixed moments, filtering the light at others, consciously washing surfaces with the changing yet predictable directionality of sunlight.

". . . the problem of the sun—as we know—is that it passes from one extreme to the other according to the change of the seasons. In this play many conditions are created which await adequate solutions. It is at this point that an authentic regionalism has its rightful place. The techniques are universal. . . . The sun differs along the curvature of the meridian, its intensity varies on the crust of the earth according to its incidence.

In this detail the Creator has given us beautiful and prodigious diversity. It is for us, in succession, to seek a solution which is worthy of the work of nature."



After Le Corbusier.

ANGLE OF INCIDENCE

The geometrical relationship of sunbeam energy to collection surface is a scaled relationship operating on a global level down to the window pane. The glancing angles of solar energy striking the earth's atmosphere (terrestrial window) due to the changing tilt of the earth determines the seasons and the varied weather conditions over the globe. This same incident effect operates on a considerably smaller, more human scale, influencing the amount of solar energy captured by the built window and other collection surfaces.

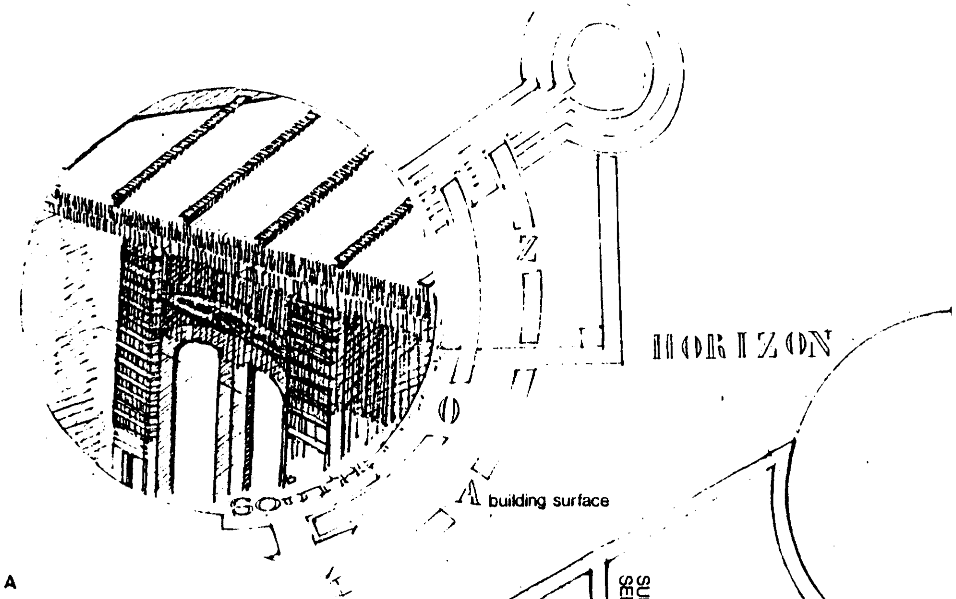
## Solar Position and Window Angle of Incidence

Part A and B of Figure 8 illustrate diagramatically the relationship of solar position at the building surface (window wall collector) and direct radiation angle of incidence.

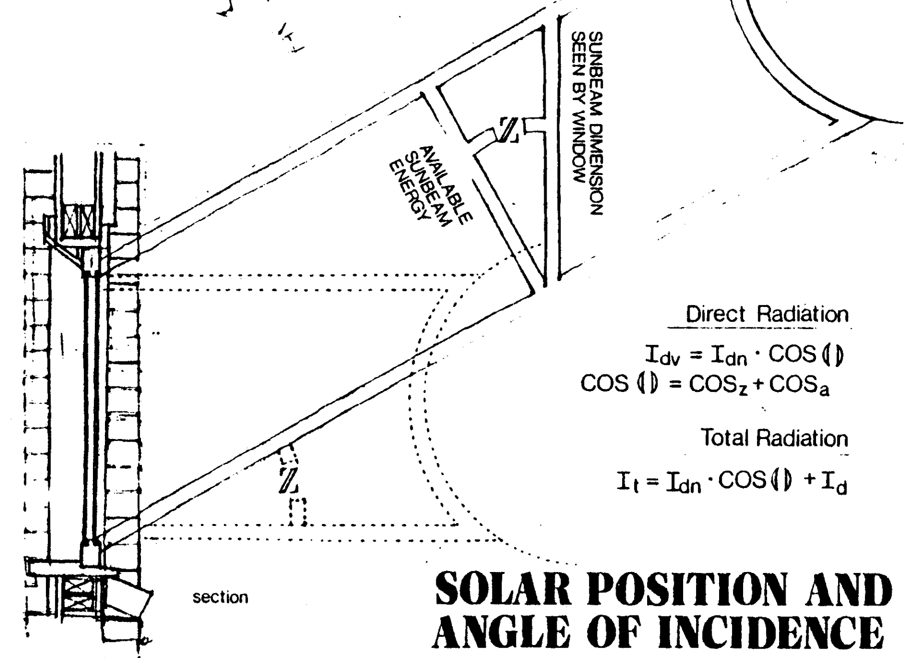
Part A Figure 8 : At this level of inquiry the building orientation is assumed fixed by the previous scale of solar positioning (solar position and building azimuth). The next step is to take a closer look at the interaction of sun and surface. The relationship is one of solar geometry described by the angle of incidence. This method describes geometrically the relationship between collector surface orientation, tilt and solar position.

At this scale specific detailing of collection surfaces are considered. The respective thermo-physical properties of glazing and wall surfaces respond characteristically to the angle of incidence. Collection of direct radiation by standard clear and translucent glazing materials is determined largely by the transmission properties (dependent upon glazing thickness, chemical makeup) and index of refraction. Whereas, opaque wall materials employ surface reflectance and absorption, texture and color to regulate heat gain.

Part B of Figure 8 shows the relationship between the rough opening collection surface dimension (window-wall), angle of incidence and available sunbeam energy. The available solar radiation is given by the perpendicular dimension of the sunbeam energy striking the collection surface at a given angle of incidence. This relative dimension is easily determined by applying




A




B

Direct Radiation

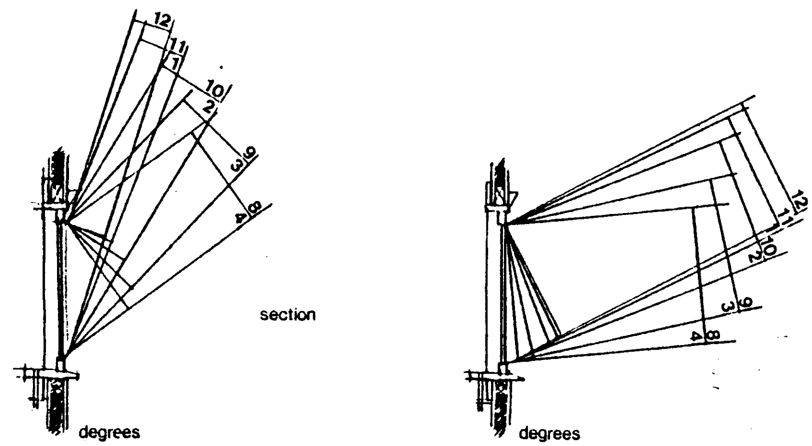
$$I_{dv} = I_{dn} \cdot COS(\Phi)$$
$$COS(\Phi) = COS_z + COS_a$$

Total Radiation

$$I_t = I_{dn} \cdot COS(\Phi) + I_d$$

# SOLAR POSITION AND ANGLE OF INCIDENCE

8

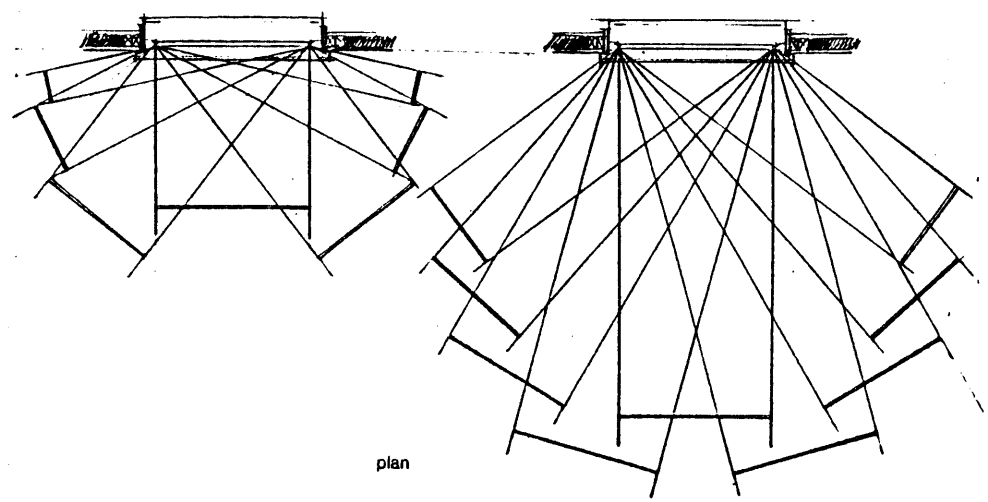



SUMMER
JUNE 22

WINTER
DEC. 22

**40** ° latitude

due south




**9**

the Cosine Law. The amount of direct radiation falling on the collection surface is further defined by the Cosine Law pertaining to vertical surfaces and is calculated by the formula given in part B of the diagram.

The formula for incident radiation falling on a horizontal surface is given where $I_{DN}$ is the amount of direct radiation normal to the collection surface.

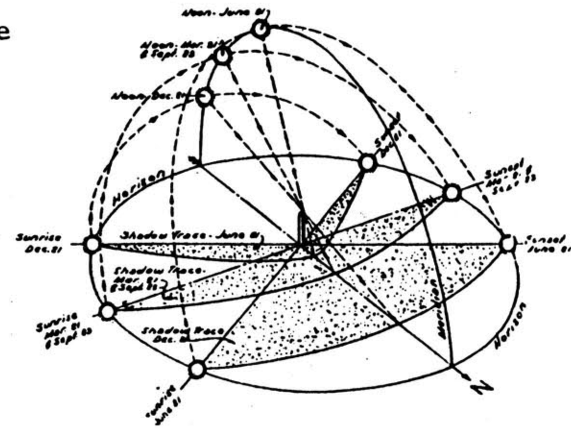
$$I_{DH} = I_{DN} \circ \text{Sin } Z$$

Although the calculations for active collectors are not addressed in this paper, other glazing surfaces may find their way to a horizontal alignment, i.e. skylights, greenhouse roofs.°

Figure **9** takes a comparative look at summer and winter incident angles through the course of a day for a south facing window at 40° latitude (Boston area).

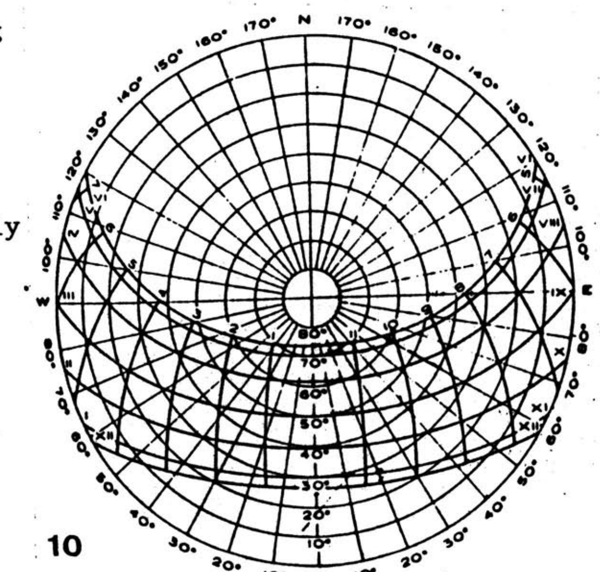
Sun angles diagrams for latitudes in the northern hemisphere corresponding to the 21st day of the month are given in the appendix. These diagrams in combination with the sun angle calculator or sun path diagrams also included (in Appendix), provide the information necessary to construct an hourly composite of incident solar angles on a given exposure (Figure **10** ).

The more favorable incident angles can easily be seen in the winter diagrams for south facing glass. The angles of reflection are closer to the optimum ray, normal to the collection surface (section), and the duration of solar energy is longer for the winter condition due to the more favorable declination (plan). At 40°N latitude, two hundred BTU strikes a square foot



*Climate and Architecture.*

°References for calculations on collection include:
<u>Solar Energy</u> by Bruce Anderson
<u>Better Homes and Garbage</u>, Leckie, Masters, Whitehouse, Young



**10**

**40°N LATITUDE**

of window surface during an averaged hour on a sunny winter day, whereas 100 BTUs, typical for an averaged summer hour.

Summer Condition

By the time the sun has climbed past the east-west compass line and has moved into a position to beam down solar heat to a south facing surface it is very near 8:00 a.m. in the morning. This vertical surface continues to receive solar energy until roughly 4:00 p.m., when the sun sneaks behind the east-west compass line again.

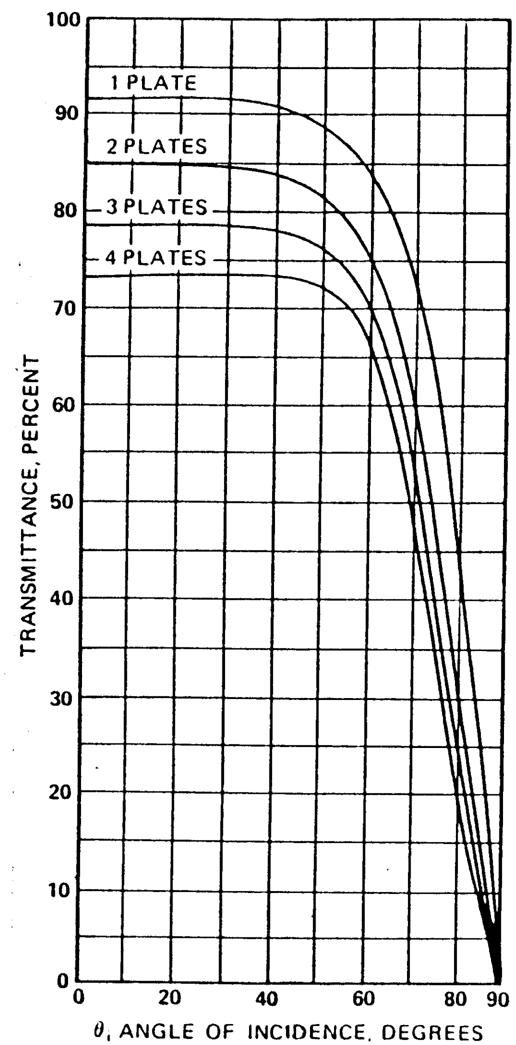
Winter Condition

Throughout this season the sun rises south of east and south of west. Therefore the sun's energy is available to a south facing facade from sunrise to sunset, approximately, 7:30 a.m. to 4:30 p.m., offering slightly more exposure time than the summer condition.

The value of incident angle as a solar design tool lies initially with its thermal quantitative aspects. A fundamental understanding of solar geometry and approximate percentages of heat gain is crucial to architectural considerations. Given other design constraints, placement, orientation and tilt of collection surfaces should optimize solar input at the times of day and seasons it is most needed. It should be assumed solar collection is used for space heating purposes. Vertical collection surfaces provide favorable solar geometry, though not optimal for all summer and winter incident angles, associated with the range of latitudes. Ideally the collection surface should adjust both orientation and tilt according to the relative impact of summer and winter conditions balancing the extremes impinging in various regions. The equinox seasons might then compromise between these extremes. Spring, solar gain desirable early in season; fall, solar gain needed later in season.

The amount of transmitted energy due to the angle of incidence is given by the Graph 11 . Note the dramatic plunge in slope around 60° angle of incidence. This effect will further reduce the summer hours impacting a south facing exposure due to reflection losses. Graph 12 shows the significant fluctuations of clear day insolation on horizontal, south-facing vertical and a 50° tilted surface over the course of the year. In northern latitudes east and west exposures receive 2 1/2 times more energy in the summer than winter. Due to the sol-air effect and local climatic conditions, the actual climatic impact is rarely symmetrical on east and west exposures. In general, west exposures display overheating while east exposures collect insolation during hours of low ambient temperatures, when the solar heat is desirable in winter and tolerable in summer.

The winter exposure diagram Figure 13 illustrates graphically the hours of solar radiation available to a given exposure and the corresponding angles




The percentage of sunlight transmitted through very clear glass. The angle of incidence is the angle between a ray of sunlight and a line drawn perpendicular to the plates.

11

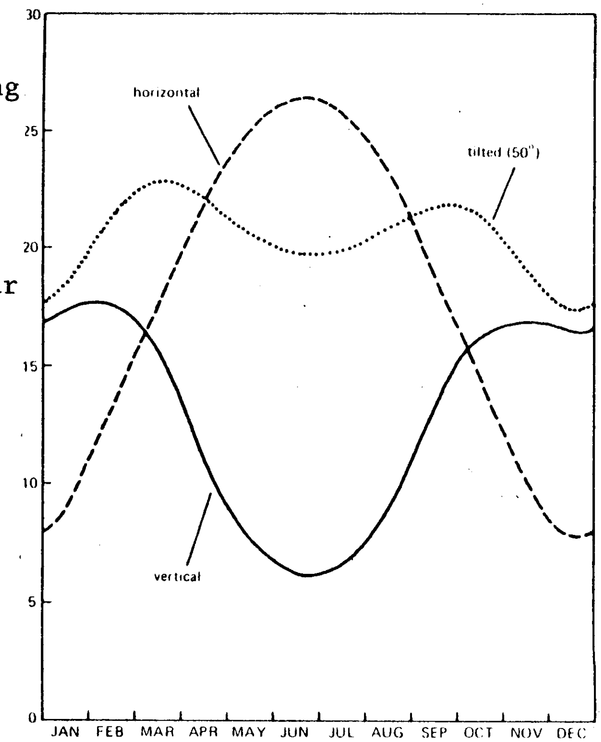
of incidence. This diagram illustrates only the extreme winter condition.

As the seasons change and the angle of declination moves toward the spring equinox the incident angles will move accordingly, providing increased heat gain to east and west exposures.

This diagram illustrates an important relationship between exposure, solar gain and heat up times. The winter exposure diagram combined with solar heat gain factors (Ashrae Handbook of Fundamentals) begin to model the interior fluctuations throughout the day: amplitude of temperatures and the resulting thermal zones associated with a given exposure and orientation.

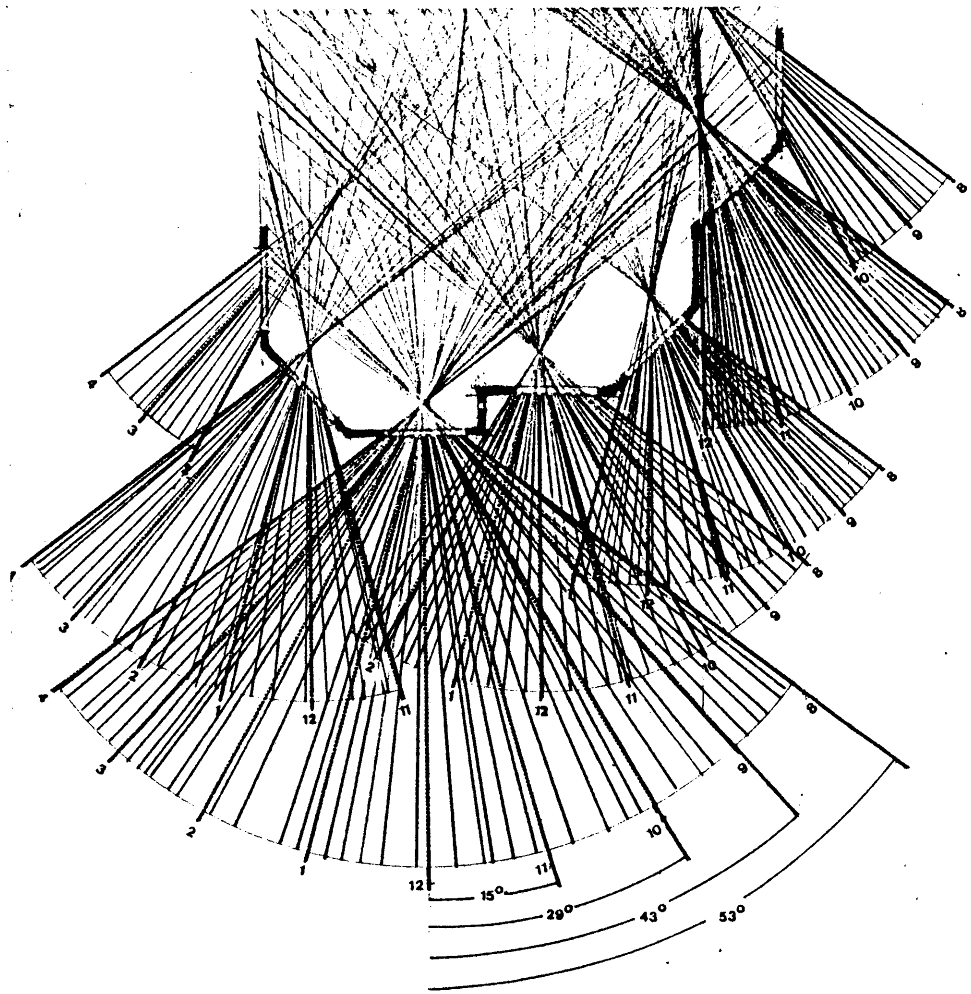
The solar heat gain factors for various compass orientations at the 40° latitude of the Boston area is figure 14 .

Solar heat gain factors presented here deal with transmission of solar intensity as a function of angle of incidence, orientation and the contribution of (.20) ground reflectance. Angle of incidence influences not only solar transmission but also the thermal response of exterior building surfaces, affecting primarily the sol-air temperature and therefore heat gain transfer to the interior. Using figure 13 as a reference for suntime versus orientation and the Ashrae figures for solar heat gain, the relationship between solar input (temperature excursions), hour and orientation can be examined. Between the hours of 8 and 10, an eastern exposure receives slightly more insolation than a south face (265 B.T.U.H./sq. ft. compared to 235 B.T.U.H./sq. ft., approximately 10% additional heat for that period). Between the hours of 8 and




Clear day insolation on horizontal surfaces, and on south-facing vertical and tilted surfaces. Reflected radiation not included.

12




60° cutoff angle

# WINTER EXPOSURE DIAGRAM for JAN. 21.

←40° Latitude
←for East
Southeast
South
Southwest
West Orientation

| SOLAR TIME | – ANGLES |
|---|---|
| 8am. | – 53° |
| 9 | – 42 |
| 10 | – 29 |
| 11 | – 15 |
| 12 | – 0 |
| 1 | – 15 |
| 2 | – 29 |
| 3 | – 42 |
| 4 | – 53 |

13

| Solar Time | Solar position | | Direct Irradiation | Solar heat gain factors B.T.U.H./sq. ft. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A ALT | Z AZI | | N | NE | E | SE | S | SW | W | NW | HOR |
| 8 | 8.1 | 55.3 | 141 | 5 | 17 | 111 | 133 | 75 | 5 | 5 | 5 | 13 |
| 9 | 16.8 | 44.0 | 238 | 11 | 12 | 154 | 224 | 160 | 13 | 11 | 11 | 54 |
| 10 | 23.8 | 30.9 | 274 | 16 | 16 | 123 | 241 | 213 | 51 | 16 | 16 | 96 |
| 11 | 28.4 | 16.0 | 289 | 18 | 18 | 61 | 222 | 244 | 118 | 18 | 18 | 123 |
| 12 | 30.0 | 0.0 | 293 | 19 | 19 | 20 | 179 | 254 | 179 | 20 | 19 | 133 |
| 1 | 28.4 | 16.0 | 289 | 18 | 18 | 18 | 118 | 244 | 222 | 61 | 18 | 123 |
| 2 | 23.8 | 30.9 | 274 | 16 | 16 | 16 | 51 | 213 | 241 | 123 | 16 | 96 |
| 3 | 16.8 | 44.0 | 238 | 11 | 11 | 11 | 13 | 160 | 224 | 154 | 12 | 54 |
| 4 | 8.1 | 55.3 | 141 | 5 | 5 | 5 | 5 | 75 | 133 | 111 | 17 | 13 |
| | | | | 118 | 127 | 508 | 1174 | 1630 | 1174 | 508 | 127 | 706 |

14

(Ashrae Handbook of fundamentals)

12, however, a southeastern exposure receives substantially more solar gain than a south face (820 vs. 692 B.T.U.H./sq. ft.). These incremental solar gains determining relative heat-up periods provide valuable design insight into the thermal rhythms of different exposures.

To a considerable extent target areas of built definition can absorb, store, re-radiate, reflect sunbeam energy into interior spaces, depending upon incident angles of light, thermo physical and surface properties of barriers.

The same values of absorption emmitance applicable to the exterior building surfaces also apply to interior finishes and construction. Heat storage is determined by the specific density, specific heat, conductance of the material while the effect of incident radiation is a factor of color and surface texture.

Partial containment near the source can provide a range of thermal zones significantly varied from indoor air temperature. The type of containment surfaces span a wide range: bearing walls, screens, partitions, window seats, furniture, to mention a few. (Refer to thermal zones, following section 3.)

Other factors related to solar energy at or near the weather edge will be discussed in Section 3.

SOL-AIR TEMPERATURE

The "sol-air temperature" is a theoretical external air temperature, dependent upon the thermo-physical properties of the materials, local site conditions and building geometry. The "sol-air temperature" is a valuable thermal design tool for heat transfer calculations and general sol-air building orientation.° Equally important, this solar tool encourages the selection of materials that exchange the natural energy flows of the site, and optimizes solar collection relative to building exposure and heat load.

°Refer to Olygay Brothers Design With Climate.

The "sol-air temperature" gives the combined thermal effect on the building exterior surface due to solar intensity and the ambient air conditions. Three component temperatures comprise the overall sol-air temperature:

- Ambient outdoor air (degrees f)
- Incidence of solar radiation ($BT/ft^2/hr$).
- Net long wave radiant heat exchange between the exterior surface and the environment ($BTU/ft^2/hr$)

Note: wind not taken into consideration.

These three parameters of sol-air temperature define the climate at the weather edge and serve as a basis of discussion concerning the thermo-physical properties of building materials and architectural considerations.

## Ambient Air Temperature

Ambient air temperature is a thermal phenomenon with special spacial and temporal characteristics. The air is transparent to almost all solar radiation. Therefore, insolation has only an indirect effect on air temperature. The air layers in direct contact with warm surfaces are heated by conduction and stirred around by convective currents.

## Incidence of Solar Radiation

The intensity of solar radiation incident on a surface is dependent upon:

- solar position
- latitude
- altitude
- atmospheric clarity or clearness factor

  The ratio of $I_{Direct}$ (spectral) to $I_{Diffuse}$ (scattered)
- angle of incidence

  A function of compass orientation, relative geometry of surfaces, Horizontal-Vertical, etc.

The total solar radiation falling on a surface is comprised of three components:

- The Direct Solar Radiation ($I_D$)
- The Diffuse Solar Radiation ($I_d$)

• The Reflected Radiation from the Surroundings ($I_r$)

Sources such as the climatic atlas provide easy-to-read charts and diagrams from which local data on solar radiation intensity can be determined.

## Direct Solar Radiation

The value of the direct solar component is generally calculated° from the solar constant (amount of solar energy striking the earth's atmosphere). For a given region, season and time of day the direct solar component varies as a function of the solar altitude and extinction coefficient (clearness factor).

° Ashrae does it this way.

## Diffuse Radiation

Diffuse radiation is not spread uniformly over the sky vault. Around the sun, diffused rays are more concentrated, decreasing with angular distance from the sun, and increasing near the horizon.

Diffuse radiation is divided into two components, one from the vicinity of the sun ('circumsolar' radiation) and the second uniformly distributed over the sky vault ('background' radiation). The first is added to the direct solar component and one-half of the second component is assumed to fall on a vertical wall, regardless of orientation.°

° Givoni, Man, Climate and Architecture, p. 179.

## Reflected Radiation

The amount of transmitted radiation varies with the reflectivity (albedo) of the ground and surrounding surfaces.

The spectral distribution of reflected light differs from the diffused and direct spectra. A larger fraction of the longer, infra-red wavelengths are absorbed by the irradiated (heated) surfaces, increasing the proportion of visible light reflected.

## Long and Short Wave Radiation

| Color/Reflectivity % | |
|---|---|
| Black surfaces | 10% |
| Dark Brown | 10-15% |
| Gray, cement color | 15-25% |
| Light brown, blues | 25-30% |
| Pale colors, straw, granite | 45-50% |
| White | 50-90% |

| Albedos/Reflectivity % | |
|---|---|
| Fresh snow | 75-95% |
| Coarse gravel | 80-90% |
| Light gray limestone | 80-90% |
| Old snow | 40-70% |

| | |
|---|---|
| Light sand | 30-60% |
| Clean ice | 30-50% |
| Sand soil | 15-40% |
| Fields, meadows | 15-30% |
| Woods | 5-20% |
| Dark, cultivated soils | 7-10% |
| Water surfaces | 3-10% |

Surface Temperature/Conductivity

| | |
|---|---|
| Air Temperature | 77° |
| Rich soils | 79 |
| Vegetation canopies | 80 |
| Grass | 85 |
| Bare soil | 93 |
| Concrete walk | 95 |
| Slate roofs | 110 |

°

°Vivian Loftness, Natural Forces and the Craft of Building

## Thermo-Physical Properties of the Weather Edge

The thermal effect of solar radiation is largely determined by the surface properties of materials, thermal capacity and building geometry. Depending on these factors, relative amounts of incident radiation are reflected and the remainder absorbed by the material, elevating the external surface temperature. A portion of this absorbed component is stored in the material, later to be dissipated to the surroundings. The remainder flows through the material to the interior. Furthermore, the rise in the localized ambient temperature through conductive heat exchange with the building surfaces decreases the Delta T (indoor/outdoor temperature differential) which indirectly reduces heat loss.

Outlined here are the over-riding physical characteristics of the building surface which interchange with the local site conditions altering the sol-air temperature. The contribution of the sol-air temperature is given by the following formula:

$$T_{sa} = t_a + \frac{AI}{h_o} + (t_r - t_a)\frac{h_r}{h_o}$$

For example, disregarding the contribution of surrounding surfaces

$$T_{sa} = T_a + \frac{AI}{ho}$$

$$= 30° + \frac{.8 \times 200}{4}$$

$$= 30° + 40°$$

$$= 70° \text{ sol-air temperature}$$

Through the direct simplified measurement of onsite conditions and a general knowledge of the surface properties of materials and their application, conscientious, responsive design decisions can be made.

$t_{sa}$ = sol-air temperature

A = absorptivity of the external surface

$I$ = intensity of total incident solar radiation on the surface

$h_o$ = overall external surface coefficient

$t_r$ = mean radiant temperature of the surroundings

$h_r$ = external radiative surface coefficient.

I is the sum of the direct, diffused and reflected radiation falling on the surface in its particular orientation. A depends on the external colour and typical values are given in Fig. 15 . The magnitude of $h_o$ depends on the air velocity near the surface and a value of (4.0 $Btu/ft^2/h$) is adopted for design purposes by the ASHRAE. The nature of the environment determines $t_r$ which can be estimated by computing the expected average ground and "sky" temperatures. The value of h increases with the average temperature of the external surface and the surroundings.°

°Givoni, B. Man, Climate and Architecture, p. 189.

Three factors, color, texture and geometry of building surfaces, comprise the architectural design palette predominantly affecting the sol-air temperature.

## Color

The color of the external surface determines the amount of solar radiation absorbed during sunlit hours. A darkly colored building surface can elevate the exterior surface temperature as much as 57 degrees fahrenheit above the ambient air temperature, while the corresponding increase for white washed surfaces can be as little as 2 degrees fahrenheit.°

°Givoni, B. p. 139.

## EMITTANCES AND ABSORPTANCES OF MATERIALS

| CLASS I SUBSTANCES: Absorptance to Emittance Ratios ($\alpha/\epsilon$) Less than 1.0 | | | |
|---|---|---|---|
| Substance | $\alpha$ | $\epsilon$ | $\alpha/\epsilon$ |
| White plaster | 0.07 | 0.91 | 0.08 |
| Snow, fine particles, fresh | 0.13 | 0.82 | 0.16 |
| White paint on aluminum | 0.20 | 0.91 | 0.22 |
| Whitewash on galvanized iron | 0.22 | 0.90 | 0.24 |
| White paper | 0.25-0.28 | 0.95 | 0.26-0.29 |
| White enamel on iron | 0.25-0.45 | 0.90 | 0.28-0.50 |
| Ice, with sparse snow cover | 0.31 | 0.96-0.97 | 0.32 |
| Snow, ice granules | 0.33 | 0.89 | 0.37 |
| Aluminum oil base paint | 0.45 | 0.90 | 0.50 |
| Asbestos felt | 0.25 | 0.50 | 0.50 |
| White powdered sand | 0.45 | 0.84 | 0.54 |
| Green oil base paint | 0.50 | 0.90 | 0.56 |
| Bricks, red | 0.55 | 0.92 | 0.60 |
| Asbestos cement board, white | 0.59 | 0.96 | 0.61 |
| Marble, polished | 0.5-0.6 | 0.90 | 0.61 |
| Rough concrete | 0.60 | 0.97 | 0.62 |
| Concrete | 0.60 | 0.88 | 0.68 |
| Grass, wet | 0.67 | 0.98 | 0.68 |
| Grass, dry | 0.67-0.69 | 0.90 | 0.76 |
| Vegetable fields and shrubs, wilted | 0.70 | 0.90 | 0.78 |
| Oak leaves | 0.71-0.78 | 0.91-0.95 | 0.78-0.82 |
| Grey paint | 0.75 | 0.95 | 0.79 |
| Desert surface | 0.75 | 0.90 | 0.83 |
| Common vegetable fields and shrubs | 0.72-0.76 | 0.90 | 0.82 |
| Red oil base paint | 0.74 | 0.90 | 0.82 |
| Asbestos, slate | 0.81 | 0.96 | 0.84 |
| Ground, dry plowed | 0.75-0.80 | 0.70-0.96 | 0.83-0.89 |
| Linoleum, red-brown | 0.84 | 0.92 | 0.91 |
| Dry sand | 0.82 | 0.90 | 0.91 |
| Green roll roofing | 0.88 | 0.91-0.97 | 0.93 |
| Slate, dark grey | 0.89 | -- | – |
| Bare moist ground | 0.90 | 0.95 | 0.95 |
| Wet sand | 0.91 | 0.95 | 0.96 |
| Water | 0.94 | 0.95-0.96 | 0.98 |
| Black tar paper | 0.93 | 0.93 | 1.0 |
| Black gloss paint | 0.90 | 0.90 | 1.0 |

| CLASS I SUBSTANCES: Absorptance to Emittance Ratios ($\alpha/\epsilon$) (Continued) Less than 1.0 | | | |
|---|---|---|---|
| Substance | $\alpha$ | $\epsilon$ | $\alpha/\epsilon$ |
| Small hole in large box, furnace or enclosure | 0.99 | 0.99 | 1.0 |
| "Hohlraum," theoretically perfect black body | 1.00 | 1.0 | 1.0 |

| CLASS II SUBSTANCES: Absorptance to Emittance Ratios ($\alpha/\epsilon$) Greater than 1.0 | | | |
|---|---|---|---|
| Substance | $\alpha$ | $\epsilon$ | $\alpha/\epsilon$ |
| Black silk velvet | 0.99 | 0.97 | 1.02 |
| Alfalfa, dark green | 0.97 | 0.95 | 1.02 |
| Lamp black | 0.98 | 0.95 | 1.03 |
| Black paint on aluminum | 0.94-0.98 | 0.88 | 1.07-1.11 |
| Granite | 0.55 | 0.44 | 1.25 |
| Dull brass, copper, lead | 0.2-0.4 | 0.4-0.65 | 1.63-2.0 |
| Graphite | 0.78 | 0.41 | 1.90 |
| Stainless steel wire mesh | 0.63-0.86 | 0.23-0.28 | 2.70-3.0 |
| Galvanized sheet iron, oxidized | 0.80 | 0.28 | 2.86 |
| Galvanized iron, clean, new | 0.65 | 0.13 | 5.00 |
| Aluminum foil | 0.15 | 0.05 | 3.00 |
| Cobalt oxide on polished nickel* | 0.93-0.94 | 0.24-0.40 | 3.9 |
| Magnesium | 0.30 | 0.07 | 4.3 |
| Chromium | 0.49 | 0.08 | 6.13 |
| Nickel black on galvanized iron* | 0.89 | 0.12 | 7.42 |
| Cupric oxide on sheet aluminum* | 0.85 | 0.11 | 7.73 |
| Nickel black on polished nickel* | 0.91-0.94 | 0.11 | 8.27-8.55 |
| Polished zinc | 0.46 | 0.02 | 23.0 |

*Selective surfaces

Anderson, Solar Home Book.

SOURCES: ASHRAE, *Handbook of Fundamentals*, 1972.
Bowden, *Alternative Sources of Energy*, July 1973.
Duffie and Beckman, *Solar Energy Thermal Processes*, 1974.
McAdams, *Heat Transmission*, 1954.
Severns and Fellows, *Air Conditioning and Refrigeration*, 1966.
Sounders, *The Engineer's Companion*, 1966.

15

It should be noted that the charts (Fig. 15 ) give absorbitance emittance values which discriminate between the wavelengths of light energy considered. The values for absorbitance apply only to the visible range of the spectrum while emittances deal with long wave radiation.

Solar radiation is absorbed selectively, according to the wavelengths incident on the surface. Thus a fresh whitewash has an absorptivity of about .12 for short wave radiation (peak intensity at 0.4 microns) but the absorptivity for long wave radiation from other surfaces at ordinary temperatures (peak at 10 microns) is about .95. Consequently this surface also has an emissivity of .95 for long wavelengths, and is a good radiator readily losing heat to colder surfaces, but at the same time it is a good reflector for solar radiation. On the other hand, a polished metal has a very low absorptivity and emissivity for both shortwave and long wave radiations. Therefore, while being a good reflector of radiation, it is a poor radiator and can hardly lose its own heat by radiative cooling.°

° Givoni, B. p. 100.

It might be interesting to investigate the metal cladded Federal Reserve building in downtown Boston and inquire about the added output of the HVAC system to handle the increased cooling load compared to limestone buildings of the same size, due to this phenomenon in the summertime.

Every surface absorbs and emits radiation simultaneously. As I have said, the color of a surface gives a good indication of its absorptivity for solar radiation. The absorptivity decreases and the reflectivity increases with lightness of color. But color does not indicate the behavior of a surface with respect to longer wave radiation. Thus dark and light surface finishes have very different absorptivities for solar radiation. Although the long wave emissivities of the two colors are equal and are cooled equally by night radiation to the sky, the dark surface becomes much more heated on exposure to the sun. And for this reason the darker building surfaces and richly colored ground soils emit long wave radiation for an extended duration due to their higher temperatures.

## Texture

The surface texture or roughness of a building material determines the convective and radiant exchange with the environment. The surface coefficient identifies the rate of heat exchange with other surfaces, or the sky. The radiative coefficient is mainly dependent on the surface emissivity and also to some degree on the mean temperature of the surfaces exchanging radiation. The convective coefficient depends primarily on the velocity of the air near the surface and the roughness of the material. A highly textured building material increases the surface area between the air and material. For very smooth surfaces, such as glass, the surface coefficient is lowered by 30% and for very rough surfaces an approximate increase of 30% can be expected.°

° Givoni, B. p. 103.

From the vantage point of design it might be reasonable to place smoother surfaces other than glass on windswept exposures and the rougher materials on more protected and sunlit exposures where the added surface area can soak up the warmth trapped by thermal pooling. The turbulence factor would tend to cancel out the effect of increased surface area on a sunny high wind exposure.

## Geometry

The principle influence of building surface geometry on "sol-air" temperature is due to the reinforcing radiant exchange. Materials in close proximity and in line of sight of each other, add to the thermal pooling effect, if wind does not strip away heat.

Sol-air temperature is considered here as an equally important thermal tool as, for instance, capacity insulation (the selection and placement of insulation). The obvious benefit of a "sol-air" response is the architectural expression offered by the outward display of materials responding to variations in climate near the weather edge. Given other design constraints it is not unreasonable for the sol-air temperature to direct the use of darker richer hued building materials on the southerly and eastern faces while lighter surface finishes are relegated to the remaining exposures, roof and western especially.

The "sol-air" temperature suggests further deployment, selection and arrangement of materials and is discussed further in "thermal aspects of the solar wall."

## Absorptance, Reflectance, and Emittance

*Sunlight striking a surface is either absorbed or reflected. The absorptance $\alpha$ of the surface is the ratio of the solar energy absorbed to the solar energy striking that surface:*

$$\alpha = \frac{I_a}{I} = \frac{\text{absorbed solar energy}}{\text{incident solar energy}}$$

*A hypothetical "blackbody" has an absorptance of 1 – it absorbs all the radiation hitting it, and would be totally black to our eyes.*

*But all real substances reflect some portion of the sunlight hitting them – even if only a few percent. The reflectance $\rho$ of a surface is the ratio of solar energy reflected to that striking it:*

$$\rho = \frac{I_r}{I} = \frac{\text{reflected solar energy}}{\text{incident solar energy}}$$

*A hypothetical blackbody has a reflectance of 0. The sum of $\alpha$ and $\rho$ is always 1.*

*All warm bodies emit thermal radiation – some better than others. The emittance $\epsilon$ of a material is the ratio of thermal energy being radiated by that material to the thermal energy radiated by a blackbody at that same temperature:*

$$\epsilon = \frac{R}{R_b} = \frac{\text{radiation from material}}{\text{radiation from blackbody}}$$

*Therefore, a blackbody has an emittance of 1.*

*The possible values of $\alpha$, $\rho$, and $\epsilon$ lie in a range from 0 to 1. Values for a few common surface materials are listed in the accompanying table.*

| | $\alpha$ | $\rho$ | $\epsilon$ | $\alpha/\epsilon$ |
|---|---|---|---|---|
| White Plaster | 0.07 | 0.93 | 0.91 | 0.08 |
| Fresh Snow | 0.13 | 0.87 | 0.82 | 0.16 |
| White Paint | 0.20 | 0.80 | 0.91 | 0.22 |
| White Enamel | 0.35 | 0.65 | 0.90 | 0.39 |
| Green Paint | 0.50 | 0.50 | 0.90 | 0.56 |
| Red Brick | 0.55 | 0.45 | 0.92 | 0.60 |
| Concrete | 0.60 | 0.40 | 0.88 | 0.68 |
| Grey Paint | 0.75 | 0.25 | 0.95 | 0.79 |
| Red Paint | 0.74 | 0.26 | 0.90 | 0.82 |
| Dry Sand | 0.82 | 0.18 | 0.90 | 0.91 |
| Green Roll Roofing | 0.88 | 0.12 | 0.94 | 0.94 |
| Water | 0.94 | 0.06 | 0.96 | 0.98 |
| Black Tar Paper | 0.93 | 0.07 | 0.93 | 1.00 |
| Flat Black Paint | 0.96 | 0.04 | 0.88 | 1.09 |
| Granite | 0.55 | 0.45 | 0.44 | 1.25 |
| Graphite | 0.78 | 0.22 | 0.41 | 1.90 |
| Aluminum Foil | 0.15 | 0.85 | 0.05 | 3.00 |
| Galvanized Steel | 0.65 | 0.35 | 0.13 | 5.00 |

*The values listed in this table will help you compare the response of various materials and surfaces to solar and thermal radiation. For example, flat black paint (with $\alpha$ = 0.96) will absorb 96% of the incoming sunlight. But green paint (with $\alpha$ = 0.50) will absorb only 50%. Both paints (with emittances of 0.88 and 0.90) emit thermal radiation at about the same rate if they are at the same temperature. Thus, black paint (with a higher value of $\alpha/\epsilon$) is a better absorber of sunlight and will become hotter when exposed to the sun.*

Anderson, Solar Home Book

## SOLAR HEAT GAIN UTILIZATION AND $\Delta T$
(Indoor-Outdoor Temperature)

Solar heat gain utilization recognizes the potential for (glazed) collection surfaces to contribute to the overall heating needs of a building in a given climatic region. Fundamental to the understanding of this thermal design tool are three concepts:

Design Temperature

Solar Gain

Transmission Heat Loss

### Design Temperature

The design temperature is representative of the severity of the climate for a given locale. The standard adopted in the U.S. is based on the lowest (within 3 percentiles) minimum temperature (winter) expected over a range of years.

Ashrae points out that sizing the heat plant (analogous to solar energy input and backup system) with the most severe winter temperature condition is economically unpractical. Weather records show that most severe weather conditions do not repeat themselves. Ashrae goes on to say, heating systems designed for extreme weather conditions on record, hold in reserve considerable excess capacity during most of the operating life of the system. Occasional failure of the heating plant to maintain a preselected indoor design temperature during brief periods of severe weather is not critical.

The strength of passive solar design in conjunction with a backup system lies in its potential to handle such adverse conditions through the added measures of increased thermal mass and insulation. Typically, the solar tempered structure does not rely solely on a heat plant to maintain thermal stability. Adjustment of the additive layers (storm shutters, blinds, insulating shutters) of the weather edge work with the heat plant (sun or secondary source) to control heat loss and gain.

Architectural variety and richness of the facade results through the additive collage of built layers in responding to the range of weather conditions, extreme to mild.

Ashrae recommends the following considerations before selecting a design temperature, given in Table 1, Chapter 23 of Ashrae Handbook of Fundamentals.

-- Is the type of structure heavy, medium or light?

-- Is the structure insulated?

-- Is the structure exposed to high wind?

-- Is the load due to infiltration or ventilation high?

-- Is there more glass area than normal in the structure? (What is the orientation?)

-- What is the nature of the occupancy?

-- Will there be long periods of operation at reduced indoor temperature?

-- What is the amplitude between maximum and minimum daily temperature in the locality?

-- Are there local conditions which cause significant variation from temperature reported by the weather bureau?

-- What auxiliary heating devices will be used in the building?

Although these considerations make up a partial list they suggest the importance of micro-climatic conditions, thermo-physical and structural characteristics and use of a particular building as factors which re-interpret general climatic data.

Ashrae has touched upon questions which should be asked about any site and are the beginnings of directing an architectural regional response.

## Solar Gain

The amount of solar flux transmitted through the glazing material is described by a brief discussion of light physics at the collection surface. Solar gain, dependent upon the unique nature of these transparent and translucent materials can be calculated by the solar admission equation, which is given on the following page.

## Solar-optical Properties of Glass

The total amount of solar insolation, $I_t$ (specular and diffuse) falling on a window wall must equal the sum of radiation, which is transmitted through, reflected downward, and absorbed into the glazing material. The values of these three solar-optical properties and resulting penetration of solar energy depend upon:

I. Thickness and chemical composition (physical properties) of glazing

II. Surface texture, atmospheric particles (dirt), film or coatings applied to surface

III. Incident angle (ϕ)

Standard clear or double strength sheet glass transmits from 85 to 90 percent of the incident radiation between 0.3 and 3.0 (microns), while bronze, grey, and green heat-absorbing glasses, .25 in thickness, transmits about 47% of the total solar spectrum.

Variation with incident angle of the solar-optical properties of typical uncoated glazing materials is illustrated by figure 16 .

As the sun progresses across the sky vault, the incident angle diminishes from 90 - 0 degrees. The transmission increases, reflectance decreases, and absorption decreases due to the shortened optical path.°

°Ashrae, 26.13

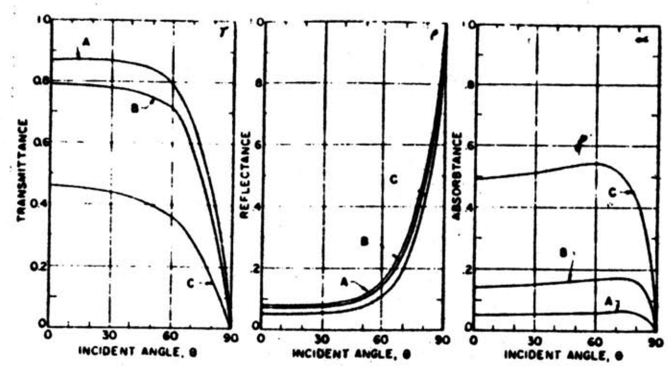


Fig. 16 Variation with Incident Angle of Solar-Optical Properties for Double-Strength Sheet, Clear, and Heat-Absorbing Glass

<u>Solar Admission Equation</u>

$$Q = (c) I_{t\phi} \cdot A \cdot$$

Where:

c = clearness factor (Climatic Atlas)

$I_{t\phi}$ = total solar irradiation (Ashrae)

A = area of glazing

= transmission coefficient (single glazing .88, double .75)

$I_{t\phi} = I_{dn}$ (direct normal) $\cos\phi + I_d$ (diffuse)

The three inter-related graphs (Figure 16 ) are important in clarifying the basis of the overall value of light (transmission) and serve to clear up some confusion regarding the relationship between angle of incidence and light transmission. Graph 11 shown earlier illustrates the overall transmission values only, whereas these last graphs show the separate contributions of reflectance and absorptance toward transmission. Without this breakdown it is difficult to know what factors are contributing to the overall value of transmission. The angle of incidence has in reality a double jeopardy effect on the amount of energy transmitted by the glazing material. Angle of incidence describes first the geometric dimension of the amount of light energy available, a function of the $\phi$ angle (refer to Angle of Incidence section for diagram).

Secondly, angle of incidence operates on another scale. Due to the index of refraction of the glazing material which differs from that of air, the interface (the glazing surface) becomes a medium for reflection.

The reflection, then, a function of the angle of incidence depends upon the surface properties of the material (e.g. smoothness of standard glass vs. frosted glass).

This implies glazing surfaces of different roughness (opacity) will control or influence to varying degrees the amount of spectral light transmitted.

The equation is provided for reference, should the occasion arise, to facilitate the incremental computation of solar irradiation at a particular location, time and collection surface. I refer you to Energy Primer for a thorough discussion of solar irradiation (p. 21)

Fortunately, Ashrae has preserved our integrity and done us the honor of calculating the solar insolation through 1/8" clear glass for given latitudes and orientations and arrives at daily totals for the twenty-first of each month. Tables are included in the appendix.

## Calculation of Transmission Heat Loss

The basic formula for the heat loss by conduction and convection heat transfer through any surface is:

$$q = AU(t_i - t_o)$$

where:

$q$ = heat transfer through the wall, roof, ceiling, floor, or glass Btu per hour.

$A$ = area of wall, glass, roof, ceiling, floor, or other exposed surface, square feet.

$U$ = air-to-air heat transfer coefficient, Btu per (hour)/(square foot) (degree Farenheit)

$t_i$ = indoor air temperature near surface involved, degree Farenheit

$t_o$ = outdoor air temperature, or tempearature of adjacent unheated space, degree Farenheit.

Example: Calculate the transmission loss through an 8-in. brick wall having an area of 150 $ft.^2$, if the indoor temperature t, is 70°F, and the outdoor temperature $t_o$ is -10°f.

Solution: The overall heat transfer coefficient U of a plain 8-in. brick wall is 0.41 Btuh/($ft^2$)(F). The area A is 150 $ft^2$. Substituting into Eq 3:

$$q = 150 \times 0.41 \times 70 - (-10) - 4920 \text{ Btuh.}$$

°Ashrae

The window wall is the principle means of solar collection in passively heated buildings. Placement and arrangement of the window surfaces and consideration of size and shape offer a good deal of design flexibility in the thermal conduct of the building.

Solar Benefit

Reference to "solar benefit values", given by Bruce Anderson in his Solar Home book initiates this sub-section of solar design tools. The table of "solar benefit values" demonstrates the potential of the south facing double glazed window wall to contribute net energy gain.

The figures are based on the average temperature during the heating season for the glazing surface only. Furthermore, the back losses (transmission losses through glass) on cold winter nights for a given structure and locale in reality determine the feasibility and extent of possible solar heating. The storage and thermal resistance capacity ("U" values) of the structure, to a great extent determine the fate of the "solar benefit".

Window Wall - Wall Ratio - Sunlit Orientations

This section investigates the relationship between solar gain, window to wall ratios and orientation. It is a valuable solar design tool for the designer to easily approximate the solar input for a given window wall area in regard to a specific wall dimension and orientation. Reference is made here to additional work pioneered by T.E.A.

## Heat Gain Through Vertical Windows

Window heat gain charts° are included to help determine how much window area, at which orientation, is needed to provide various amounts of heat for use in buildings. There are many sources of data on solar heat gain through windows, but two important stumbling blocks make the determination of actual solar heat gain difficult. First, the sources list heat gain factors (SHGF) for various orientations of glass at different latitudes. Secondly, the information is given on an hourly and daily basis. The difficulty is in going from these values (which are for sunny conditions and include factors for diffuse radiation), to monthly and then seasonal values for windows at all orientations, figure **17**.

These charts are based on ASHRAE and Koolshade Solar Heat Gain Factors for latitudes closest to the area being examined. Data on Horizongal Windows (skylights) are included for comparison. Btu values are given per square foot of window area. Percent of possible sunshine data is from page 65 of the Climatic Atlas of the U.S. The number of days per month times the percent possible sunshine gives the number of effective sunny days per month. The effective sunny days per month times the solar heat gain factor per day gives the solar heat gain through one square foot of window per month (Btu/sf/mo). This computation is carried out for window orientations of S, SE, SW, E, W, NE, NW, and N for each month of the year. Totals are given for the whole year, only for the heating season, and the cooling season, at the bottom of the page. (Values for horizontal windows are given at the far right hand column.) These computations must be made for each region separately because the percentage of possible sunshine varies widely from region to region. The chart cannot be used based solely on the latitude of the site.

(Anderson, Solar Home Book, p. 41)

Solar heat gain through the window wall as well as the wall and roof can be used in a positive way to affect heat loss.

Graphs are not the most appealing way to communicate design related information. The following graphs, however, present clearly the heat gain and loss for a complete sweep of compass orientations.

°Figures **18** AND **19**

DESIGN INFORMATION - 6

Region: II BOSTON AREA Climate: TEMPERATE Latitude: $42^{\circ}$-2' N. LAT.
Regions with similar climate characteristics: MID-OHIO REGION-Columbus, Ohio - $40^{\circ}$-0' N.LAT.

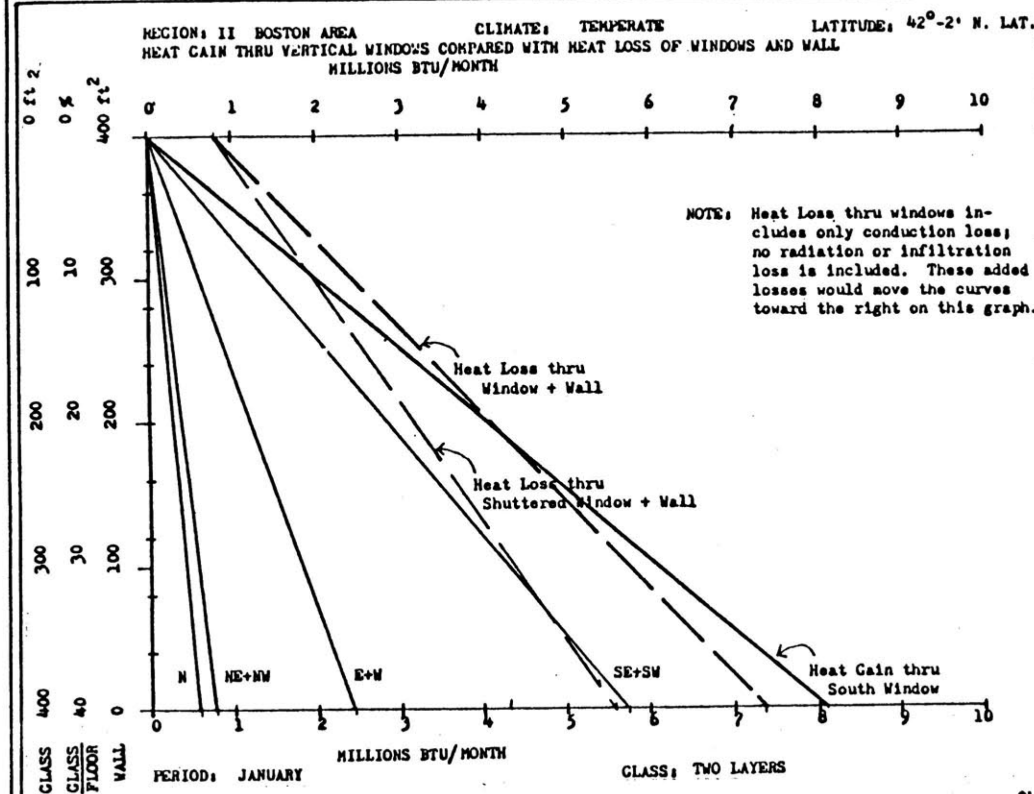
HEAT GAIN THROUGH VERTICAL WINDOWS OF SINGLE PANE GLASS: MULTIPLY BY .86 FOR DOUBLE GLASS

| MONTH OF YEAR | SUNNY DAYS A DAYS MO. | B %POSS SUN | AxB DAYS MO. | ORIENTATION OF WINDOW N S.H.G.F.* BTU/FT² DAY | N MO. | NE DAY | NE MO | E DAY | E MO | SE DAY | SE MO | S DAY | S MO | SW DAY | SW MO | W DAY | W MO | NW DAY | NW MO | HORIZ. WINDOW DAY | HORIZ. WINDOW MO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAN | 31 | .47 | 14.6 | 109 | 1590 | 122 | 1780 | 481 | 7020 | 1144 | 16700 | 1595 | 23300 [o] | 1144 | 16700 | 481 | 7020 | 122 | 1780 | 706 | 10300 |
| FEB | 28 | .56 | 15.7 | 151 | 2370 | 210 | 3300 | 683 | 10700 | 1269 | 19900 | 1632 | 25600 [o] | 1269 | 19900 | 683 | 10700 | 210 | 3300 | 1092 | 17100 |
| MAR | 31 | .57 | 17.7 | 209 | 3700 | 410 | 7260 | 948 | 16800 | 1334 | 23600 [m] | 1432 | 25300 [o] | 1334 | 23600 [m] | 948 | 16800 | 410 | 7260 | 1528 | 27000 [o] |
| APR | 30 | .56 | 16.8 | 291 | 4890 | 642 | 10800 | 1112 | 18700 | 1228 | 20600 [o] | 1037 | 17400 | 1228 | 20600 [o] | 1112 | 18700 | 642 | 10800 | 1924 | 32300 [o] |
| MAY | 31 | .59 | 18.3 | 394 | 7200 | 810 | 14800 | 1185 | 21700 [o] | 1106 | 20200 | 776 | 14200 | 1106 | 20200 | 1185 | 21700 [o] | 810 | 14800 | 2166 | 39600 [o] |
| JUN | 30 | .62 | 18.6 | 470 | 8740 [m] | 907 | 16900 [m] | 1230 | 22900 [o] | 1055 | 19600 | 687 | 12800 | 1055 | 19600 | 1230 | 22900 [o] | 907 | 16900 [m] | 2242 | 41700 [o] |
| JUL | 31 | .64 | 19.8 | 410 | 8120 | 819 | 16200 | 1177 | 23300 [o] [m] | 1088 | 21500 | 762 | 15100 | 1088 | 21500 | 1177 | 23300 [o] [m] | 819 | 16200 | 2148 | 42500 [o] [m] |
| AUG | 31 | .63 | 19.5 | 307 | 5990 | 648 | 12600 | 1092 | 21300 | 1194 | 23300 [o] | 1008 | 19600 | 1194 | 23300 [o] | 1092 | 21300 | 648 | 12600 | 1890 | 36900 [o] |
| SEP | 30 | .61 | 18.3 | 217 | 3970 | 403 | 7370 | 907 | 16600 | 1278 | 23400 | 1383 | 25300 [o] | 1278 | 23400 | 907 | 16600 | 403 | 7370 | 1476 | 27000 [o] |
| OCT | 31 | .58 | 18.0 | 155 | 2790 | 214 | 3850 | 663 | 11900 | 1223 | 22000 | 1570 | 28300 [o] [m] | 1223 | 22000 | 663 | 11990 | 214 | 3850 | 1070 | 19300 |
| NOV | 30 | .48 | 14.4 | 113 | 1630 | 124 | 1790 | 475 | 6840 | 1123 | 16200 | 1563 | 22500 [o] | 1123 | 16200 | 475 | 6840 | 124 | 1790 | 706 | 10200 |
| DEC | 31 | .48 | 14.9 | 90 | 1340 | 99 | 1480 | 396 | 5900 | 1057 | 15700 | 1501 | 22400 [o] | 1057 | 15700 | 396 | 5900 | 99 | 1480 | 564 | 8400 |
| TOTALS# | 365 | .57 | 207. | 51930 | | 98130 | | 183660 | | 242700 | | 251800 | | 242700 | | 183660 | | 98130 | | 312300 | |
| COOLING SEASON # | | | | 22450 | | 45700 | | 67500 | | 64400 | | 47500 | | 64400 | | 67500 | | 45700 | | 121100 | |
| HEATING SEASON # | | | | 29480 | | 52430 | | 116160 | | 178300 | | 204300 | | 178300 | | 116160 | | 52430 | | 191200 | |

* S.H.G.F. indicates Solar Heat Gain Factor # Yearly totals are indicated
SOURCES: ASHRAE, Kool Shade, Climatic Atlas of the U.S.

o : Best orientation for a given month
m : Best month for a given orientation

17



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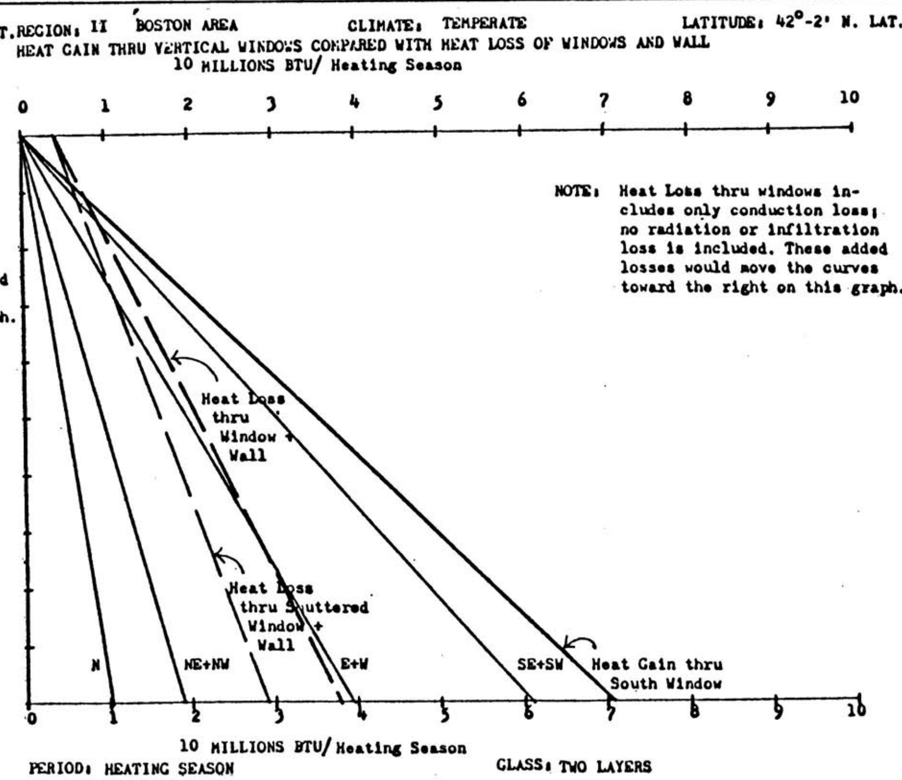

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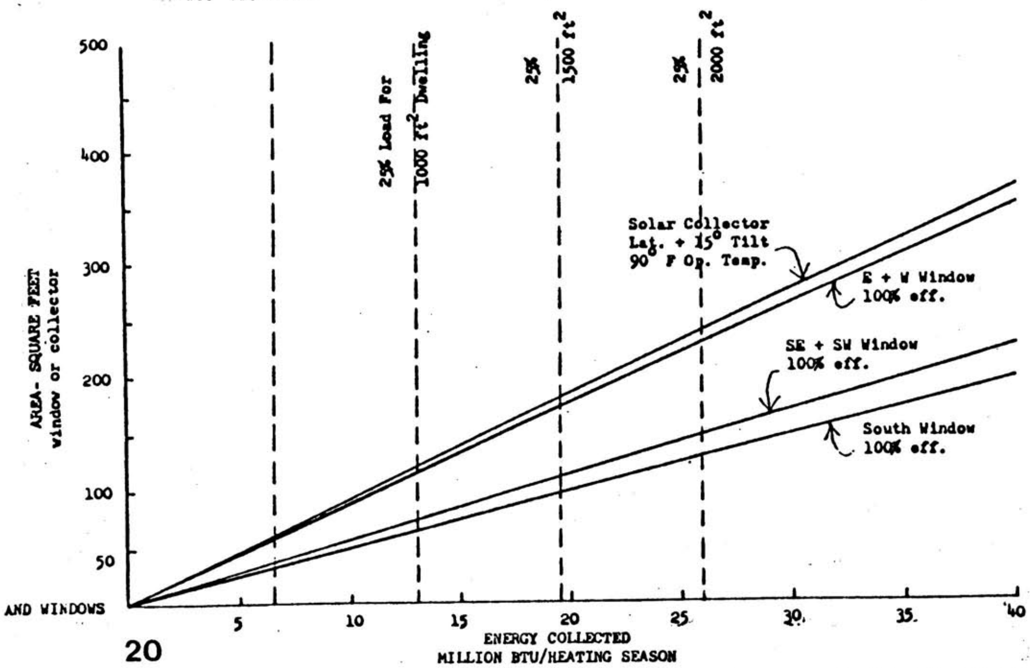


ENERGY COLLECTED BY SOLAR COLLECTORS AND WINDOWS

20

TEA's "Heat Gain and Loss" graphs help determine the window orientation and area necessary to supply various amounts of heat. These graphs also indicate the net heat gain or loss from windows facing in any of eight major compass directions. The heat gain varies with orientation considerably. As a result, some window orientations yield greater heat gain than others. Graphs were prepared for the month of January (the month with the most heating degree days) and for the heating season, defined as those months averaging more than 100 degree days. The graphs are based upon one or two glass layers, depending on the climatic region under consideration.

The graphs are based only on conduction losses through the window and the wall. Radiation and infiltration losses are not included due to their complexity and relationship to specific design conditions. These additional losses would move the heat loss curve further to the right making the use of south facing windows even more important to achieve net heat gain. Heat loss is indicated for conventional window and wall combinations, and for shuttered window (8 out of 24 hours) and wall combination. The importance of using shutters in all regions can be readily appreciated from the graphs.

The Boston graphs generally indicate that in order to receive a net gain in heat, a window-area to floor-area ratio of at least 10% must be achieved. Before heat gain approaches heat loss during the coldest month (January), a 30% window-area to floor area ratio is required. The actual glass area required is dependent on the specific orientation of the windows. This might indicate that the FHA minimum standard of a 10% window-area to floor-area ratio might be increased to increase the natural solar heat gain during the heating season.

A second set of graphs, "Energy Collected by Solar Collectors and Windows", compare the energy collection capabilities of a typical collector with windows at different orientations. Graphs were prepared for each site. Figure 20 is the graph for the Boston site. Solar collector capabilities are based on the results of solar collector output and sizing studies prepared for each site. Window capabilities are transcribed from the appripriate "Heat Gain Through Vertical Windows".

The load factors (shown by vertical dashed lines) are based on TEA dwelling insulation standards. TEA research and experience shows that a reasonably linear relationship exists between collector size and percentage of heating load supplied for systems providing up to

50% of the heating load. Therefore, the graph can be used to estimate the collector area needed to supply a 50% load for a 1000 sf house as well as a 25% load for a 2000 sf house (assuming the same degree of insulation).

Window size cannot be extrapolated in a straight line manner with any predictable accuracy beyond a 25% load factor for any building. Windows are considered to be 100% efficient in order to provide the energy indicated. This implies that enough thermal storage mass is provided near the windows to absorb the incoming heat so that the space remains in the comfort zone. The thermal storage must be allowed to fluctuate in temperature if the absorbed heat is to be used to warm the adjacent spaces. This temperature fluctuation is provided for by allowing a dwelling to heat up during the day and cool down at night rather than trying to maintain a constant internal temperature. The thermal mass, which is heated during the day, transfers heat to the cool space during the night.°

°T.E.A., Solar Homes in Four Climates, p. 42.

In addition, the following points are considered important when using these graphs.

Solar heat gain through walls and roofs is relatively small in comparison to the gain through window walls. However, the contribution of the "sol-air" temperature toward the heat gain of sunlit surfaces is significant.

The sun exposure contribution is dependent upon how well-insulated the structure is and a host of other design factors which modulate the impact of "sol-air" temperature (i.e. orientation, thermo-physical properties). The important point reiterated here is the relationship between sun soaked building surfaces, Delta T ($T_{indoor} - T_{outdoor}$), and heat loss.

The solar heat gain bounced back out by the insulation can be held in the outer surface material of the weather edge, thus reducing the overall heat loss. This dynamic implies structural-contextual relationship between sun, mass and insulation. This thermal dialogue will be further explored in the following section.

It is also important to note that the effect of infiltration (excluded in graphs) is of major significance in the total heat loss of buildings. Infiltration can strip away as much as 30% of buildings' inner warmth, which alter the graph lines considerably, perhaps pushing the line representing (heat loss through window and wall), right off the chart. Infiltration must be ascertained for a specific building(s) and locale -- remember not to underestimate its importance.

## THERMAL DESIGN INFORMATION

REGION: Boston Area
CLIMATE: Temperate
LATITUDE: 42°2 North
DEGREE DAYS: 5 to 27

| | FHA | TEA |
|---|---|---|
| HEAT LOSS: BTU/FT°/ DD | 19 | 9.5 |
| HEAT GAIN: BTU | NA | 25% heat load |
| "U" VALUE: BTU/FT°/HR/°F | | |
| Ceiling | .05 | .035 |
| Wall | .09 | .045 |
| Roof - exposed structure | .09 | .035 |
| Window, door | .65 | .35 |
| Floor | .51 | .20 |
| Floor on grade | .10 | .055 |
| INFILTRATION | 1.0 | .75 |

| | |
|---|---|
| Floor area: $FT^2$ | 1000 |
| Roof area: $FT^2$ | 1000 plus |
| Wall area: $FT^2$ | 900 |
| Window and door area: $FT^2$ | 300 |
| Floor to ceiling height: FT | 8 ft. plus |
| Building Volume: FT | 9000 |
| Mass of Building: FT | 180,000 |
| Stories alt. levels including basement if any | 1-2 |

| | FHA | TEA |
|---|---|---|
| Indoor Design Temperature | 72° | 70° |

THERMAL ASPECTS OF THE SOLAR WALL

The following 3 sections present a range of architectural examples that illustrate a solar approach to design. These examples, often inspired by historical precedent, include both innovative solar design concepts and contemporary built applications.

Furthermore, they show how the selection, arrangements, and placement of materials employed at the weather edge can be beneficial to both solar conditioning and to the indoor-outdoor connection. This list of solar architectural examples is by no means exhaustive.

The intent of this work is to begin to show how the formal language can address certain drawbacks of passive solar design. Therefore, the examples introduced here, by and large, are attempts to ameliorate the unfavorable conditions associated with passive solar design.

- High contrast glare
- Over heating
- Hot spots
- Sun bleaching
- High back losses and heat sink effect

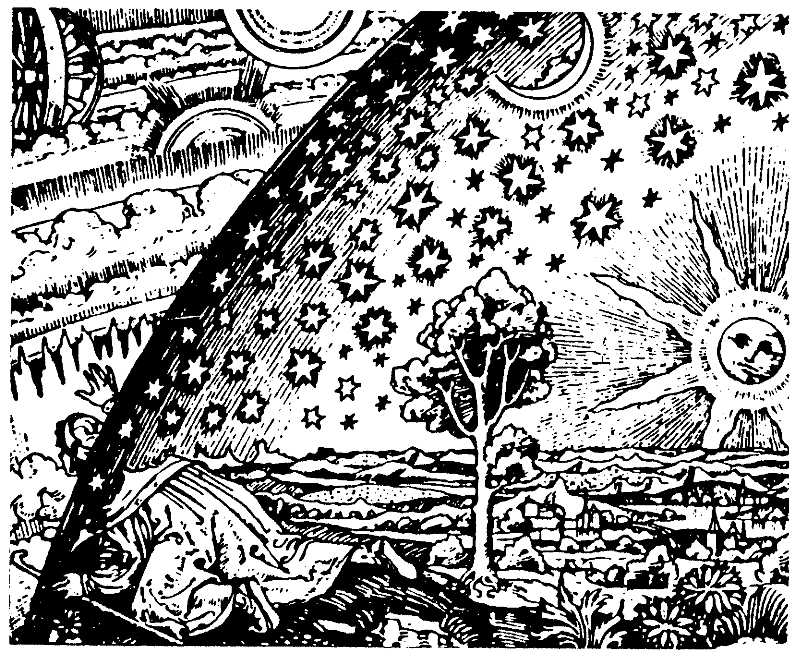
A primary concern is how the weather edge by thermal damping, control and distribution of solar energy balances external loads impacting various exposures. A subsequent concern is the quality and animation of life within the building.

The solar aesthetic begins to take on a fuller meaning when it is founded upon the practical and enhances the perceptual. Thus the aesthetic to be explored encourages a range of possibilities which lie in the visual play of light and shadow.

The design of the architectural vocabulary is correlated to the movements of the sun, natural flows of wind, dynamic action of rain and snow and man's biological needs.

It is my belief that through the interlocking of an architectural vocabulary with nature's variations and recurring patterns, a rich and substantial architecture follows.

# SECTION 3



## Window Wall Materials

There are four fundamental types of glazing materials:

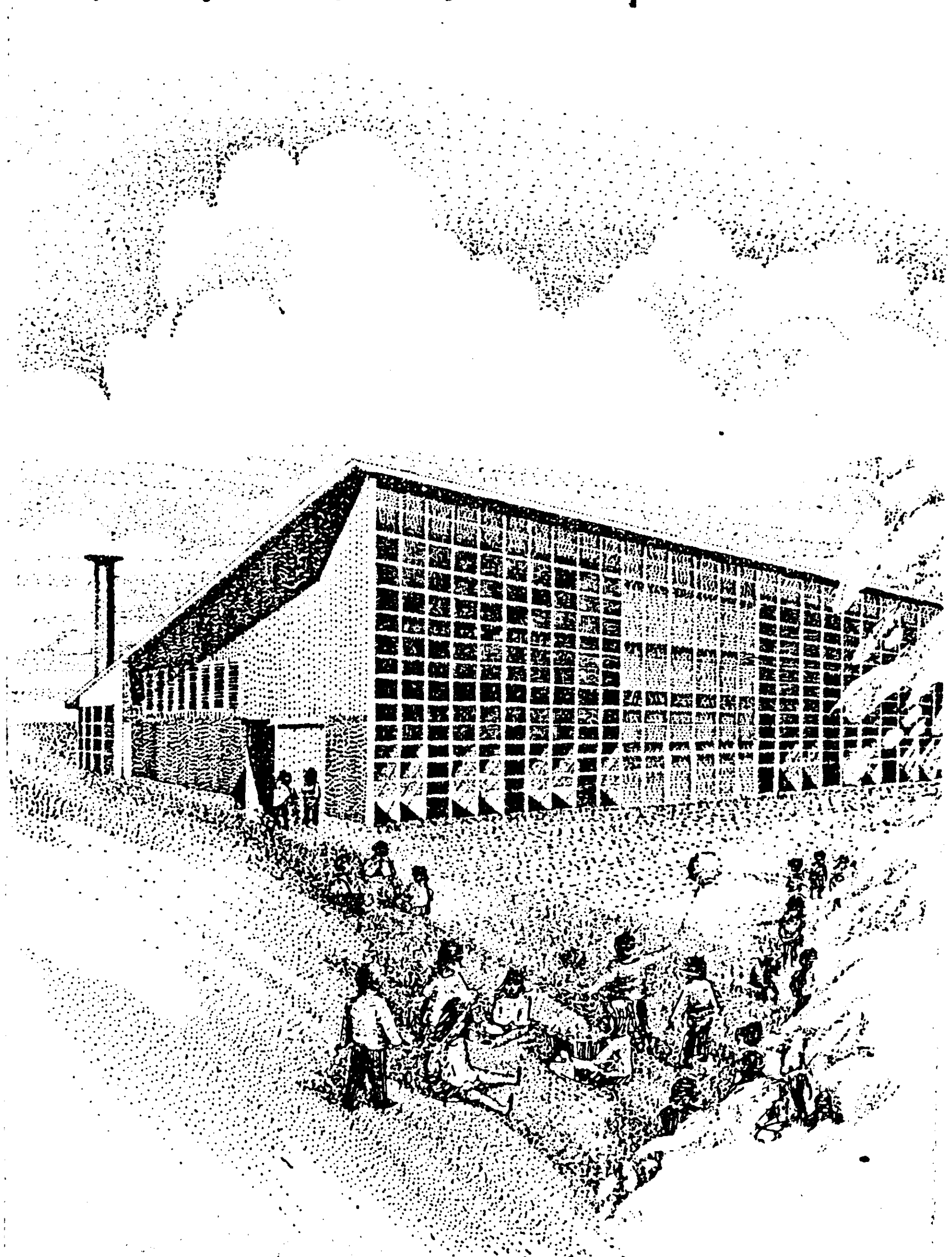
- o Transparent (standard clear)
- o Diffusing
- o Directionally transmitting
- o Selectively transmitting, including directionally selective and spectrally selective.°

°Roger Goldstein, Natural Light in Architectural Design, Element and Determinant.

The variety of glazing types described by the above categories are extensive. The following section narrows the range to a few examples of conventional glazing materials which have solar merit, and a number of more innovative applications selected for their solar benefit and aesthetic interest.

Solar benefit implies a net solar gain during the heating season. Because winter sun angles are limited to the south, east and west exposures, north aspects make little contribution to solar gain. For this reason a discussion of north facing windows are all but eliminated. The component of diffuse energy received on the north faces are generally 10% of direct radiation; not enough to offset the heat loss through an equivalent square foot of glass. Windows in general lose 6 times the amount of heat as a conventional wall. In harsh climates, therefore, north facing window-wall area should be kept to a minimum and if possible triple glazed.

*Annex of St.George's School, Wallasey. Chesire. England, 1957*



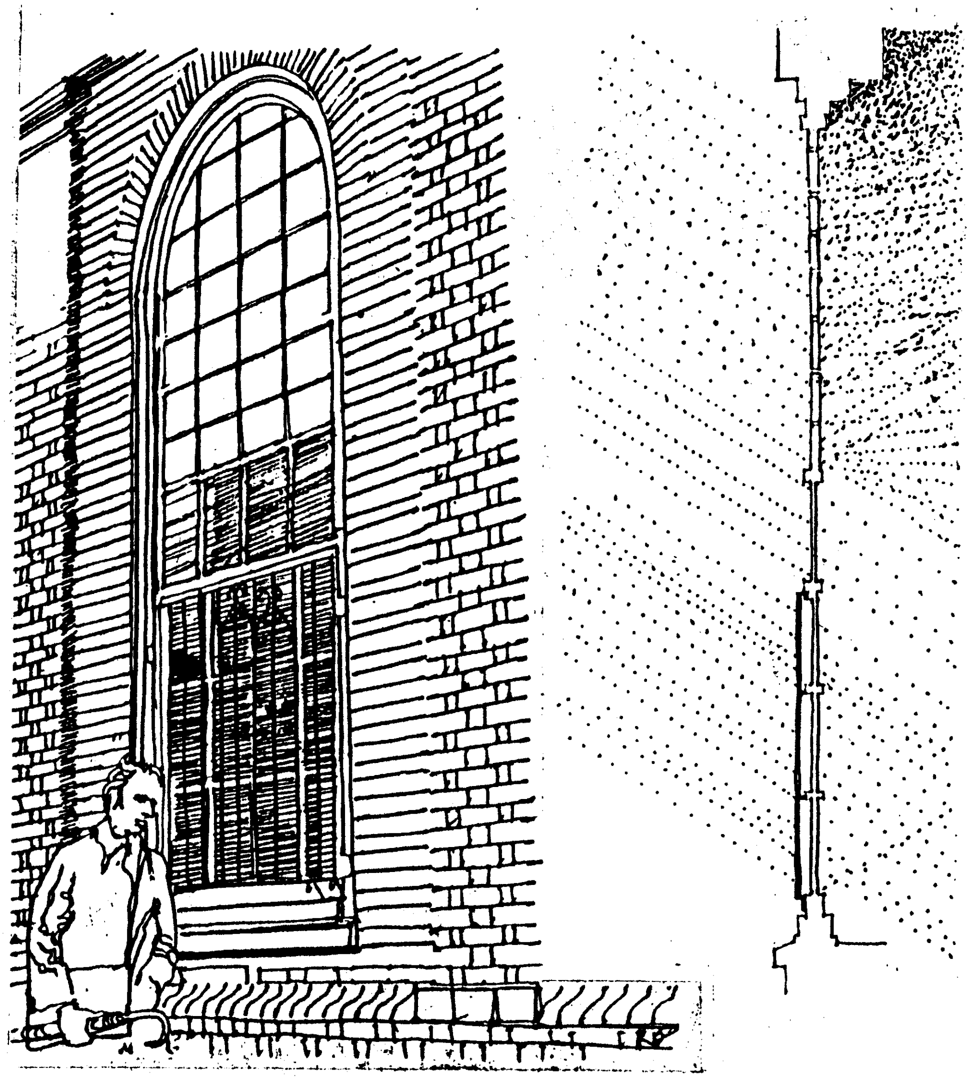
Solar Designing, James Lambeth, p. 9.

Diffusing Materials

-- Diffusing materials produce non-selective diffusion of transmitted light. The various types of screens, kalwall, tedlar, steel glass as well as patterned, hammered and textured (frosted) glass are considered diffusers.

-- The St. George's School in Wallasey, England,° uses textured glass for nearly its entire south face. Because this glazing material is a good diffuser, the flood of natural light is spread evenly throughout the room. Because all light ultimately reduces to heat, this diffuse light energy is absorbed by the massive materials via multiple reflections within the spaces.

° Refer to "Solar Energy" Volume 18 Number 4, 1976 (for a thorough discussion).



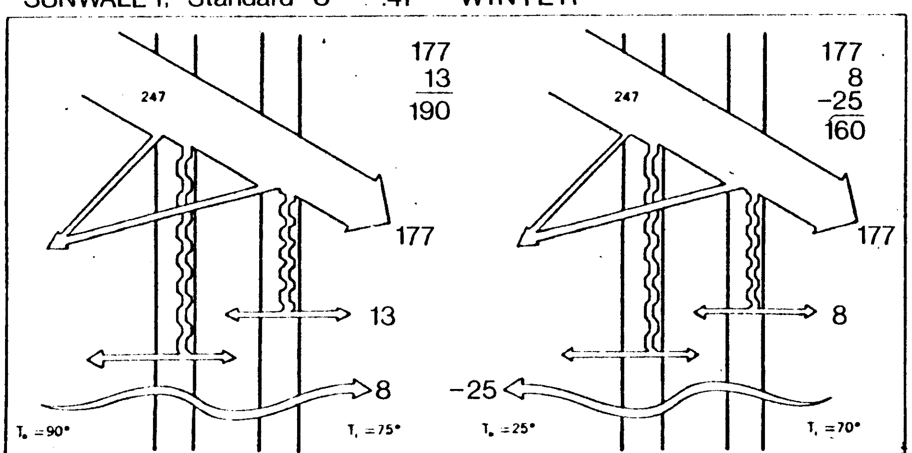
21

-- Shown here are two architectural treatments using Kalwall. Warren School, Newton, a traditional brick building uses gridded Kalwall primarily to reduce sky glare and maintain good thermal resistance (for glazing materials) (Figure 21 ) Kalwall is made up of two sheets of fiberglass reinforced polymer material separated by a structural lattice made of extruded aluminum cores.

Wellesley Service Center illustrates the use of Kalwall in a floor to ceiling application (Figure 22). The use of large expanses of Kalwall on the southern and eastern faces provides solar input, in the form of diffuse light and the wall substantially reduces overheating and high contrast glare conditions. Small windows are

22

SUNWALL 1, Standard "U" — .41 WINTER

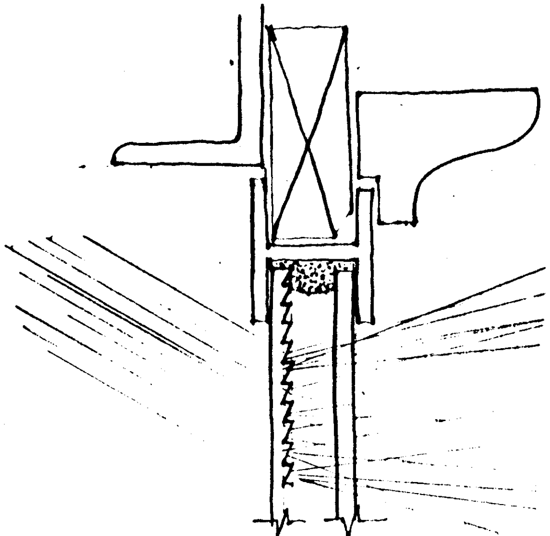



Estimated at 0° incident angle. Grid not included.

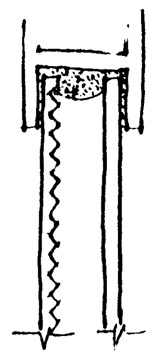
set into the translucent wall at various intervals. The overall effect is one of a glowing wall, having an almost oriental feel, that of the Shoji screen.

This soft glow animates the wall surface on sunny days giving a pleasant visual effect. This light quality is partly due to a spun glass material used as infill between the layers of fiberglass. It serves both to diffuse the light and decrease backlosses. In addition, high backlosses are partially compensated for by the heat given off by lab equipment, students and lights.

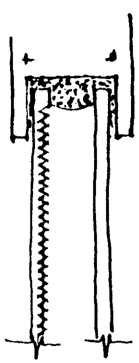
There are good diffusers and bad diffusers. Kalwall without the infill material is a poor diffuser of direct sunlight. It creates the sun disk effect which enlarges the apparent size of the sun and creates a concentrated glare source.



NO.1 ≤ 30°



30° ≤ NO.2 ≤ 40°



NO.3 > 40°

Directionally Transmitting

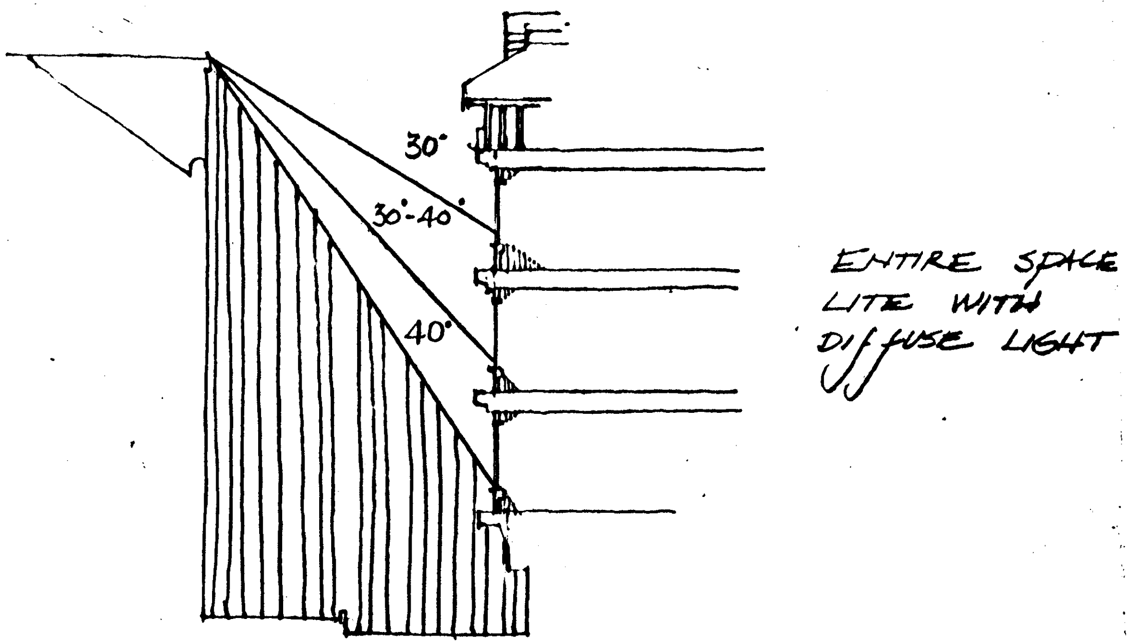
The following section is excerpted from Natural Light and Architectural Design, Roger Goldstein, 1976.

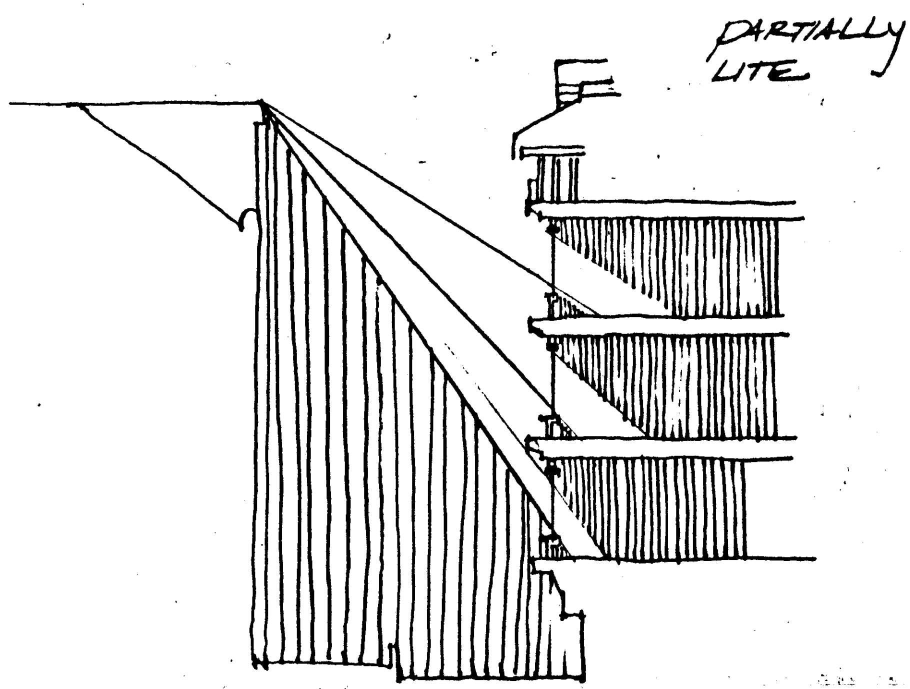
Prismatic and maxium glass are the two most common varieties of directionally transmitting glass. Both produce a change in the direction of transmitted light by refraction.

Prismatic glass has one smooth face (the outside one) and one surface made up of parallel prisms which refract the light in a specific direction according to the angle of incidence of the light, and of the prism.

Prismatic glass is available in three angles, each of which is precisely designed for a particular angle of incidence.

One of the most suitable applications of prismatic glass is to counteract




the effects of high obstruction such as a tall building which blocks out the direct view of the sky. It must be installed with prisms running horizontally on the inside surface of the window. Note also that this glass is translucent and that transmittance is less than that of clear glass.

Maxium glass is simply a type of prismatic glass, most applicable to angles of obstruction less than 30° and greater than 40°. It is also a rolled glass, the inside surface of which has paralleled prisms that refract the light horizontally. Its outer surface is fluted at right angles to the prisms, in order to give better lateral diffusion.

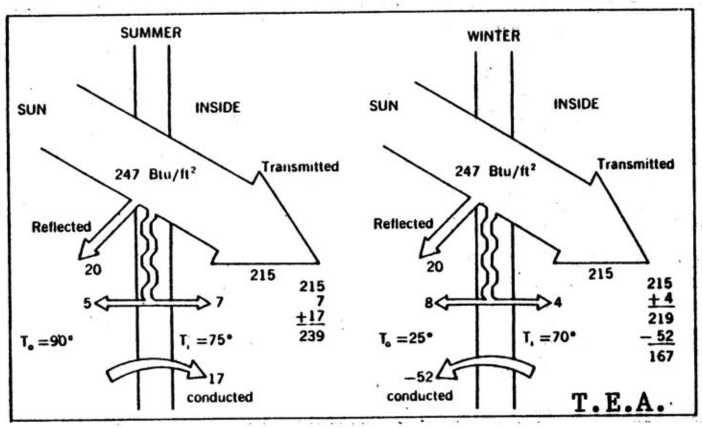
The performance of this glass suggests a number of applications. One possible application in an obstructed sky situation might be to use prismatic glass for the upper half or third of the window, and clear glass for the lower part. This condition takes advantage of the sky seen by the upper part and directs that light to the back of the room, while the lower part still allows outward view. An example for direct application which has little or no solar heating potential is a room with windows facing an open light well or courtyard.

Another application is to use this glazing material in an unobstructed-sky view situation. The refracting geometry will reduce the high glare value of the upper window when the sun is in a lower position on the horizon.

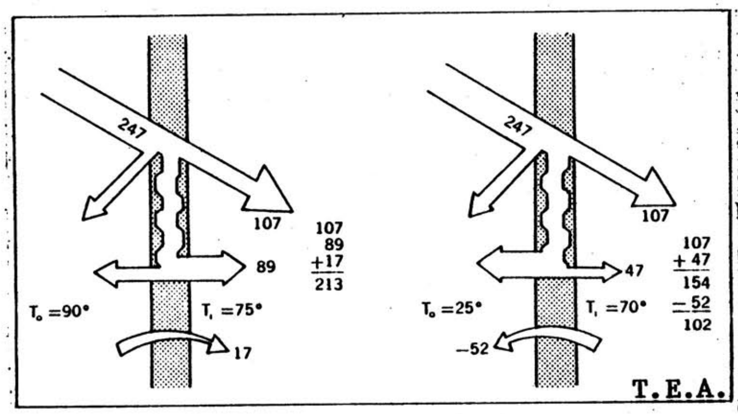
The low transmission factor of this glass makes it very suitable for the window wall collector.

Briefly described, the window wall collector utilizes heated air trapped in the double glass construction for space heating. The high percentage of light that does not penetrate the prismatic glass is transformed into useable heat which is ducted passively into the adjacent space by the window wall collector. Refer to section on window wall collector for a more complete discussion.

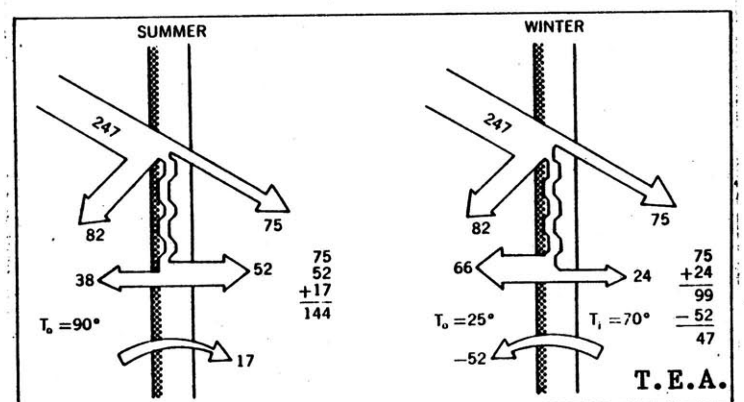
In a conventional window wall design, the low transmission value of prismatic glass (37%), in conjunction with clear glazing (10%), reduces the overall transmission and therefore the solar benefit considerably. Due to the low transmission of prismatic glass the solar benefit is realized either through utilization of single glazing (in a mild climate condition) or in the window wall collector. In both cases, prismatic glass reduces glare and increases rear lighting levels.




Solar heat gain through clear glass, single glazing.




Solar heat gain through heat-absorbing glass, single.




Solar heat gain through reflecting glass, single glazing.

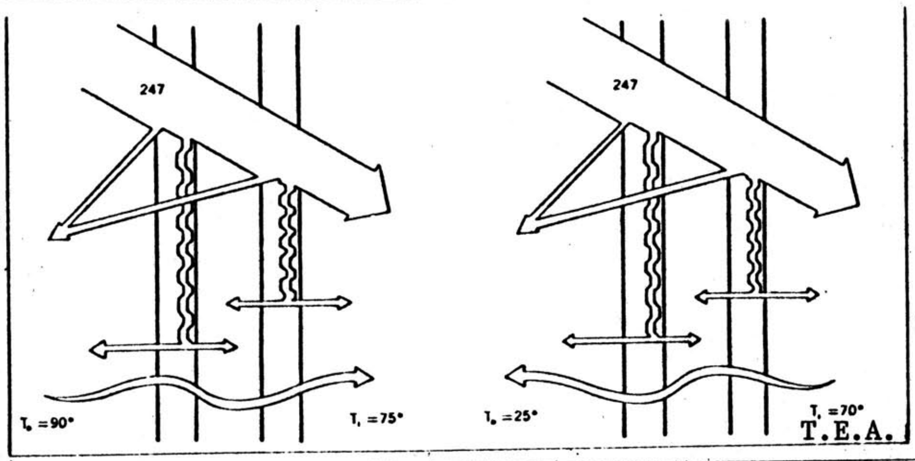
**Selective Transmitting**

-- Three subgroups cover a range of high and low heat glazing materials under this heading:

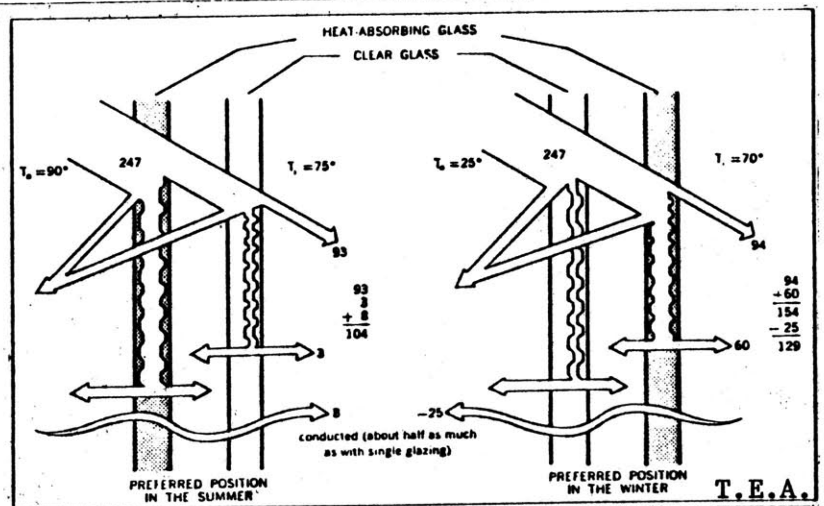
-- Spectrally selective material such as tinted glass, heat-absorbing and heat reflecting glass, core glass. Note the tinted glazing materials, most effective in reducing interior solar gain, correspondingly reduce the brightness of the exterior view.

-- Directionally selective glazing materials such as prismatic glass block.

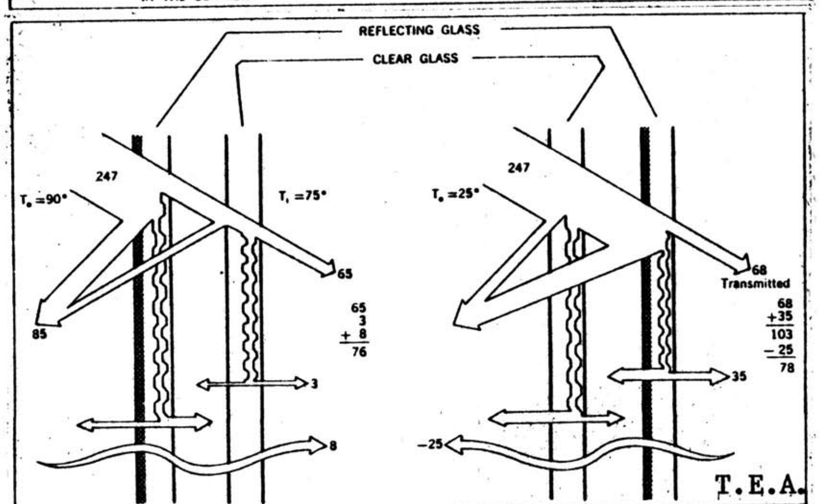
-- Radiation selective material such as heat mirror.




Solar heat gain through clear glass, double glazing.




Solar heat gain through heat-absorbing glass, double glazing




heat gain through reflecting glass, double glazing.

## Heat-Absorbing and Reflective Glass

Given here are solar heat gain values through spectrally selective materials, compared to values for single and double clear glass.

Heat absorbing and reflective glazings are responsible in part for the extensive use of glass with little or no regard for orientation and the solar impact upon adjacent buildings, i.e. the "glass boxes" of modern architecture.

High internal heat gains of office buildings, for example, have legitimized the extensive use, i.e. large amounts of glass, of these glazing materials from an energy standpoint.

Office and commercial buildings in general have a year-round cooling problem which can be attributed to high internal gains, i.e. lights (10 watt/sq. ft., average), people

(100 watts/person) and office machinery. The outside energy needs, if any, for these structures are predicated on ventilation requirements. In terms of this (energy-load usage demand) it is important to distinguish between commercial and residential buildings. Partly for this reason office buildings have been neglected in this thesis. Although a different set of energy conservation principles are in effect, commercial buildings tend to heat themselves, relying very little on any outside energy source to provide heat.

If one refers to the diagram on heat absorbing glass, it becomes obvious that the material does little to ameliorate the overheating problems for both residential and commercial buildings. The application of heat absorbing or tinted glass controls solar gain and glare by soaking up the sunlight. The thermal absorption and conduction shown in the summer and winter diagrams illustrate how the material performs in a counterproductive way under its respective seasonal load. In the summer, conductive solar gain to the interior is relatively large when compared to overall transmission. This heat flow is reversed in winter. Heat always flows downhill. The delta T will flow from a warm to a cold body.

In the summertime the heat absorbed in the glass flows to the interior at a time when it is least needed, especially with regard to commercial buildings. During winter the heat flows to the exterior at the time when it is most needed. This statement is qualified by indicating that with most commercial buildings the associated heat loss is appropriate when the high interval gains are considered.

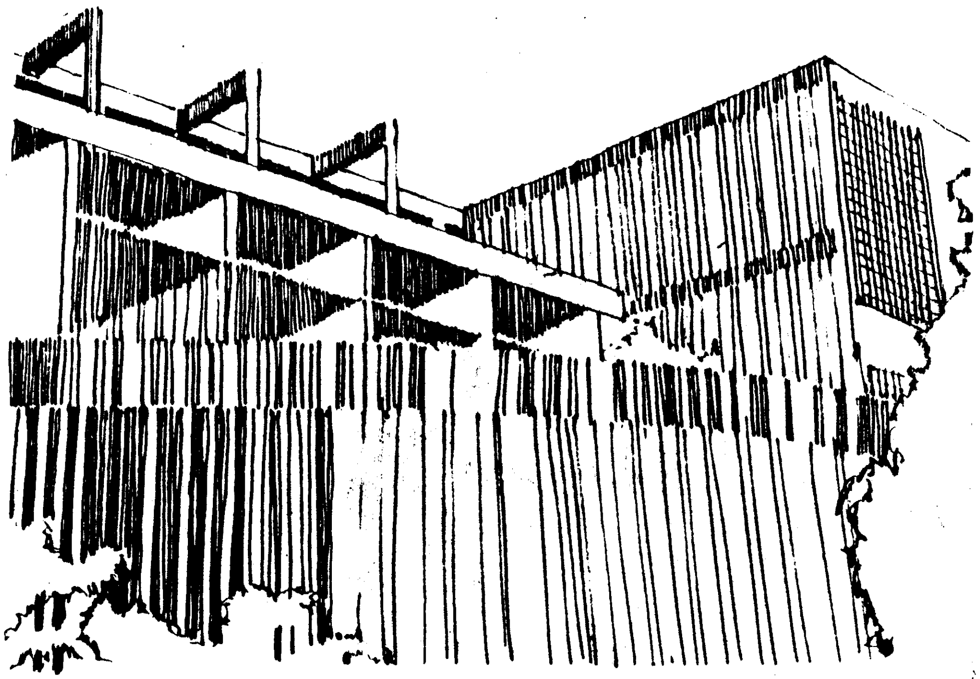
However, for residential dwellings the positive solar heat factor is being discarded.

It seems that a more responsive architecture, sensitive to both climatic elements and behavioral considerations are met by regional design which considers: orientation, external sun controls, framing of views and modulation of light as important design inputs.

Furthermore, better use can be made of these materials when applied as solar sun glasses (i.e. selectively placed glazing, upper or lower bands, which allow placement of clear glass for viewing). This helps considerably in reducing the "gloom" effect associated with these tinted glazing materials also.

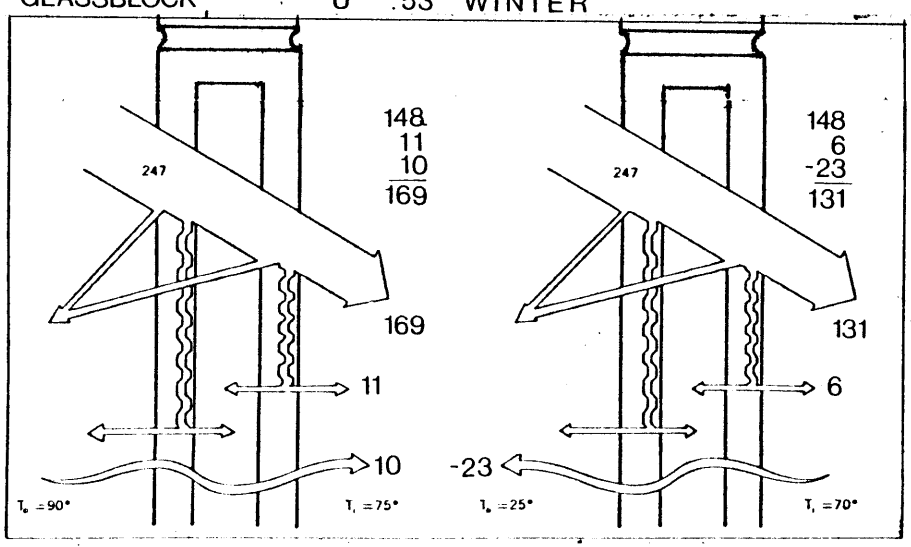
From a design standpoint the arrangement and respective amounts of glazing material will determine its success or failure. Too much tinted glass can cause some gloom effect and the color rendering of greyed glass contrasted with clear glazing can cause color disorientation.

The specialized application of tinted glazings for solar utilization is recognized in conjunction with the solar window wall (following section). Other circumstances though, may warrant its specialized use. In reflective solar gain situations, designed placement and orientation of these surfaces can provide solar heat and natural light to building surfaces and window walls otherwise devoid of direct sunlight.



Carpenter Center, Cambridge, Mass. Le Corbusier.

GLASSBLOCK "U"—.53 WINTER



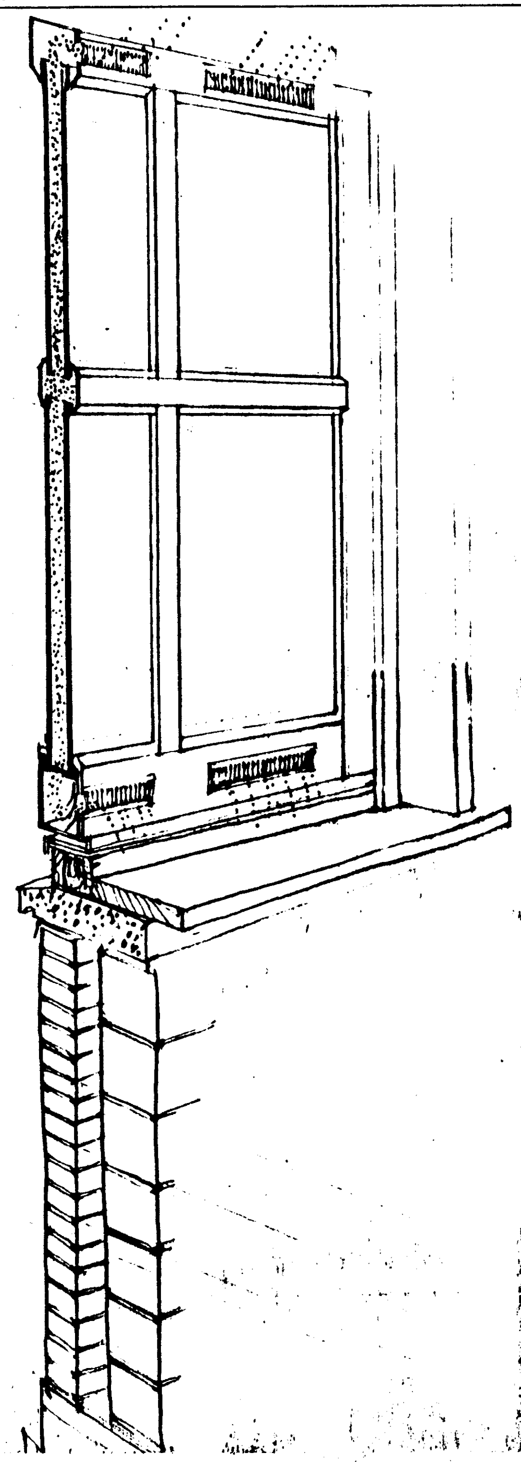

## Glass Block

Glass block is the genuine building material of the window wall. It is available in almost as many varieties as is sheet glass: clear, textured, prismatic.

Glass block is a glazing building material that offers the transparency of glass and the structural strength close to that of masonry. It is fabricated at high temperatures for rigidity and strength and is evacuated and sealed. The conductance value is quite good, about 1/2 that of single pane flat glass. Solar gain is about 1/3 that of single glazing. Accoustically it also performs well as its sound reduction characteristics are equivalent to a 4" concrete wall--an average reduction of 40 decibels.

This material in combination with clear glass has been used extensively in American schools, universities and factory buildings, throughout the late 40's and early 50's. The Architecture Department at M.I.T., whether it be university or factory, boasts this window wall design, the Emerson Room. Here the placement of the glass block is much like Kalwall design; light diffusing material above to reduce sky glare, clear glass below for view and outlook.

Glass block is the masonry version of the individual window pane. While mullions and window boarders act as framing elements and break up the visual field, glass block structures a not so dissimilar framing of the light field. Mortar is the stop which secures the chunks of glass and gives dimension and color, outlining the liquid nature of glass block light. Its beauty lies not only with light and thermal aspects but with the additive nature of the material. The pieces add up to potentially build the interlock between glass light and its opaque boundary.



Solar Window Wall

-- This innovative design incorporates hollow metal mullions and window frame with a double layer of glazing separated by a non-evaluated space.

-- A cross section through the mullion and dual layers of glass show how the window is utilized as a passive solar collector. The exterior layer of glass in this prototype is standard clear glazing and the interior sheet is selected for its diffusing and or thermal-retention properties.

-- This window wall is designed to be self-ventilating with seasonal controls. Adequate shading is assumed, especially, for east and west exposures, during the cooling season. The type of glazing material chosen for the interior layer is based on the given lighting condition desired and the amount of solar protection needed. Frosted or textured surfaces eliminate the spectral component (direct sunlight) from entering the window wall. A portion of the light energy scattered at the surface of the second layer is retained as heat and by natural convection flows between the layers of glass into the hollow window mullions and to the perimeter structure of the window frame.

-- Heat absorbing (retentive) glass intensifies the interstitial heat regime, allowing more heat and less direct light entry into the space.

-- Ideally, the mullions would take on a dark surface treatment on the exterior, absorbing a large fraction of light energy which is carried away as heat. The interior surfaces of the window frame are lightly colored helping to reduce high contrast glare and give an even gradation of light.

-- The window wall structure supports the glazing material and ducts heated air. Both the mullions and window glazing serve as collector surface.

-- It can be anticipated that the mullions and window frame, by breaking up the large sheets of glass will help reduce the heat sink effect. This condition is simply the flow of radiant heat away from the body to a cold surface (window wall) causing chilling.

This heat flow is dependent on a number of factors: delta T (indoor-outdoor temperature); glazing type (construction, single or double); surface area or glazing to volume ratio; and the relative distance to heat sink (glazing). The importance of small framing elements in this regard is crucial. These supports accomplish two things: First, and most obvious, the framing elements decrease the overall surface area of glass and second, the mullions reflect room and body radiant heat energy which aid in the reduction of M.R.T. (M.R.T. 42° f, for double glazed windows, with ($T_i$ = 70°F and $T_o$ = 30°F) -- wind not accounted for.

The overall thermal exchange is dependent upon all of the interacting factors. Thermally, glass is seen as a black body. Heat is absorbed well by black surfaces. This thermal aspect and its thin dimension and good conductance explain why glass is so good at sucking away heat. The relative glazing surface area to mullion area, for a given outside temperature and indoor comfort temperature, will effect this flow. The mullion material and surface properties will also alter the heat exchange. A mullion surface of low absorptivity and emissivity such as foil, reflects a large percentage of heat, striking its surface. An interesting architectural treatment would therefore suggest the incorporation of polished metal with wood supports.

Another important thermal aspect is the thermal bridging of metal mullion construction. Thermal bridging of metal mullions is severe enough to reduce the effectiveness of double glazing to that of single glass. For this reason wood or plastics are more suitable and reduce heat transfer (though hollow wood construction could be prohibitively bulky).

Also back draft dumpers in the form of lightweight flaps should be incorporated to hault reverse thermosiphoning during non-collection hours.

-- The solar window operates in 3 modes. The window wall in the shut position heats inside air whenever sunlight strikes its surface and vents are open to pass ducted air back into the space.

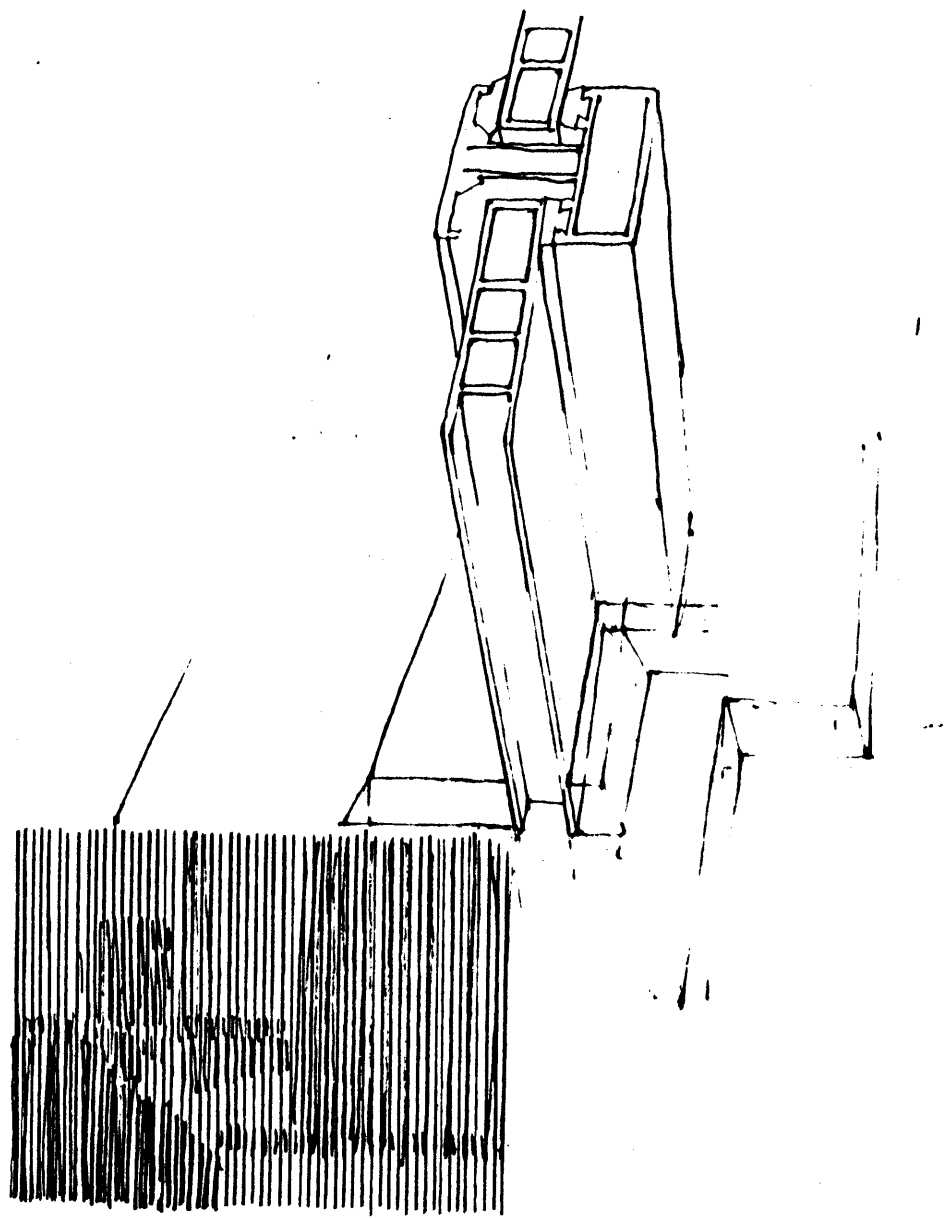
-- The window wall operates in the cooling mode whenever sunlight falls on its surface and the vents are open to the outside.

-- The third mode is neutral. The window is opened to allow for natural ventilation.

-- Other modifications and variations of the solar window are numerous. The introduction of stained glass for the interior is one possibility. This option, combining the functional with the picturesque is tantalizing.

-- Architecturally, the small scale framing elements provide the observer with a framed view which offers a visual transition between the interior of the room and the outside world.[o]

[o] This is the author's original design. Since its conception, numerous variations of the solar window wall idea have been published. Some are documented by Donald Watson, Designing and Building a Solar House, p. 30 and 31.



Core Glass

Core glass is a double skinned hollow core panel fabricated from thermoplastics, acrylite and poly carbonates and not a glass material as the name implies. The panel is a sandwich design to which integral ribs give rigidity in the double skin construction.

The interesting aspect of this glazing material is its innovative application as a window wall collector. In standard practice this semi-transparent material is used in place of double glazed glass. As a window wall collector the hollow core is filled with a liquid. Water can be used but presents fungus problems and has an index of reflection different from that of the core glass. The difference in refractive index causes the core glass to appear translucent. A liquid of higher specific density is used to match refractive indexes and provide transparency.

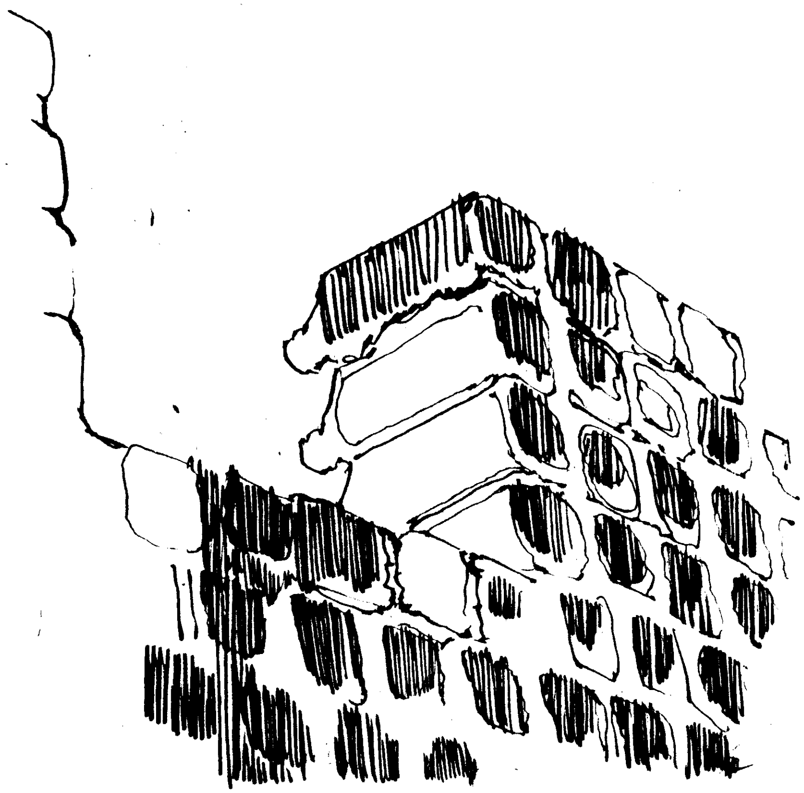
The most important thing about this liquid in regard to its collection potential, interestingly enough, is its color. Core glass is really a colored transparent water wall. Without color very little heat absorption takes place.

This design provides a glowing colored heat source with a clear though tinted exterior view. The proper liquid solution can be chosen to avoid freezing problems, if the structure is left vacant for an extended period of time. In an occupied building interior heat loss through the water wall will offset harsh outdoor temperatures.

Capturing thermal energy at the window wall has the effect of reducing solar heat gain. The selection of color balances the efficiency of the collection medium with the intensity of natural light allowed to enter the space. The darker the tone, the more efficient is the collection medium and the smaller the percentage of natural light transmitted. The collection color can be related to orientation and reduction of heating loads and glare. Such is the case with western facing exposures. Here subtle differences in color can modulate the overall solar impact. The same considerations of the "gloom" effect, however, as that of tinted glazings should be kept in mind.°

°Manufactured by Cyro Industries

As an added note, Frank Miller, a fellow architecture student at M.I.T. has suggested filling core glass with eutechnic salts. This high heat of fusion material filling (phase change) used with a modified core panel (core dimension less than 1/4") prevents phase separation and stores nearly 9 times more heat per volume than water. The core panel provides a non-corrosive, high thermal storage container and translucent window wall.



<u>Recycled Materials</u>

In his book, <u>All Their Own</u>, Jan Wampler comments, "The tops are left on the bottles to provide better insulation." Re-use of either empty or water filled bottles is an ideal window wall material, well suited to solar application. Glass bottles, whether they held embalming fluid or carried the label of a fine imported wine can take on a renewed use as both a building material and heat and light source.

In this very specific case economics become a looming factor. Generally, the undertaker disposes of his containers of uncivilized fluid and the drunkard never remembers where the vessel goes. With some imagination, however, the otherwise useless containers take on a new life, in a different way.

The application of recycled materials to simple shelter and housing is an important reminder that we are not solely dependent on new materials to add to or enlarge the building stock. Furthermore, we can successfully apply new technology to old buildings and old technology to the new. Recycled materials comprise the stockpile of indigenous materials readily available to those people resourceful enough to deploy them.

The bottle wall provides for a colorful composition of stained glass light, supplying better thermal storage than a concrete trombe wall twice its thickness. Some precautions should be taken against freezing and algae, however. This is accomplished simply by not filling the bottles completely and using an additive such as Ethylene glycol. Economics are sufficient reason to take advantage of an empty bottle of Bordeaux, '72, or for that matter Mogen David, '78.

Heat Mirror - Transparent Insulation

Heat mirror represents a major breakthrough in the area of passive solar design. The uniqueness of this radiation selective material lies with its seemingly contradictory nature. It is highly transparent yet provides four times the insulation value of a double glazed window if used in conjunction with two glass lites.

Heat mirror consists of a coating approximately one thousand atoms thick, vacuum deposited upon thin film-like materials, either mylar or teflon. The composite material, plastic film and special coating transmits a large percentage of the sun's energy but prevents heat loss by re-reflecting the thermal energy back into the space. This is accomplished by the material's ability to differentiate between the short wavelengths of incoming solar radiation (0.3 to 2.0 microns) and the long wavelengths (4.0 to 50 microns) of thermal radiant energy, radiated as infrared from interior building surfaces. In this respect the material is radiation selective and can be thought of as a tuned mirror.

Heat mirror is utilized in passive solar design in primarily two ways: One application uses single sided heat mirror, mounted on the inside surfaces of double glazing (refer to diagram 23 ). This application is more appropriate to retrofits because it is easily attached to window wall surfaces. In this case a "U" value of 0.23 is attained and allows for an overall transmission of 52%.

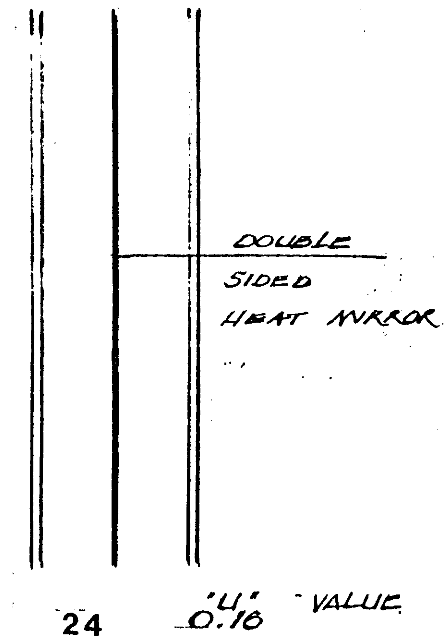
An alternative application utilizes double sided heat mirror. It is suspended between the two layers of glass providing an added dead air space and a "U" value of 0.16, with a transmission value of .60% (refer to Diagram **24**).

Architecturally, the ramifications of heat mirror are extensive. Its application tremendously enlarges a whole range of design issues and opportunities. The crystal palaces of bygone eras may again shimmer in the sun providing more than enough heat to be self sustaining. Greenhouses and membrand structures, "climatic envelopes" will benefit greatly from the use of transparent insulation.

Along with the application of heat mirror to 'glass box architecture,' a means of controlling solar penetration is inevitable. This also implies a segregation of transparent insulation to given exposures or an enlivened architectural treatment providing solar protection. Optimistically, the architecture can open more to the outside environment, allowing a greater flexibility of the indoor-outdoor edge.

In addition, thermal comfort is potentially enhanced. Because heat mirror reflects back body radiant heat, the heat sink effect of large areas of glass is substantially reduced.

One rather impressive example of a passive solar design contrasts a "heat mirrored glass box" with a conventional structure, glazed only on the south wall. A quick calculation of heat loss and gain for both structures (refer to diagrams    ) shows a surprising result. The contribution of diffuse energy on cloudy days to sunless exposures is sufficient to offset the heat loss giving an overall solar benefit. While in the conventional structure, substitution of opaque materials having approximately the same "U" value (standard stud wall construction) suffers on cloudy days and has a net solar loss over a 24 hour period.

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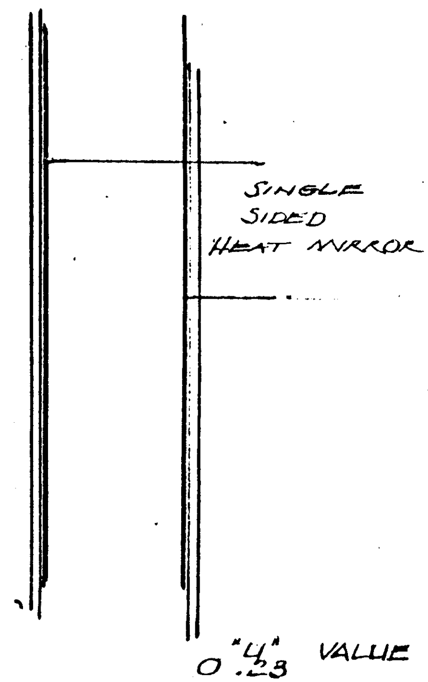



23

## MIT's Solar Five combines high technology with extreme simplicity

**By RICHARD STEPLER**

CAMBRIDGE, MASS.
"You're standing in a solar collector." The man who made that remarkable statement was Timothy Johnson, architect-engineer and head of the research team that designed MIT's Solar Five, latest in a series of solar-heated structures that dates back to 1938.

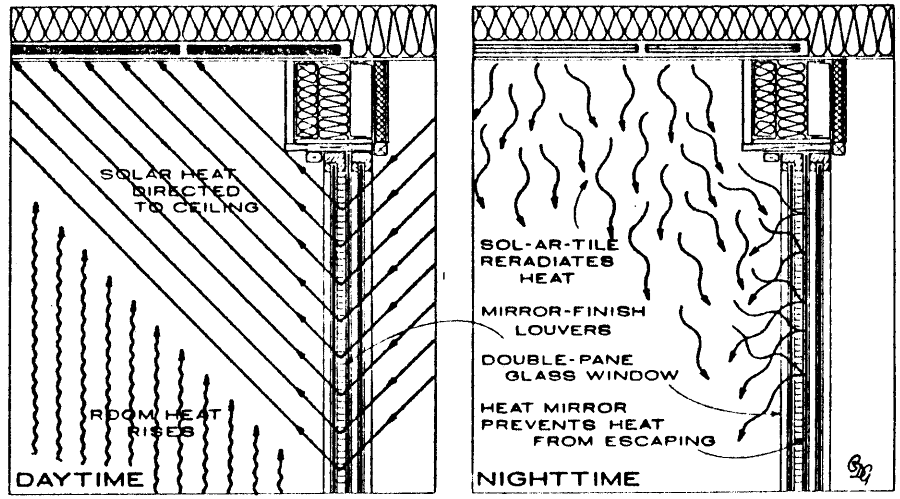
We were in a one-room building on the west end of MIT's campus. Outside, the February sun shone brightly on the remnants of Boston's brutal blizzard of '78. Inside, the room was comfortable—not too warm, not too cold. And the light that flooded through the south-facing windows was diffuse and glare-free.

These desirable characteristics are no accident. They result from a carefully considered approach to the typical problems of direct-gain solar heating. In the past, these problems have mainly been: wide fluctuations in interior temperature—15 to 20 degrees in a 24-hour period is not unusual; uncomfortably warm daytime temperatures—85° F is possible; and glare.

Solar Five uses unique materials to avoid these problems:

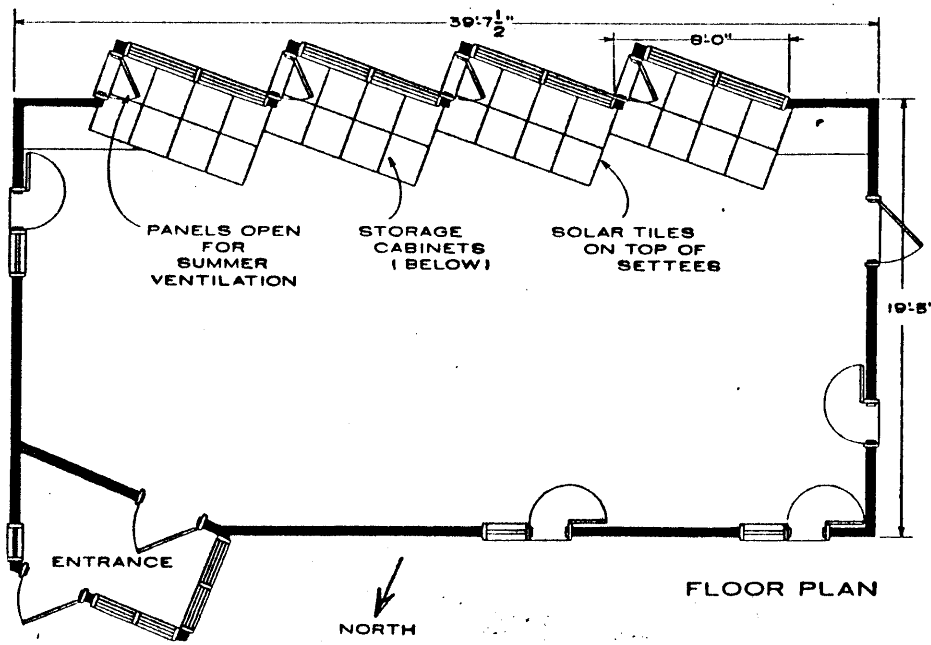
- A ceiling tile that contains a eutectic-salt core.
- An ultra-thin venetian blind with mirror-finish louvers.
- A transparent insulation that lets in sunshine, but blocks the escape of room heat.

### High-technology passive solar heating




**By day, solar radiation** is reflected to ceiling by mirror-finish venetian-blind louvers. Ceiling tiles with chemical cores store heat. At night, tiles slowly reradiate heat as outside temperature drops.

Transparent Heat Mirror in window lets in solar radiation, but prevents room heat from escaping. Floor plan shows airlock entry and additional tiles used as surface of window seats.



DOUBLE SIDED HEAT MIRROR - GLASS BOX

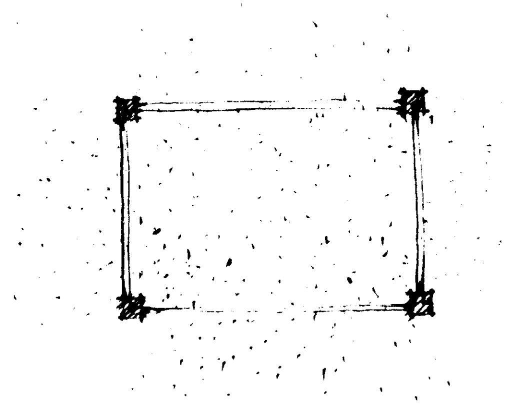
<u>Heat Gain</u>

Assume 1630 $BTU/ft^2/day$ or $203/BTU/ft^2/hr$ x 8 hours of collection

Approximately

10% of total radiation - diffuse energy - $163/BTU/ft^2/day$

60% - transmission - 163 x .6 = 98 $BTU/ft^2/day$



<u>Heat Loss</u> -- "U" value for double sided heat mirror - 0.18

-- $\Delta T = (T_{indoor} - T_{outdoor})$

$= U^{BTU} \cdot A^{ft^2} \cdot \Delta T \cdot 24\ hr$ Boston Average Temperature (winter) 40°

$= 0.16^{BTU} \cdot 1\ ft^2 \quad 25° \cdot 24\ hr$ Indoor Temperature 65°

= 96 $BTU/ft^2/day$

Assume one square foot per side of box - 4 sides

Heat Gain = 98 x 4 = 392 BTU/hr

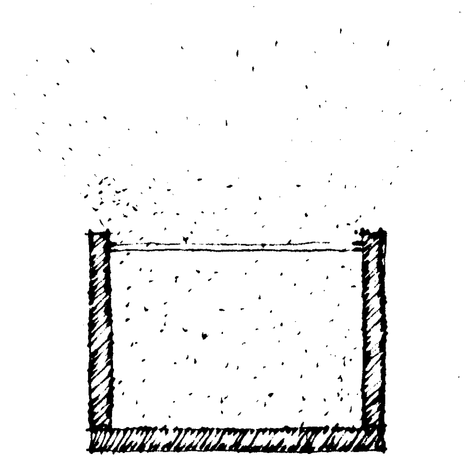
Heat Loss = 96 x 4 = 384 BTU/hr

Net Gain = 8 BTU/hr

DOUBLE SIDED HEAT MIRROR - ONE SIDE

Conventional masonry construction on remaining faces

4" brick - 1 " styrofoam - 8" block - "U" - .147



Heat Gain

$98/BTU/ft^2/day \times 1\ ft^2$

98/BTU/day

Heat Loss

$= U \cdot A \cdot \Delta T \cdot 24\ hr$

$= .147 \cdot 1\ ft^2 \cdot 25° \cdot 24\ hr$

$= 88.2\ BTU/ft^2/day$

Heat Gain = 98 BTU/day

Heat Loss = $88.2\ BTU/ft^2/day \times 3$ sides = 264.6 BTU/day

Net Loss = 264.6 - 98 = 166.6/BTU/day

## Architectural Materials

The potential of architectural finish materials at the building edge to serve as collection surface is well worth exploring. The strength of this idea lies in the utilization of conventional building materials in multi-functional ways. A given material, due to its construction, specific design characteristics, material properties, dimensions, and geometry increases in sophistication as a larger range of functional capabilities are met. In the following examples architectural wall materials passively collect and duct solar heat by utilizing the building wall fabric to its utmost. Relaxing the window wall area requirements, e.g. the reduction of large expanses of south facing glass, eliminates a number of symptomatic problems inherent to passive design. The building edge helps mitigate seasonal impact by capturing solar heat at the edge; providing an added air space (insulation) in non-collection hours and a buffer in extreme cold conditions. The importance of shading should be recognized though, as ducting to the outside is essential for cooling purposes in summer.

The Thermosiphon wall along with other solar architectural collection materials, e.g., corrogated siding, additional glazing layers, represent in part the solar motif of passive solar design. These adaptations of the weather wall are clearly an outgrowth of an attitude which attempts to synthesize the organization and layering of building materials with natural energy flow. Their invention exemplifies the emergence of a vocabulary of materials which present a new way of thinking about the weatheredge.

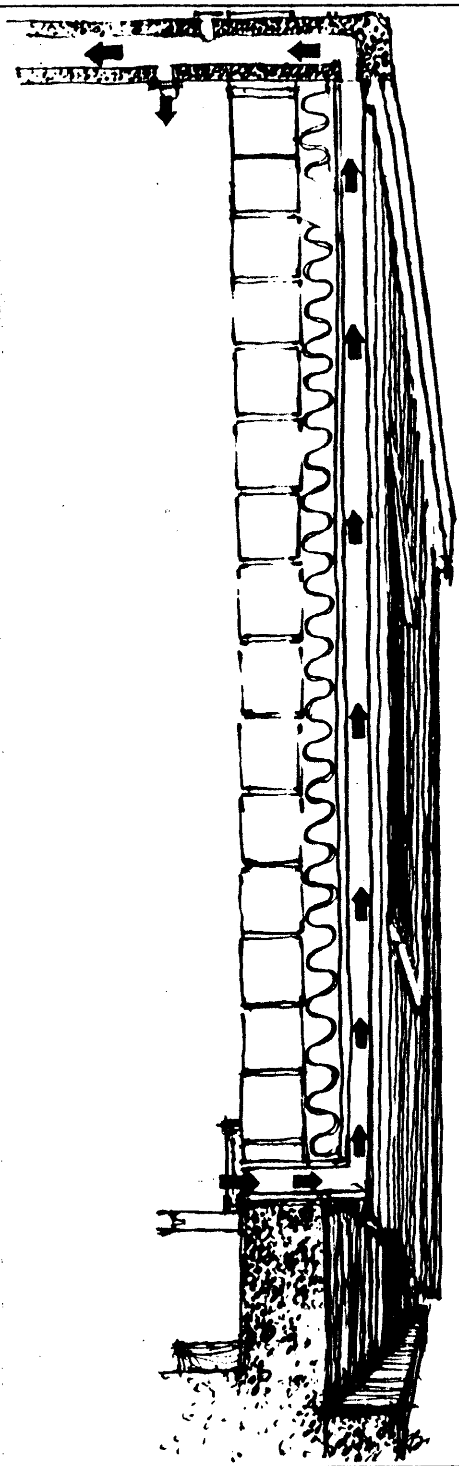
"All major scientific advancements are made by a change in notation."

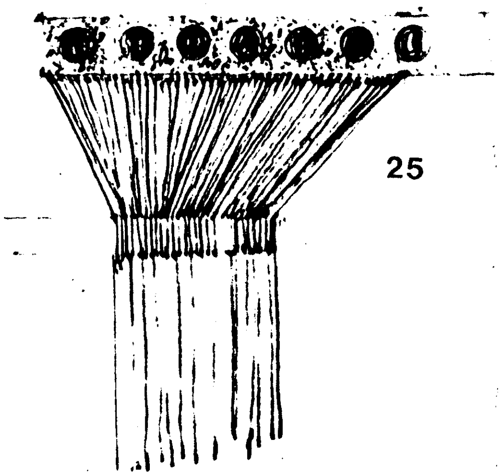
In the realm of passive solar design, new potentials, uses and applications of materials comprising the building fabric are accomplished through the re-structuring and organization of existing and emerging materials. The organization of materials is crucial not only to its functional performance but to human intervention as well. The solar motif becomes much more than siding treatment or wallpaper by becoming an active enlivened element which invites human involvement and control.

The re-organization of materials at the weather edge generates this self-sustaining activity. The activity is fueled by naturally regenerative processes and is regulated with a minimum of human effort. Furthermore, these natural processes become economically significant when a reasonably dependable source of energy is provided. These first generation passive solar building materials make up a partial list. Many more could be identified, each contributing in varying degrees to the thermal aspects of the building fabric and each assemblage displaying a varied range of architectural applications.

These building materials are a part of the first wave. They have set the ground work for a second wave of solar related building materials, second generation passive materials. These new materials developed largely here at M.I.T. (Timothy Johnson) and in conjunction with Sun Tek Corporation, California

(Sean Wellesley-Miller and Day Charoudi), are meant to augment first generation materials -- not replace them. These high tech materials, which include transparent insulation (heat mirror), the solar modulator and thermo-crete or solar tiles, applied to natural-passive systems make up a sophisticated science.





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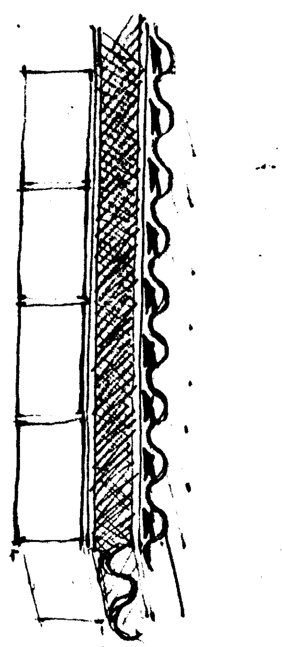
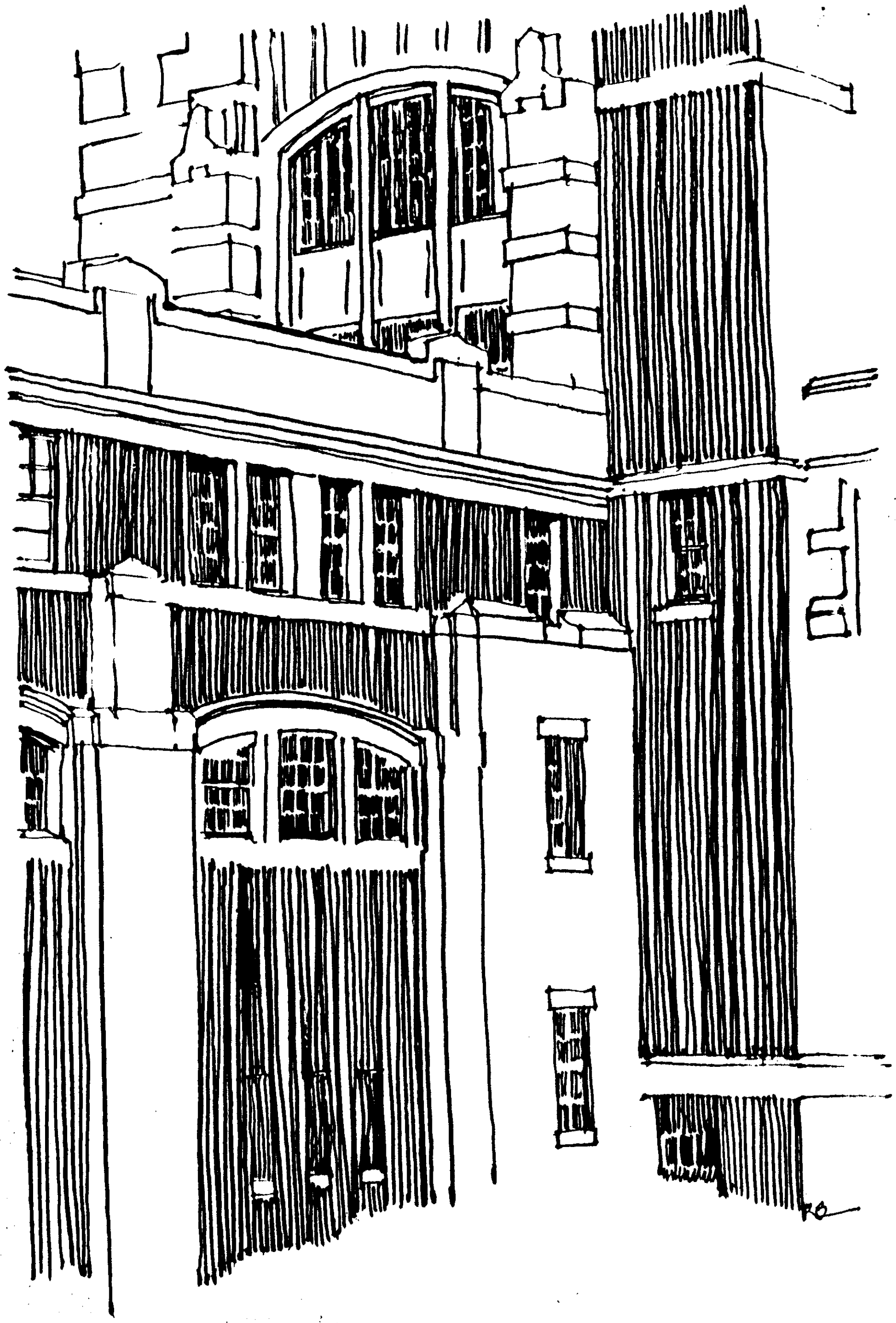


Corrugated Siding

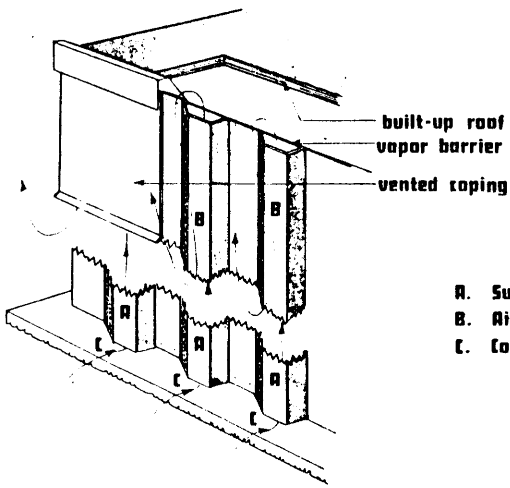
An excellent example of an exterior wall surface material which has potential to perform as a collector is corrogated siding. With a minimum amount of modification, natural convection currents can carry warm air heated by the darkly colored siding into wall ducts for space heating. This idea is actually a simplified version and predecessor of the thermo-siphon wall (following section).

This material's structural stability, a result of its tesselated (wiggly) section, provides the built-in ducting channels. Some measures must be taken to stop reverse thermal siphoning. A similar solution applied to the solar window wall using a lightweight diaphram should be adequate. Some means of ducting heated air further into living spaces should be considered.



Hollow core concrete planks may be ideally suited for this application (Spancrete) (figure 25 ). The synthesis of these two designs demonstrates clearly the synergistic possibilities of building materials. In this case what remains after streamlining the structural member becomes the primary means of thermal transport.

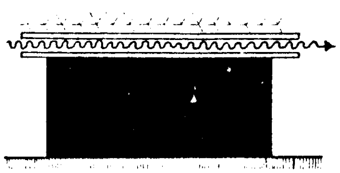
This is clearly not an original principle. In nature, for example, the hollow bone structure of the vulture's wing eliminates excess weight, consequently lightening the frame, a necessary factor for the special gift of soaring. The hollowed out core further provides the passages for fluid nutrients. In a similar way leaf veins carry plant nutrients while simultaneously giving structural stability to the leaf form, stem and branches. The plant




When solid walls are preferred, the diagram at left illustrates a method of using the sun's heat for cooling.

A. Sun's heat warms air in the vertical flutes.
B. Air rises in flutes and escapes at vented coping.
C. Cooler air is drawn in at bottom

AIR-COOLED WALLS



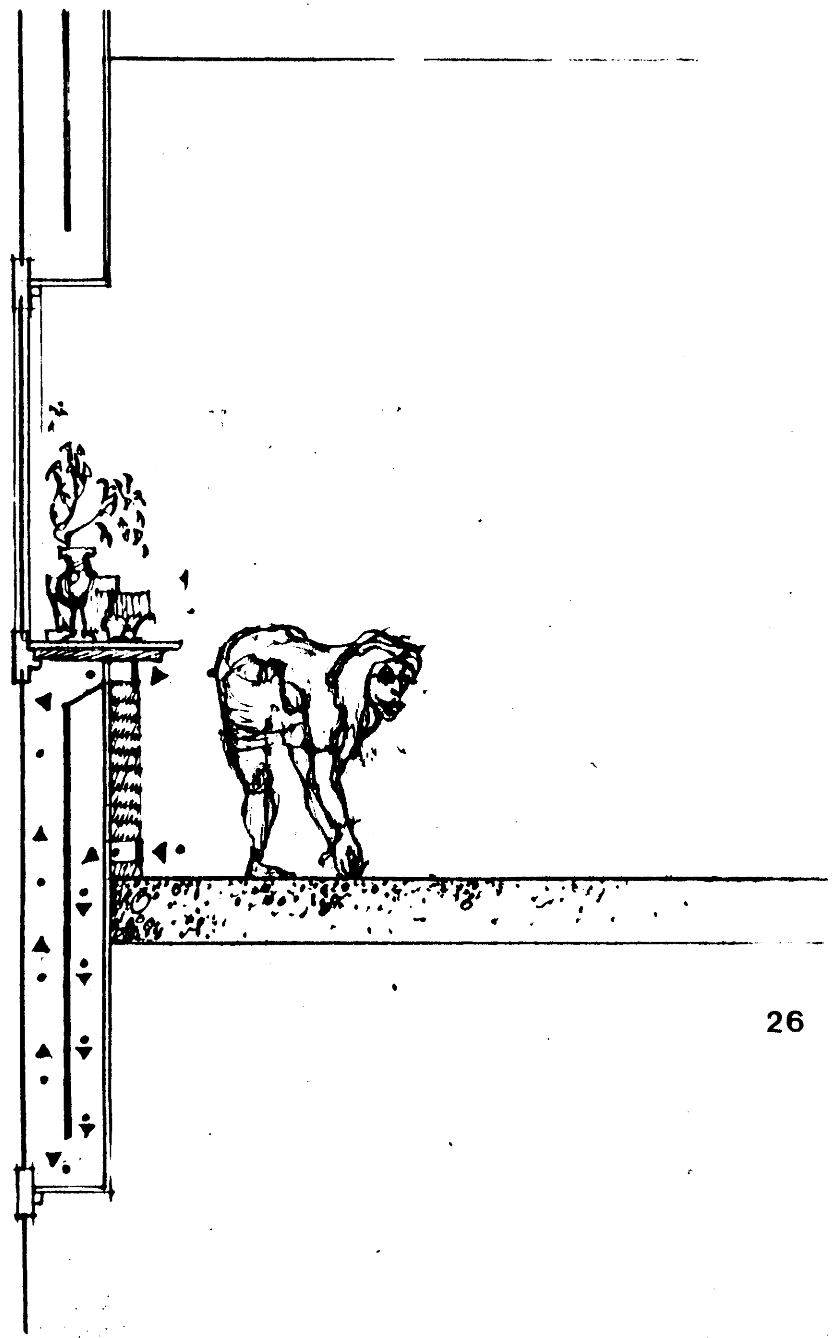
Double roof cools structure by reducing radiation and by allowing cool air flow over ceiling.

°

is the ultimate example of an integrated system. The entire food chain and atmospheric symbiotic relationships are dependent upon the existence of the plant species on earth. It is a delightful reminder to catch a whiff of the flowers' perfume and realize that this scent floats on swirls of life giving oxygen. There is no living thing we know of outside the plant kingdom, capable of synthesizing light, water and mineral nutrient into a self sustaining life form. The act of photosynthesis is a miraculous transformation of light and nutrients into matter.

The ultimate metaphor for the solar wall is the plant leaf. The leaf itself is the solar collector and its structure is the trunk lines.

°<u>Ife Campus Plan</u>. University of Ife, Physical Development Plan, Ife, Nigeria, 1969



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Thermosiphon Air Collector

The beauty of the thermosiphon collector is its straightforward design, simple operation and high efficiency.

The natural buoyancy of heated air powers the gravity convection cycle. In turn this pulls cool air in, near the bottom of the thermosiphon loop and pushes the air up past the collector surface and out the top into the space. (Refer to diagram **26**.) The convection process circulates warm air into the space as long as there is enough sunlight to elevate the temperature of the blackened absorber plate above the room air temperature.

A few important points about this thermosiphoning collector:

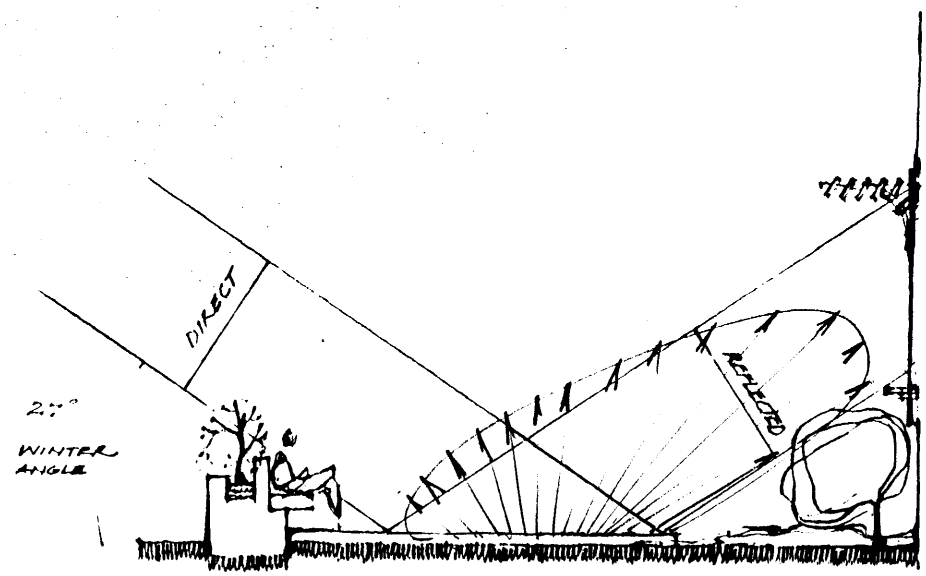
-- This wall collector design lowered partially below the floor level halts reverse thermal siphoning by pooling cool air below the floor level. The denser cool air fills the bottom portion of the collector and stabilizes gravity convection.

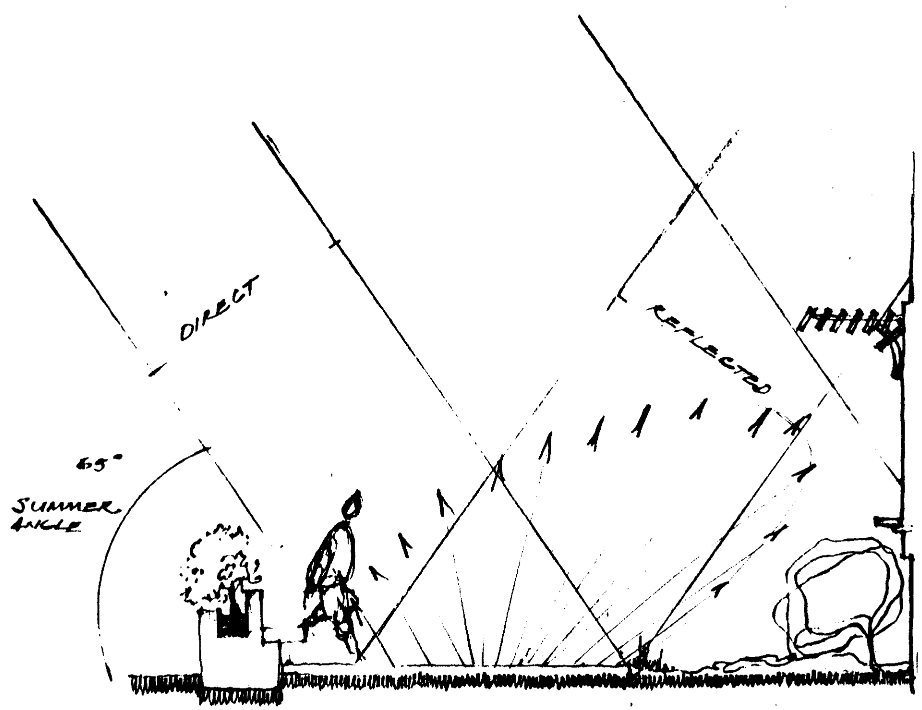
-- The placement of the absorber plate divides the wall collector into separate volumes, providing a double dead air space. This set-up gives added insulation value over the window wall area, the collector replaces.

This type of collector design has high efficiencies for two basic reasons: low operating temperatures and heated air is dumped directly into the space doing away with ducting and heat exchangers. This indirect gain system, however, makes no provision for storage of the solar heat other than the thermal mass of the building. To improve the performance of the wall collector a number of measures can be applied to the basic scheme. These additions include insulation, improved absorber surfaces (i.e. selective surfaces, increased surface area) thermal mass, dampers and fans to further regulate the flow of air.

The section on thermosiphoning collectors is recommended in Bruce Anderson's Solar Home Book which goes into wall and window collectors in detail and also includes a discussion on louver type (venetian blind) collectors.

A final note points out an important secondary benefit of the wall collector. That is the collector depth gives a projected dimension to the wall and provides for a use dimension and work surface.




## Solar Collection -- The Wall and Built Ground

Sol-air temperature, introduced in the section on thermal design tools, is an important factor affecting solar collection at the building edge. The selection and placement of ground form materials can beneficially influence the micro-thermal climate at the weather edge via the sol-air temperature. Diagrammed here is an important sun-building geometry relationship which can specify in a generalized way the placement and color choice of ground form materials.

Apart from the intensity of incident radiation which is controlled by latitude, elevation of the sun, clearness factor, and slope of the land, surface temperature depends on the water content (of soils), the thermal conductivity of the underlying soil (and paving material), its albedo as well as on the movement of air over the surface.

The point to be considered is the influence (the type of soil planting and built ground material) exerted on the heat balance of the ground, and hence on that of the adjacent air layer. Equally important the albedos of various ground form materials differ considerably depending upon texture and color. For example, a granite path or gravel path differs from black top or a dark mulchy soil. There is less reflected heat and hotter air over dark surfaces (lower albedo or reflectivity) than light surfaces. However, the lower reflectivity implies higher absorption and retention of heat for delayed reradiation.

The temperature near the building weather edge surface is the result of a complex set of interactions in which albedo (surface color) and ground surface-heat-balance dominate. Geiger, in Climate Near the Ground, is an excellent resource for further reading (chapters 2 and 3).

# SECTION 4

Pliny and Solinus, had admitted into their geographical accounts legends of strange tribes of monstrous men, strangely different from normal humanity. Among these may be mentioned the Sciapodes, or men whose feet were so large that when it was hot they could rest on their backs and lie in the shade.

## Shading Devices

Shading devices or "sun breakers", as the Olgyay brothers referred to them, make up the palette of built configurations which selectively assure solar protection at the weatheredge. The selective nature of the shading mechanism implies protection from the intense rays of the summer sun and passage of beneficial rays of the winter sun.

Corbusier began in the 1920's to develop a rational and architectural vocabulary (Brise-Soleil) which responded to the impacts of the sun and is expressed most accurately in his own words.

> "...Today as we possess steel and reinforced concrete...nothing these days prevents us from opening toward the solar rays. not a mere fraction, but a 100 percent of a facade...

This freedom gave enormous possibilities for fantasy--but it is evident that it posed new time problems at the same time."

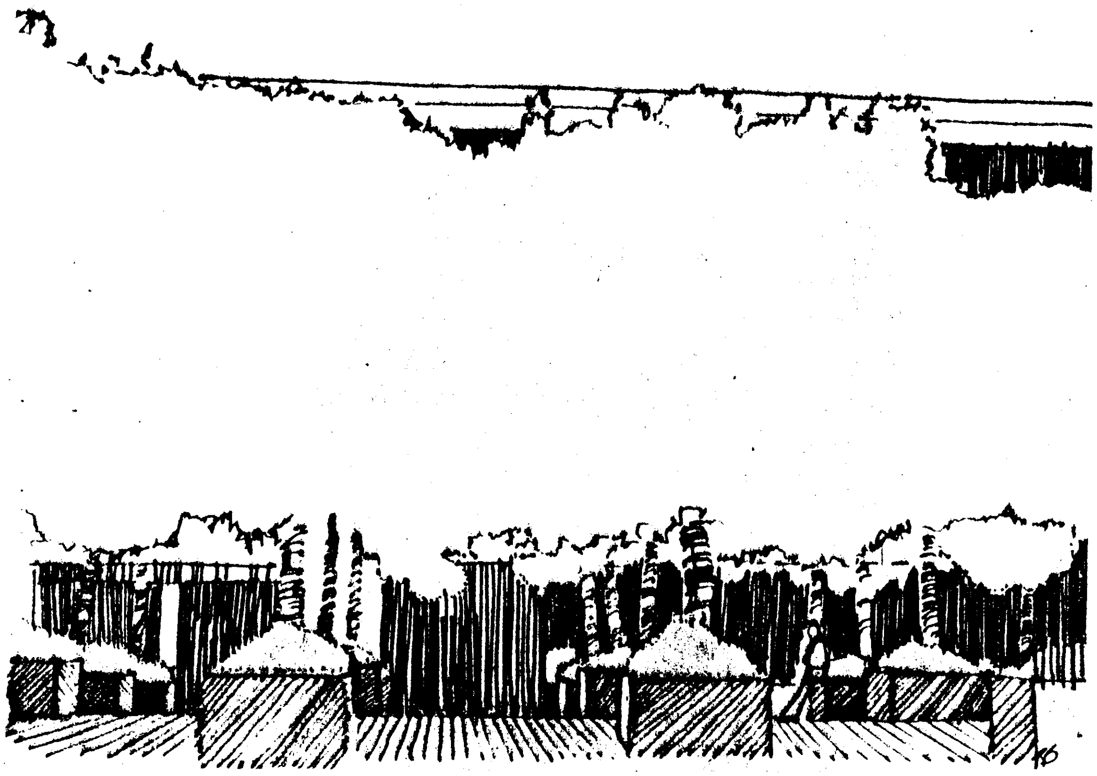
"The play of the seasons brings its adverse and beneficial effects--at the winter solstice the sun lies low at the horizon and its rays are welcome in the interiors of our habitation where they kindle our moral and physical self. The spring and fall mid-seasons greatly gratify themselves by offering sunlight, which is sweet to all creatures. During the dog-days of the summer solstice, with its intolerable temperatures, the sun, our customary friend; the need in those hours for shade is imperative.

"It becomes necessary to stop up the windows, to 'diaphragm' the glass pane. What aids are available to achieve this purpose? There may be superimposed curtain filters of loose and tight texture, shutters of various nature applied inside or outside, and screens of new design which can be developed to work in mutual conjunction with the glass pane."°

Olgyay Brothers, Solar Con- and Shading Devices.

The shading mechanism is on one hand an element of the facade, an architectural element which provides a screen between humankind and nature. It is an opportunity to elaborate the building surface and give it a dimension which potentially defines a territory for human use. The individual elements are proportioned to the human scale; in aggregate form the elements add to spatial composition and give visual ties of rhythm, light, color and texture.

On the other hand, the shading mechanism can extract itself from the building surface and expand the weather edge. The detached frameworks can provide for seasonal use and offer a structure (posts and the like) for the addition of benches, planters, railings, partial vertical screens to protect against sun and wind. It is this extended edge that begins to build the interlock between the landscape and the building. A negative aspect of shading devices on cloudy days is an effect which causes a reduction of natural lighting into the interior.



Built Tree Grove

This built grove of trees significantly alters the ground level micro-climate. The stand of trees provides for very effective solar protection at the ground level floor and considerable shading of the entry court. The trees alter the air flow around the buildings, filter the air of particulates by absorption, oxgeneration and dilution, and contribute significant moisture to the air (in summer roughly 20 gallons a day per tree).

The tree canopy alters the local micro-climate in a number of ways:

- shading
- insulation
- heat sink

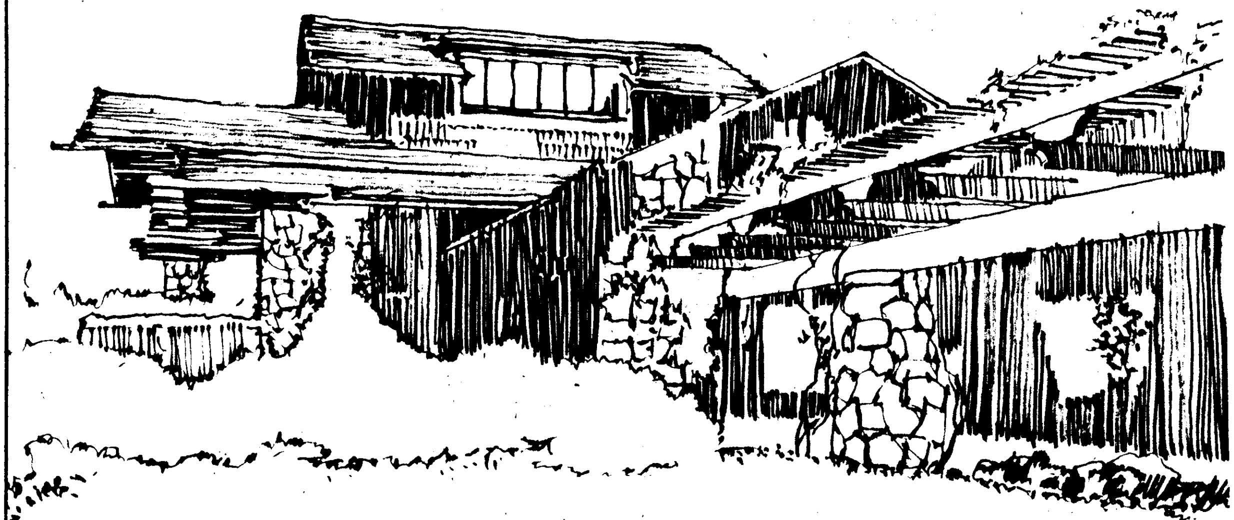
"besides providing the shading to cool the ground below, tree canopies act as an insulation buffer between the ground and sky; inside the building and outside. Ground temperature can be up to 25° cooler than the temperature at the top of the tree canopy. However, temperatures are nearly uniform from tree canopy to tree base, as in good insulation design. In addition, the moisture content in vegetation increases the enthalphy considerably. Water retains heat much longer than air on dry land, keeping the surrounding environment cooler on hot days, later releasing its heat to the colder night air. Overall, vegetation slows temperature exchange, acting as a natural insulator.

By absorbing and emitting radiation by evaporating moisture -- leaves, twigs and branches play a significant part in the exchange of heat with the surrounding air. The percentage of reflected radiation falling upon the canopy is expressed by the albedo "R". The portion of sunlight which passes through the leaf cover is expressed as "D" the penetrability coefficient. The remainder "A" is the percentage absorbed. "R" lies between 5 and 30% and exceptionally may rise to 60% on the lighter surfaces of variegated leaves. The amount of radiation which penetrates, varies from 10 - 15%, giving the absorption value a higher percentage 50 to 60% most of the time.°

According to Prof. A.F. Bush, professor of engineering at the department of engineering at U.C.L.A., an inhabitant of town centers could require 30-40 sq. ft. greenery surface (trees, shrubs, to cover oxygen requirements on an hourly basis).

°Vivian Loftness, <u>Natural Forces and the Craft of Building</u>.

Due to the mild climate of Carmel the trees hold their leaves nearly all year round. In the urban landscape a grove of densely packed trees of this size is unusual. The trees are natural frameworks which serve as an extension of the building. Hidden from view are trees similarly placed on the upper levels. The stand extends from the upper reference level all the way to the street curb, providing a canopy for pedestrian traffic as well. The density of trees is such that it becomes a definable territory, which not only tempers the environment near the building's weather edge but the micro climate of the entry court as well.



McCoy, Esther, Five California Architects.

## Trellis

The trellis defines a unique transitional zone. As an extension of the building, it makes up a special edge condition which incorporates a structural framework and vegetation. The unique quality of the trellis is the overlap of built and plant form. Together they expand the boundaries of the weather edge, creating a tempered thermal zone.

All year round the lattice of wood and natural framework, of bare vines and branches, act as a filtering mechanism controlling the play of light and shadow. In all seasons the trellis screens the penetration of direct sunlight yet allows natural light (indirect) to filter through.

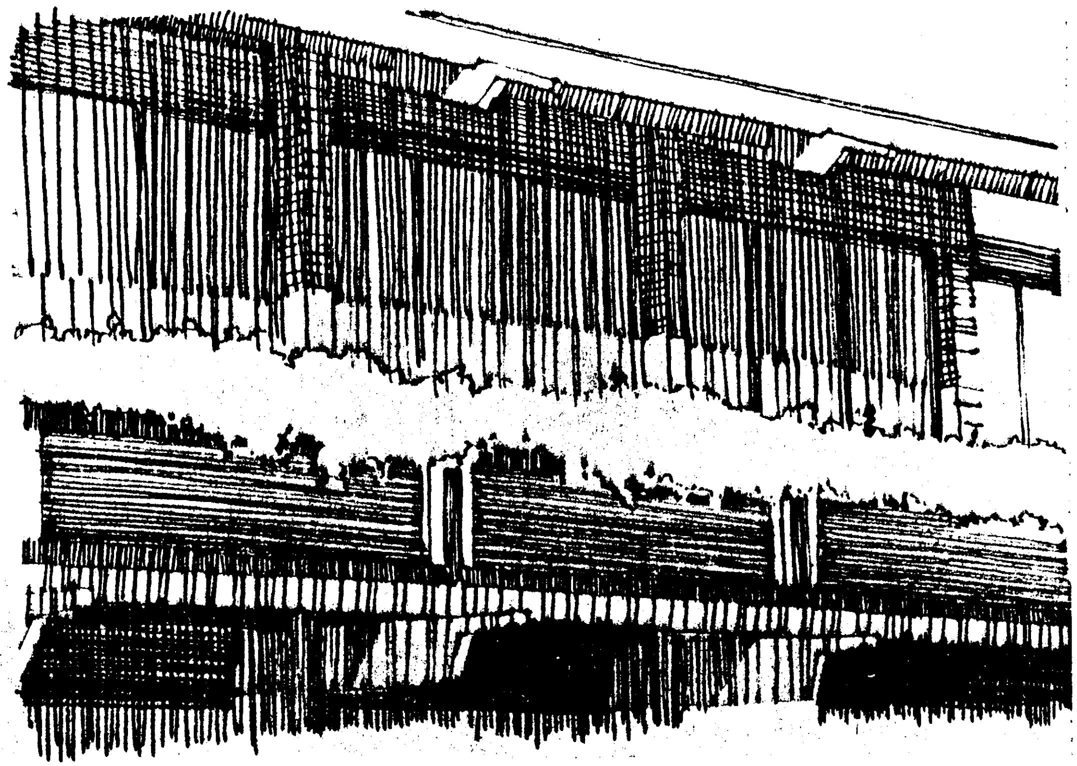
As the planted trellis moves through its yearly growth cycles it follows the climatic seasons, affording a range of shading conditions. One negative characteristic of most shading devices is that it follows the seasons of the sun rather than the climatic seasons. The planted trellis, however, responds to the climatic seasons. For example, at Spring equinox (March 21) the vines of wisteria are still bare, allowing for the penetration of direct sunlight to the building surfaces. At the Fall equinox (September 21), however, the vines are leafy and full from the summer and offer adequate shading. To clarify this point, "the middle of the summer for the sun is June 21, but the hottest times occur from the end of July to the middle of August. A fixed overhang designed for optimal shading on August 10 causes the same shading on May 1. The overhang designed for optimal shading on September 21, when the weather is still somewhat warm and solar heat gain is unwelcome, causes the same shading situation on March 21, when the weather is cooler and solar heat gain is most welcome."°

Exterior shading devices, the trellis being one example, are more efficient at controlling overheating than interior shading devices, and can be designed to serve as both a canopy and vertical screen. The seasonal character of the planted trellis provides a buffer zone which allows the building fabric and landscape to interlock/intertwine and together are expressive of the microclimatic region.

Furthermore, the trellis and planting, because of their relatively lightweight nature, can be incorporated with the balcony, on multi-family

°Bruce Anderson, Solar Home Book, p. 88.

housing. In addition, the planted trellis provides the visual and operational link between the groundscape and the roof garden.



Plant Boxes

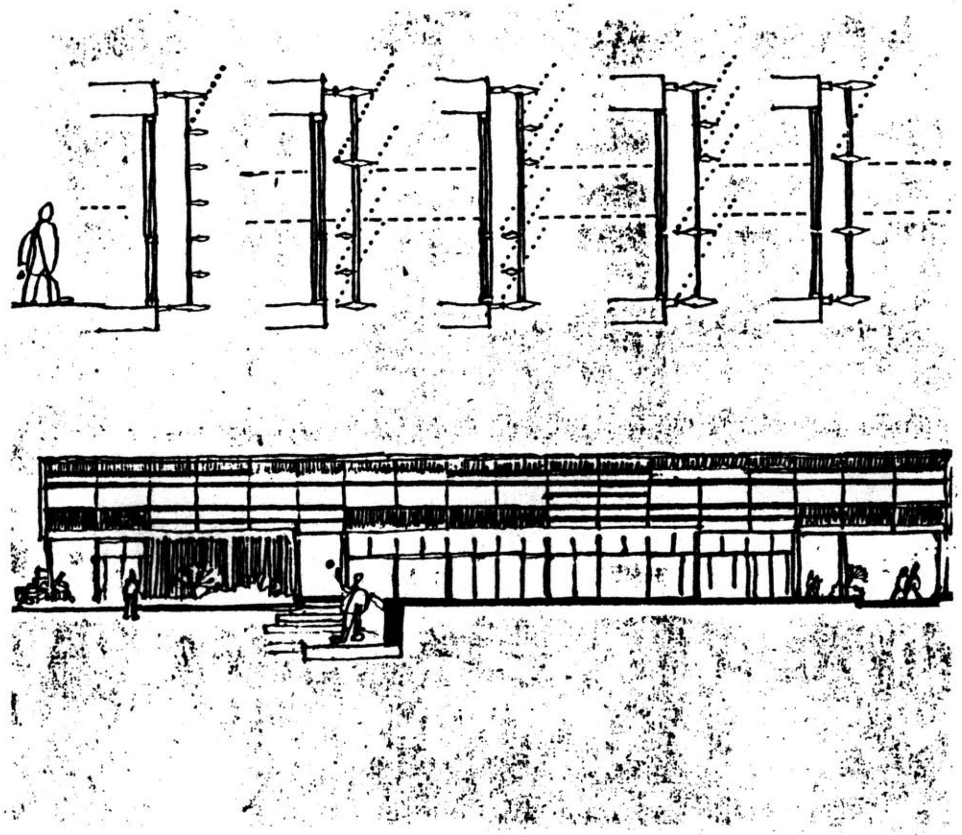
The short shrub jasmine plants provide a multi-faceted canopy of leaves; elevated one story up from ground level. The glossy leaves break up the harsh sunlight and reflect a diffuse glowing light into the interior spaces. It is not unreasonable to extract a small piece of the landscape and place it where it can provide a special function like this.

These enlarged window boxes and flowering plants provide not only the reflected light above, but shaded light below as well. In this case, the primary purpose of the planter boxes was not to provide shade. However, the plant containers have sufficient depth to completely screen the windows below from the summer sun.

The window box plants provide a

pleasing view transition against the backdrop of the cityscape. And what's more, this variety of hearty outdoor jasmine provides the most provocative air freshener on the block.

The Olkowski's directors of research and education within the Farallones Institute oversee both a rural center and what they call the integral urban house, in Berkeley, California. They avidly support the plant box notion and would like to see the concept enlarged to include roof top gardens. They recommend, however, that vegetables replace ornamental plants. In China nearly every house with a small plot of land grows their own food. The vegetable plot replaces the lawn.



Shading characteristics are uniform, namely, complete shading up to a 60° altitude angle.

Louver Shading Device - Olgyay Brothers

Shading devices are well documented and covered extensively in a number of good resources. One highly recommended reference is Solar Control and Shading Devices by Aladar and Victory Olgyay, from which the following example is taken.

This design example is unlike most shading devices in that it makes special allowance for view, takes on a range of dimensions and allows for some design flexibility and diversity of shading seen in elevation.

Different arrangements of the basic shading device are used on the south elevation of a proposed design for a factory for Universal Corporation. The vertical distribution of shading devices are varied to achieve a composition of discontinuous yet pleasing lines.

Structure

Architectural siding materials: the thermal siphon panel and added glazing layers act primarily as infill and are especially designed for solar collection. On the other hand, the structural framework of a building can be used for not only supporting secondary structure and infill but to provide solar protection as well. The primary structure is carried out beyond the closure (weather skin) of the building to provide shading of the window wall. The verticality of the primary structural system exposed on the exterior is most appropriate for east and west exposures. In practice vertical shading is used for these exposures to block the lower angle of the sun in the early morning and late evening.

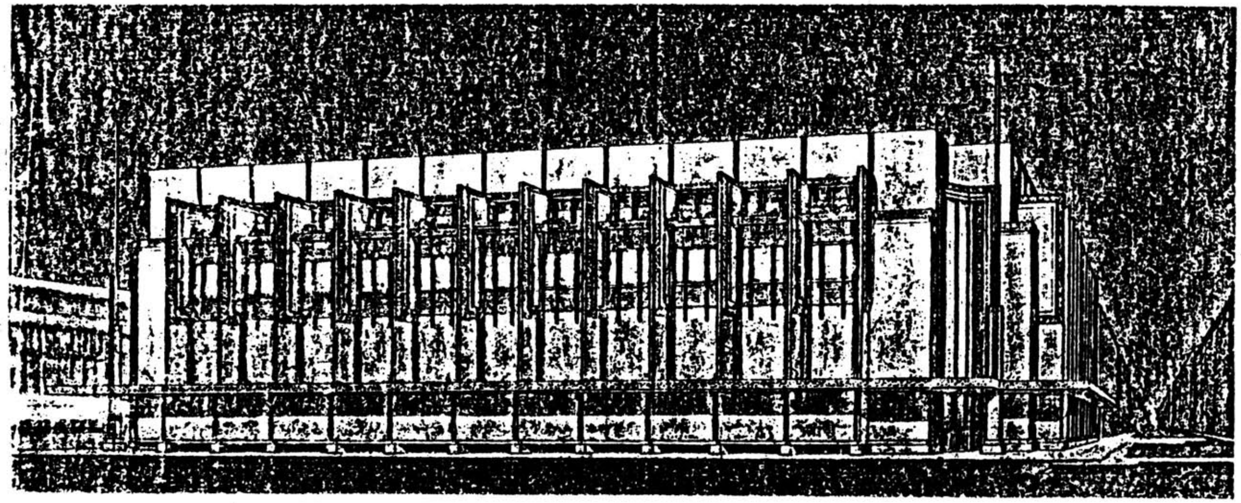
The usefulness of the structural supports is further exacerbated if they also serve as air pleniums for heat transport during solar collection and ventilation channels for cooling throughout overheating hours. Taking this one step further; the shading devices which serve primarily as solar protection (though they could also be use areas, balconies, etc.) might also perform an added function acting in solar collection.

In this regard the shading device can be easily designed as a hybrid collector. With little alteration it performs as a thermosiphon air collector. For example, the sunlit surfaces are simply darkened and glazed; heated air is ducted into the structure and dumped into the space or ventilated to the outside. High temperatures of the collection surfaces during overheating periods (summer), necessitates the use of the ventilation mode. The collector is utilized for cooling purposes, in this case by priming the thermal chimney effect. The air drawn from the space through the structure is accelerated by the escape of heated air from the collector.

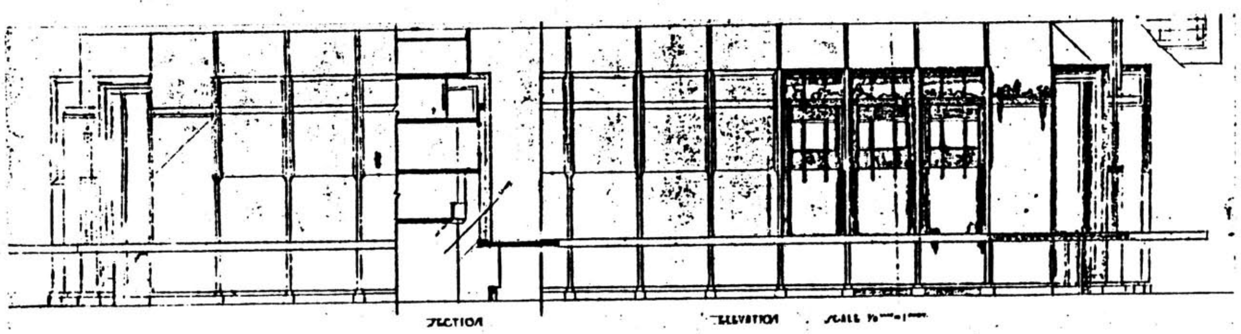
The synergetic nature of the structure comes alive as a wider range of functional capabilities are met. The primary structure provides vertical shading predominantly on the east and west exposures while secondary structure, (shading devices, balcony, roofs) serve for both solar protection and collection. The structure, at the same time resolves the gravitational forces and facilitates thermal transport. Architecturally the structure is expressed as an extension of the building and gives added dimension to the texture of the exterior building fabric. As mentioned before the verticality of the primary structure works well on the east and west exposures. Somewhere in between the vertical and horizontal lines, expressive of the given orientations, merge and define a built boundary condition.

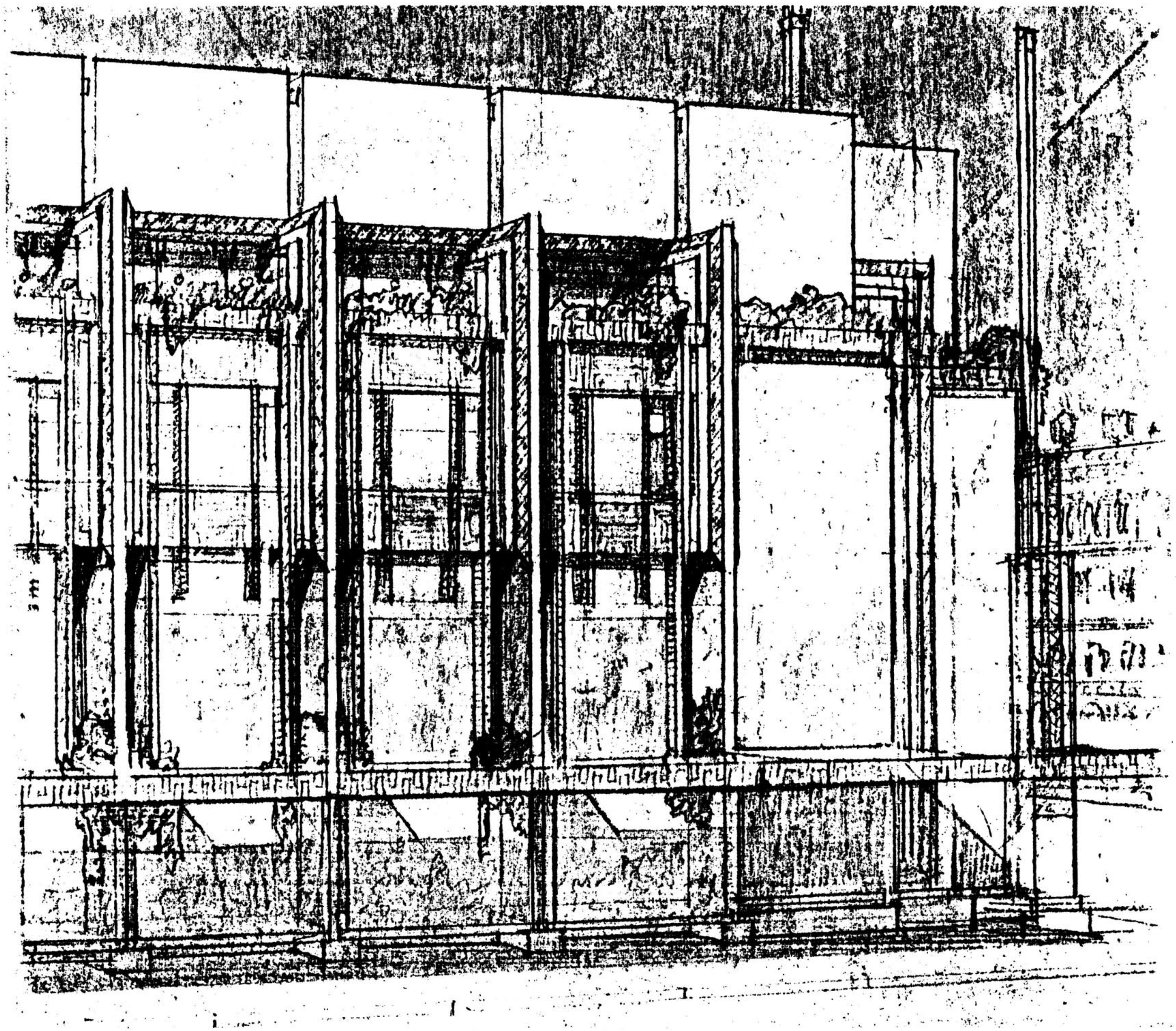
The following examples represent only a few of the many works by Frank Lloyd Wright which have utilized the structure for solar protection.°

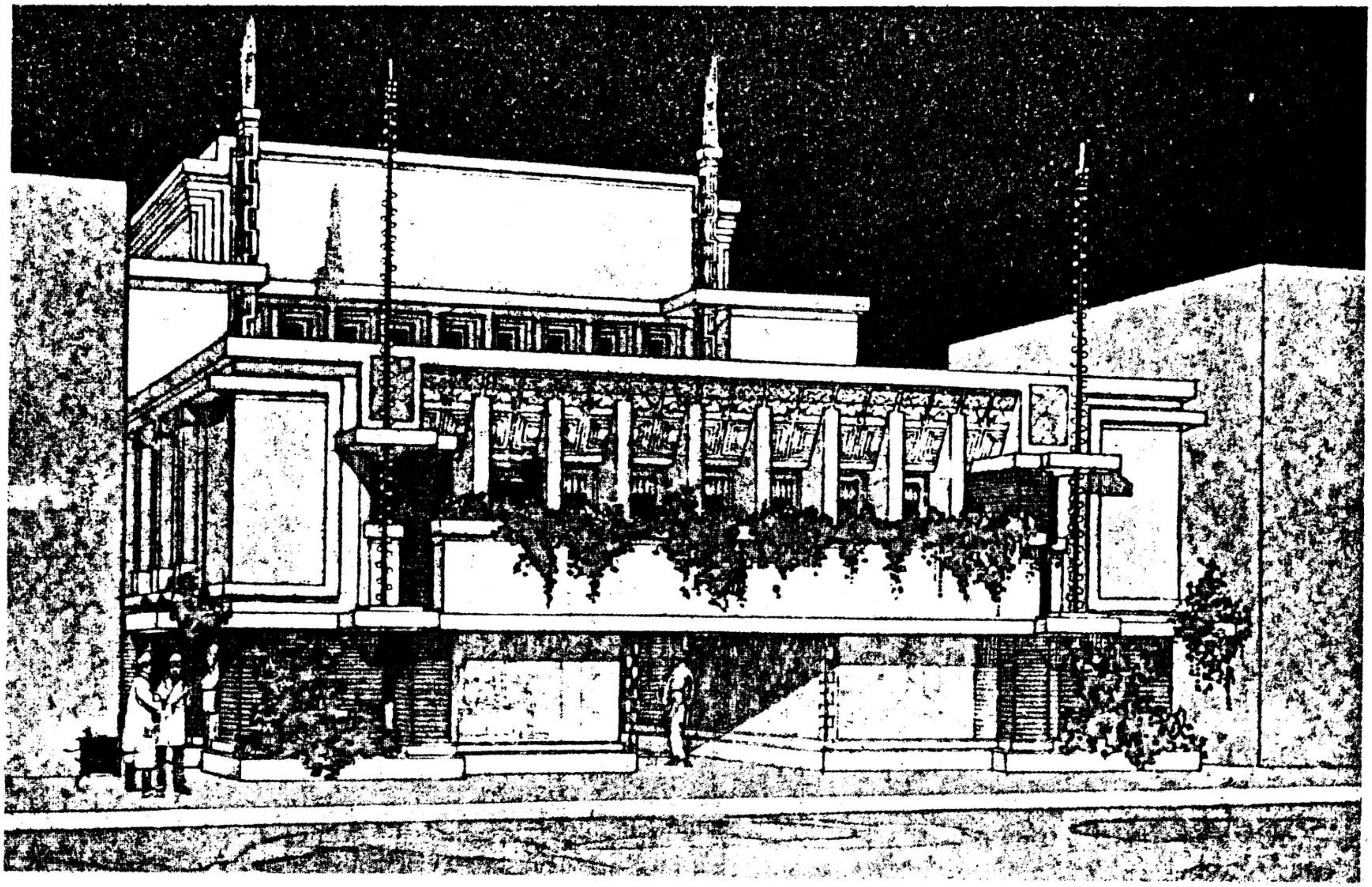
°Resource: The Work of Frank Lloyd Wright The Wendingen Edition.

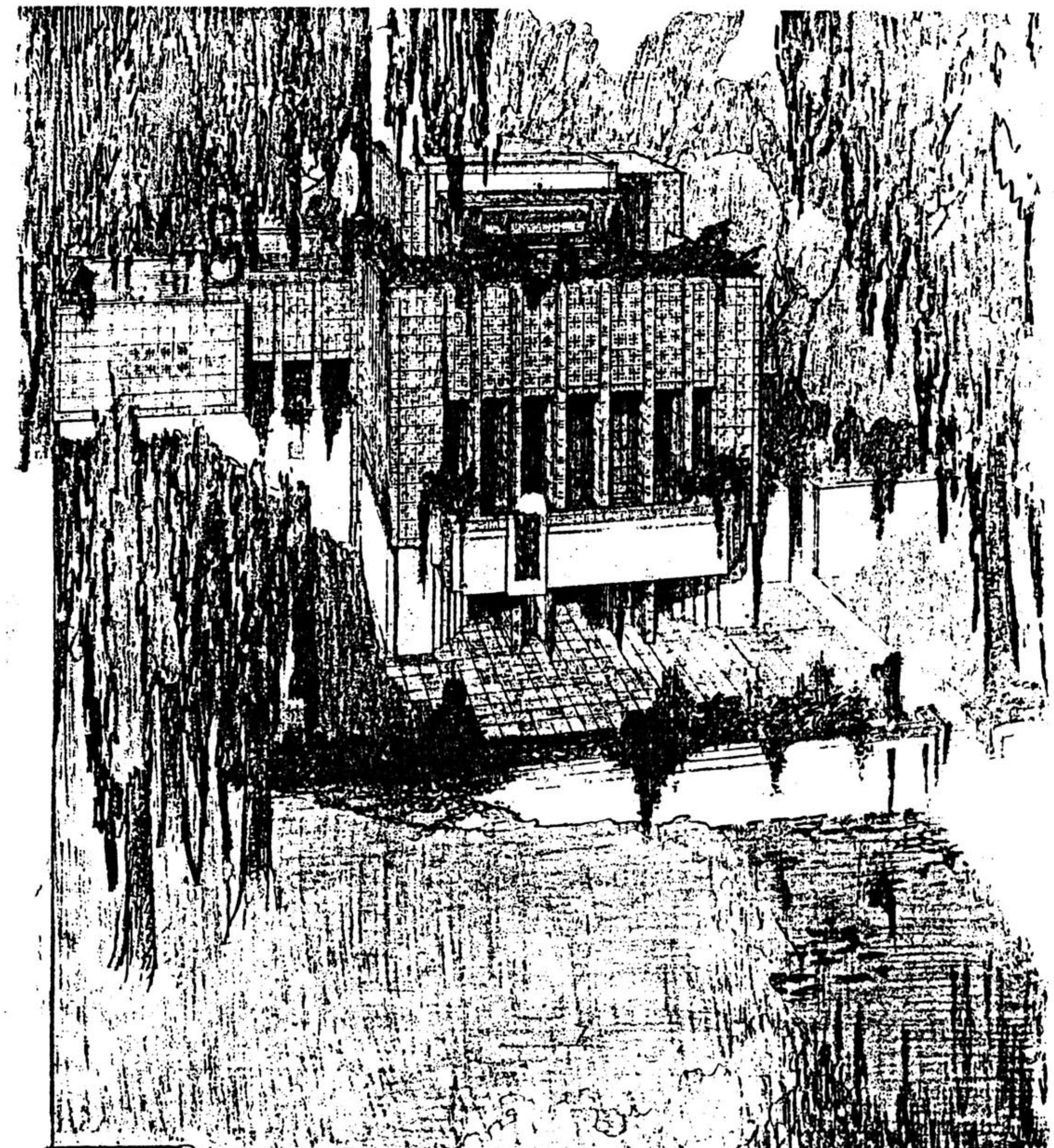



FLOOR PLAN
TOP FLOOR

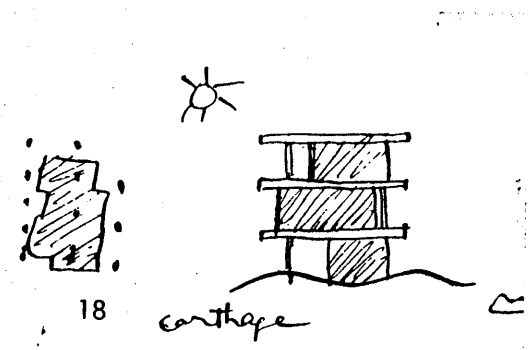

SECTION
ELEVATION







DWELLING ... AT ... PASADENA ... CALIFORNIA .... FOR
MRS ... GEORGE ... MADISON ... MILLARD ...
F ..... L ..... WRIGHT ..... ARCHITECT ...... LOS ANGELES ...




Corbusier.

Hans Jurgen Hansen, Architecture in Wood

## Set Back - Arcade

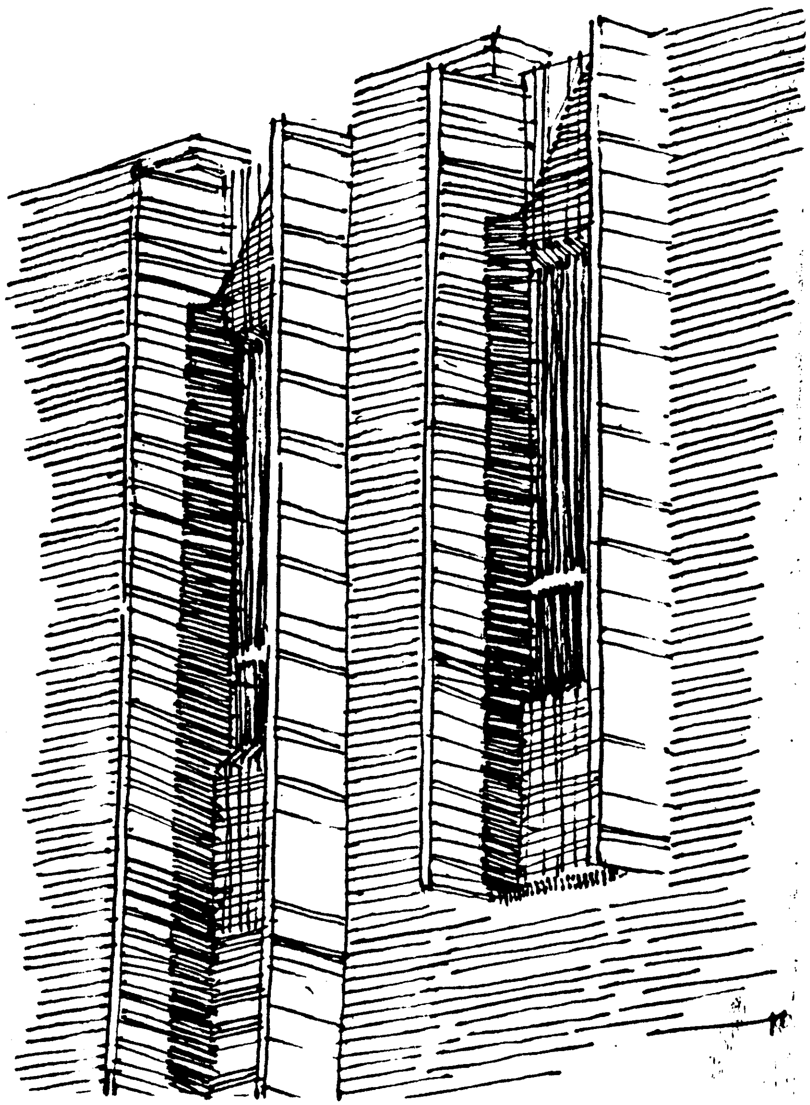
> "In 1928 a house was planned. Carthage. Here the structure of the house is completely independent of the form of the habitation proper, which retreats for shade protection, giving the structure the added role of a sun breaker."°

A sketch done in Corbu style diagrams how the closure (the secondary structure, infill) further enlarges the weatheredge zone.

The examples of solar protection thus far have shown how solar protection can be achieved by hanging or detaching the secondary structure from the building surface or primary structure. The zone of the weatheredge is further expanded by moving the closure (infill) inside the primary structure allowing the building through its form to become self-shading.

° Olgyay Brothers, Solar Control and Shading Devices.

There are numerous examples of this architectural means of solar protection throughout the world. The colonial country house built after European tradition offers its galleries and arcades to provide shade in summer, yet admit sunlight in winter.



## Wing Wall

The vertical definition provided by the wing wall allows for selective shading of the building surfaces of different orientations. The depth of the wing wall can vary in this respect depending upon amount of shading desired for a given orientation. The wing can be an extension of the structure, e.g. bearing wall, or it could be designed as a separate element from the facade. Either way the extended wall can provide protection from both the sun and wind, in some special cases facilitating the collection of solar energy. In the latter case this is accomplished by reflection of direct sunlight on to window wall surfaces.

Depending on the prevailing wind directions the wing wall can potentially shelter against wind. The wing wall can be utilized to screen the sun's rays selectively, by blocking, for example, the western rays of the sun.

Heat Transfer - Wind

Air boundary conditions of the building surface effecting heat transfer are principally determined by turbulent and liminar flow.

Laminar flow maintains stability in wind speeds under 20 m.p.h. Within these limits the wind speed alters the air film coefficient yet retains laminar flow characteristics.

At wind speeds exceeding 20 m.p.h. turbulent flow takes over. At these speeds, surface roughness of material becomes insignificant. However, recesses in building surface (weather-edge); windows set back 6" or more, act as cavities.

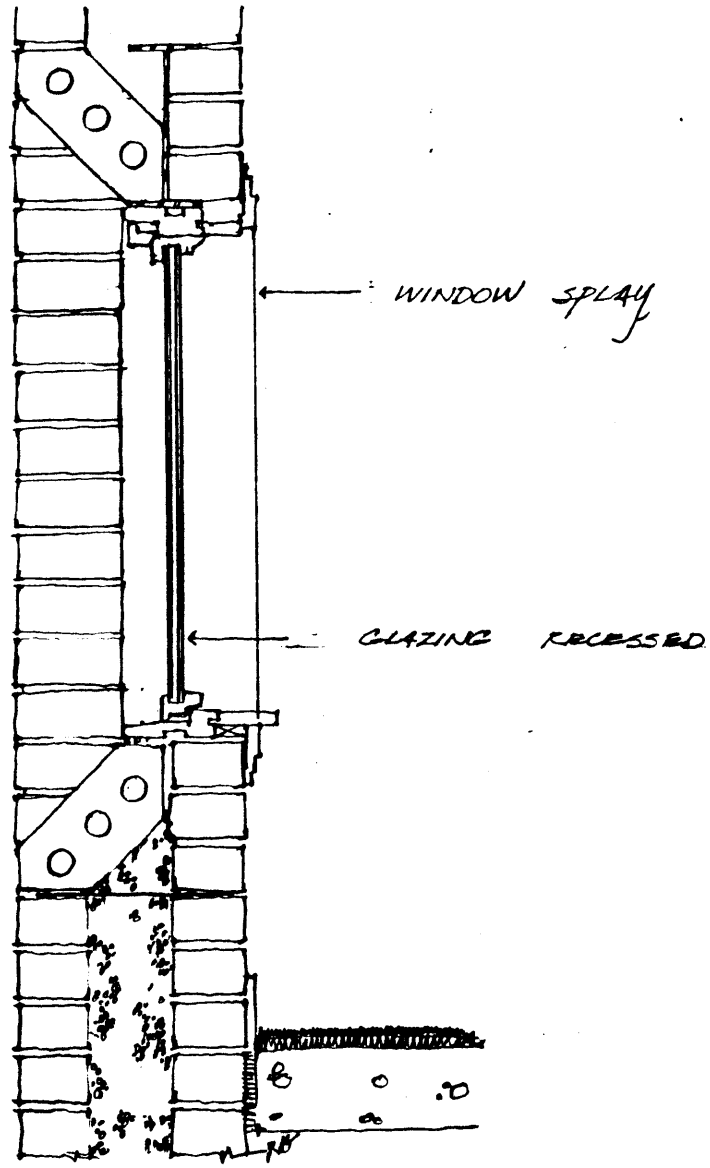
Depending on the velocity and direction of wind, air currents tend to slip over set back window surfaces, and reduce heat transfer.

A similar effect can be achieved by the use of projections (e.g. structure, enlarged window frame projections), which allow for separation from the flow surface.°

There is some debate over the question of architectural projections, air turbulence and heat transfer. The answer seems to lie in the scale relationship between the depth of window relief and wind speed. Small projections from window surface such as mullions and window frames may cause turbulent mixing and hence increase heat loss.

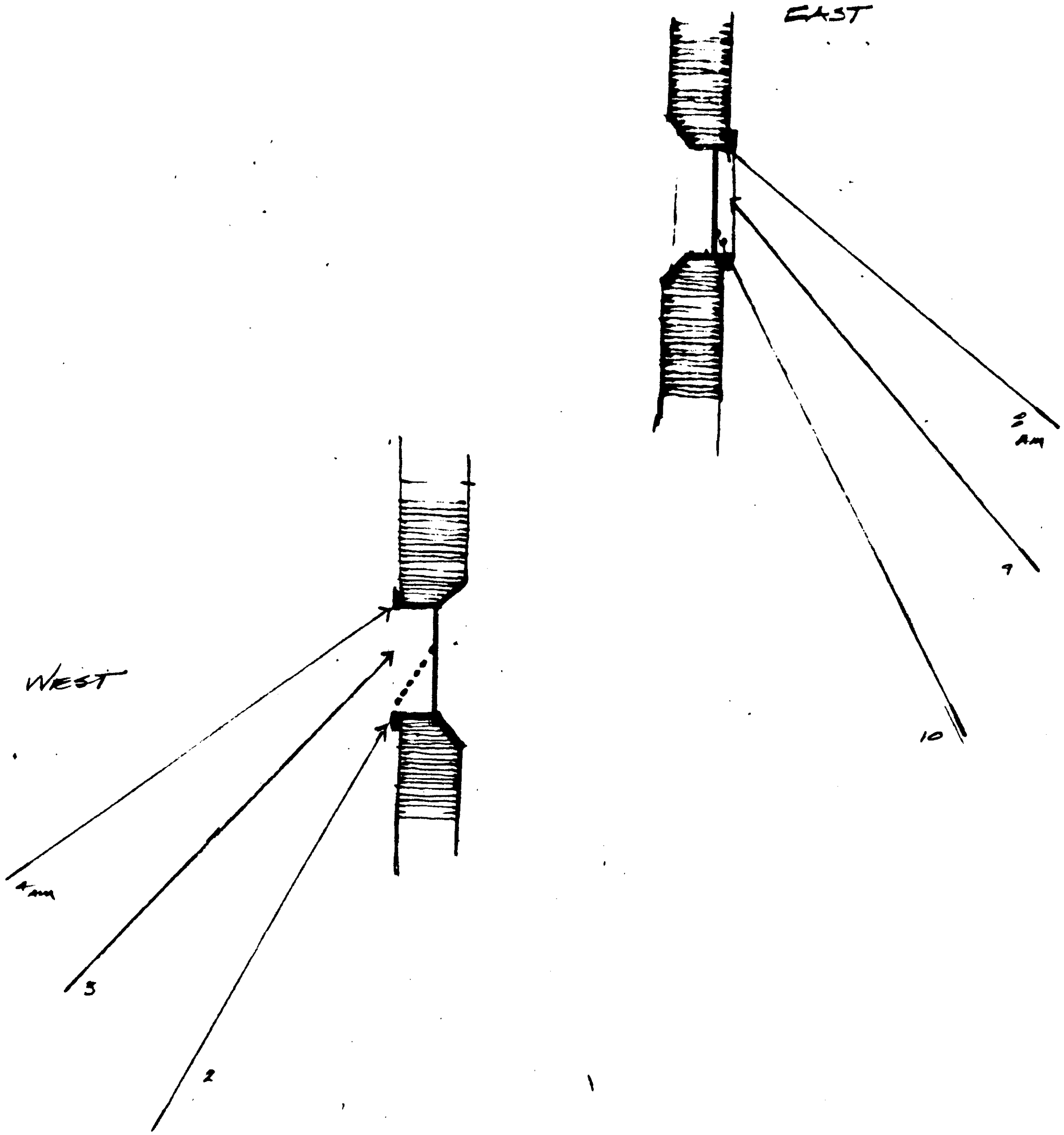
°Conversation with Frank Durgin, Wright Brothers Wind Tunnel

°Additional reading in Energy and Buildings, Volume 1, No. 1, May 1977, The Effect of Wind on Energy Consumption in Buildings.

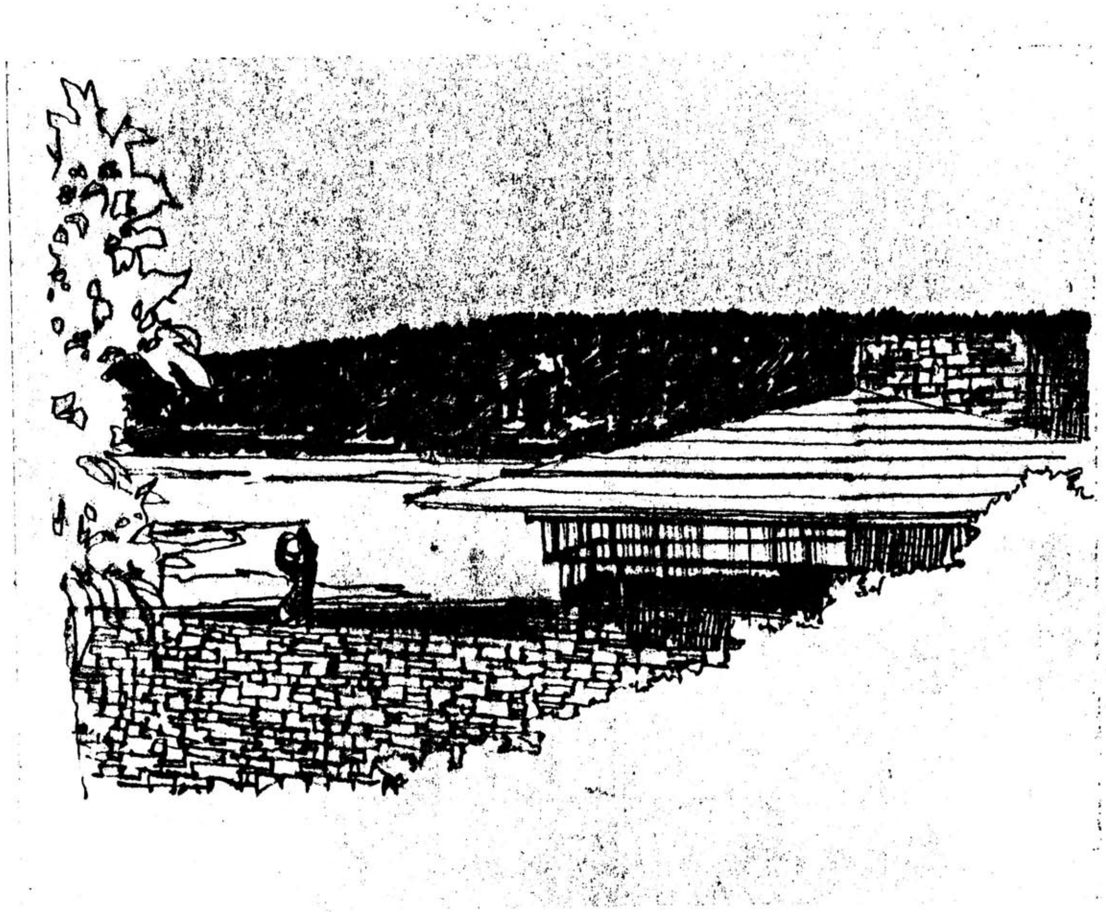



Wall - Depth and Glazing

The glazing material is the principle means of solar collection in any passively heated structure. Controlling the amount of sunlight striking the surface determines solar gain through the window wall. Glazing position within the wall dimension (large wall thickness--appropriate to masonry construction) is a means of architecturally controlling the amount of solar insolation penetrating into the space. Once again the overriding purpose is to selectively control the sun's rays by blocking the high summer angles and accepting low winter ones. Recessed glazing on the south faces takes advantage of the seasonal solar geometry. The opaque boundary edge of the window wall can effectively shade the glazing surface depending upon the window wall proportions and solar position (altitude and




position). Windows elongated horizontally are more appropriate on the south faces while tall narrow windows are more suited to the east and west orientations. Applying the winter exposure diagram (refer to thermal design tools section) for the Boston area (figure 13 ) the recessed glass on the east and west exposures can respectively screen out the early morning and late evening hours of sunlight. This sun geometry relationship may be favorable for west exposures, but east orientations receive less early morning sun. To compensate for the loss of insolation on the east window wall during winter, the glazing can be moved out some and horizontal shading can be further extended or introduced as the case may be.

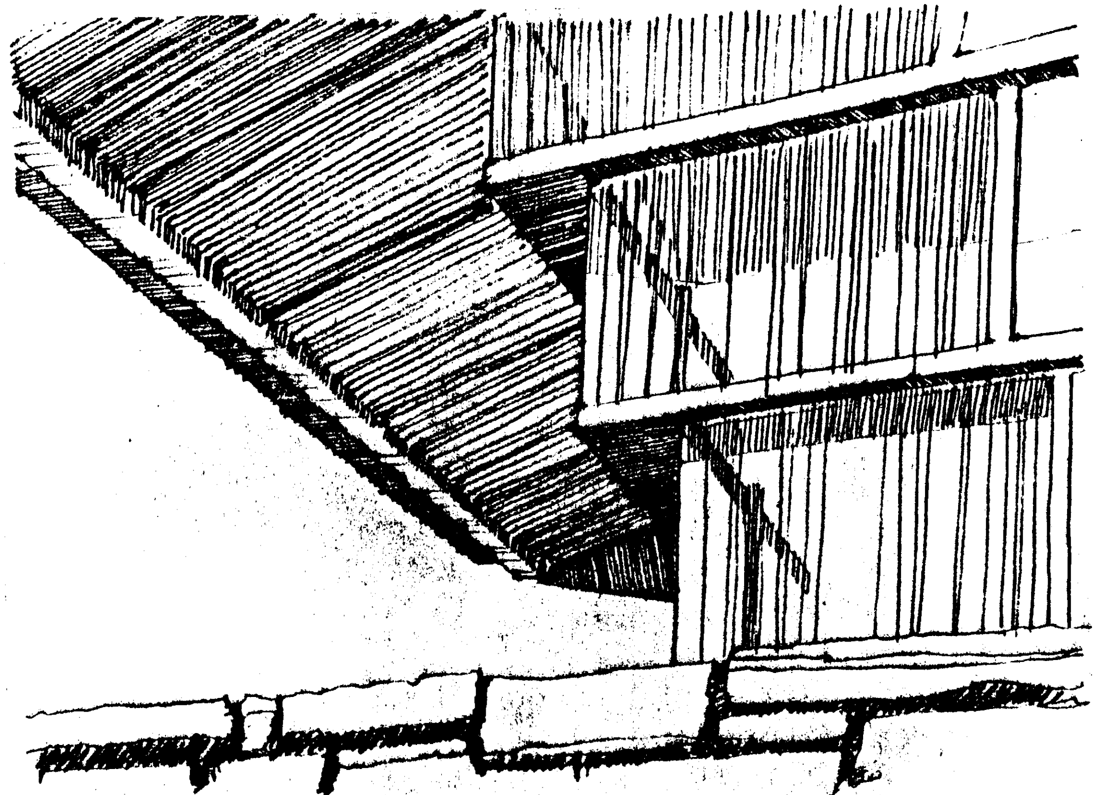


Window Wall Step Back

Frank Lloyd Wright, author of this building, responded skillfully to the forces of sun and sea. Whether or not the sun served as the prime generator is uncertain. From a solar standpoint, however, it is clear that this inventive window geometry is sensitive to the seasonal movements of the sun. The window wall accepts the sun's winter rays, yet steps back in section to protect itself against the intense, sometimes sweltering, summer sunlight. This self-shading design allows for an open, expansive view of the Carmel sea.

In a romantic sense, Wright sights this building in graceful repose on a rocky point. This poetic structure answers to the sea like a ship's prow.

Perhaps the most impressive or enchanting aspect of this small house



comes from its two-fold response to the environment. On one level it embraces the seascape with enormous hunger but on the second level it screens out those forces detrimental to the inhabitants. Most notably in the fenestration, 50 years before it became fashionable, Wright's sensitivity as a designer cognizant of the natural forces were evidenced in this humble undertaking.

Both with regard to use and geometry, Wright's setback section was remarkably innovative for its day. Perhaps as a response to the functional limitations of the conventional window, Wright designed this three dimensional zone of glass and steel. The vertical glazed surfaces allow for the penetration of sunlight and the horizontal planar elements provide for use surfaces. In this design, the personal artifacts arranged on the window wall ledges: plants, artwork, become added shading elements and compose the sunlight-window wall silhouette.

Ancient builders sensitive to solar potential, rarely disregarded thermal storage and carefully exploited its capacity in the building. In passive solar design the building's fabric, its construction (selection and arrangement of materials), and the amount of thermal mass (weight) determine its solar storage characteristics. A passively solar designed building relies exclusively on its own materials to store thermal energy and maintain a range of thermal stability within the space.

Heavy materials are borrowed from the natural landscape and comprise a vocabulary of ground form materials directly associated with earth and water.

These ground form materials -- stone, rock, granite, soil, masonry and water -- provide the primary link to the landscape and have associative as well as thermal qualities. These materials have traditionally been valued for color, composition and textural qualities, and from a thermal standpoint, for high storage capacity. These materials because of both heaviness and density visually, metaphorically and physically respond to the forces of gravity and offer some degree of stability in a world of change. In addition when used in an additive fashion, the builder has the opportunity to generate the major definitions in his landscape.

For centuries the Indians of the Pacific Southwest have utilized adobe, a heavy, high thermal mass material, to temper the extreme fluctuations of both daily and seasonal temperatures. These desert dwellers once called this territory, "land of the dancing sun".

Along the Sangre de Cristo Mountains the strong winds, the Banshee's, sweep down from the high altitudes bringing snow to the desert floor. The sun, though, prevails most of the year, transforming mud into ceramic-like material. In the austere desert where the architecture is mud, contemporary forms are built on the Indian adobe model. The passive solar buildings of this region have altered to a small degree neither the nature of construction nor the building materials. The adobe wall has maintained its usefulness and integrity, absorbing the sun's energy during the day and slowly releasing it at night. The use of adobe for solar heating is most applicable to a cool winter climate with sun almost every day, such as New Mexico or Arizona, where the climate only demands overnight storage.

Contemporary materials such as glass, steel, wood and insulation enhance solar collection and thermal storage. Insulation is selectively placed on the interior of certain walls or over windows to reduce heat loss, during sunless periods. Moving further south, in drier, more severe climates insulation is eliminated entirely. The heavy earth material dampens the temperature extremes by its thermal time-lag properties, performing as "capacity insulation". At night when the outside temperature plummets the inward heat flow simultaneously counteracts with the cooling of the outside surface and the outward heat flow stabilizing the overall heat loss. Each exposure interacts with the sun differently. Thus the heat loss-gain for each exposure correspondingly differs.

On the eastern seaboard and in northerly climates thermal mass materials have been traditionally used in a different way. Walls are built of heavy materials with or without a hollow cavity acting as insulation or the masonry materials are used in conjunction with the hearth mass or constitute flooring.

In wood and masonry construction, a hollow cavity or some form of insulation is often used within the wall dimension. Like the performance of the adobe, the masonry soaks up available thermal energy, stores it and releases the heat as the interior air temperature begins to fall. The heavy material in a reverse way has cooling potential; sponging up the heat during the day and releasing its energy during the cooler evening hours. The insulation or air gap reduces heat loss and helps the building retain the heat given off by the masonry.

Three relationships of thermal mass to insulation can be identified in the foregoing discussion and are crucial to understanding the performance of solar storage in a given climate.

In general, insulation should be placed on the inside of high thermal mass materials when the overall heat loss-gain on a given exposure in winter provides a solar benefit over a 24-hour period. The insulation in this case assures some control over radiant exchange between the masonry surface and interior space. In the vernacular, this means lots of sun!

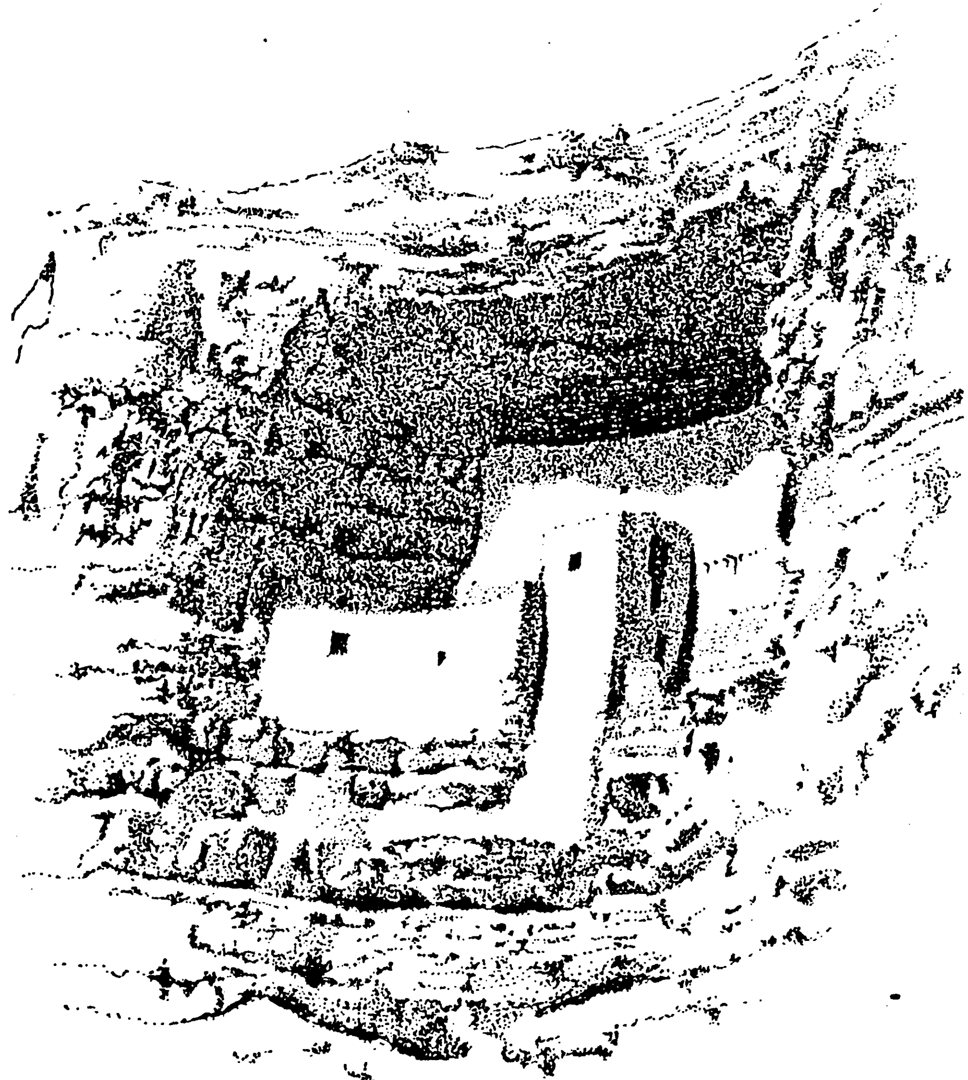
In cold climates insulation placed within the wall dimension should offer sufficient thermal resistance to meet energy conservation standards (This is a regional consideration). High thermal mass materials on sunny south facing exposures can be a thermal asset by taking advantage of the sol-air temperature at the exterior surface. Sunlit surfaces warmed by incident radiation effectively reduce the delta T (T indoor - T outdoor). This sol-air effect can also be utilized on other exposures if the solar gain is desirable.

In harsher climates with extended winters, insulation is placed on the exterior of wall surfaces and covered with perhaps a siding material. The thermos bottle approach is most applicable to these climates. Heat absorbed by heavy materials within the interior volume are retained by the insulating envelope.

In summation: place the mass where the weather is (temperature fluctuations). Use insulation when average diurnal temperature is not in the comfort zone.

Behind the scenes, experimentation with other kinds of thermal storage (phase change materials in particular) has progressed over the years. These lightweight high thermal mass materials, notably Eutectic salts, have only recently become economically attractive. The phase change materials themselves, principally Glaubers salts, are relatively cheap. New methods of containerizing the material which have been developed by Timothy Johnson at M.I.T. have reduced its cost considerably and extended the life of the material.

*Montezuma's Castle, Arizona, U.S.A., 1100 A.D.*



James Lambeth, Solar Designing

# SECTION 5

Solar collection and storage is explored in the following section by investigating a number of specific examples which define a range of thermal zones.

In the Thermal Design Tools section the notion of thermal zones, associated with a given built condition was introduced. That exploration is continued with the use of diagrams and design sketches which illustrate a range of built definitions (e.g. partial containment) that influence the thermal zones at the weatheredge.

The proportioning of building surfaces, orientation, arrangement of glazing and wall surfaces, controlled penetration of sunbeam and diffuse energy all regulate the amount of light and heat input filling a given space.

The saturation and dissipation of input energy will depend largely on the design and thermo-physical properties of the specific materials impacted.

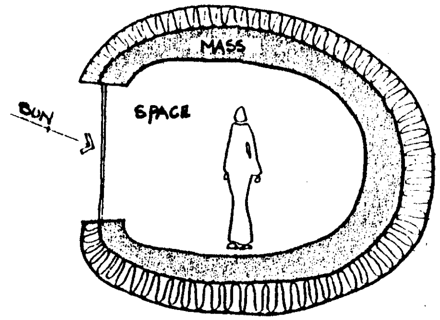
The design of both the filtering mechanism (window wall-wall) and absorption medium (thermal mass), complete and partial interior barriers, (e.g. walls, screens, partitions, furniture) determine the heat regime of the thermal zone(s).

Passive solar space heating systems or "integrative systems" fall into three generic categories: direct gain, indirect gain and isolated gain.

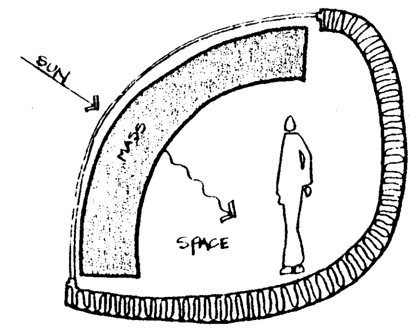
In the direct gain system the solar radiation passes through the living space before being stored in the thermal mass. (Sun-space-mass) In this case, the working-living space is directly heated by the sun and serves as a "live-in" collector.

In regard to indirect gain systems, solar radiation heats storage mass directly which then transfers heat to the living space. (Sun-mass-space)

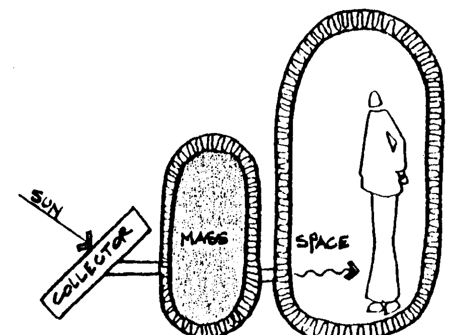
Isolated gain systems incorporate a collector-storage arrangement separate from the living space. Solar radiation is collected and transferred to storage or distributed to the space directly. (Sun-collector-mass-space) This system allows the collector-storage system to operate independently from the building and space heat on demand.



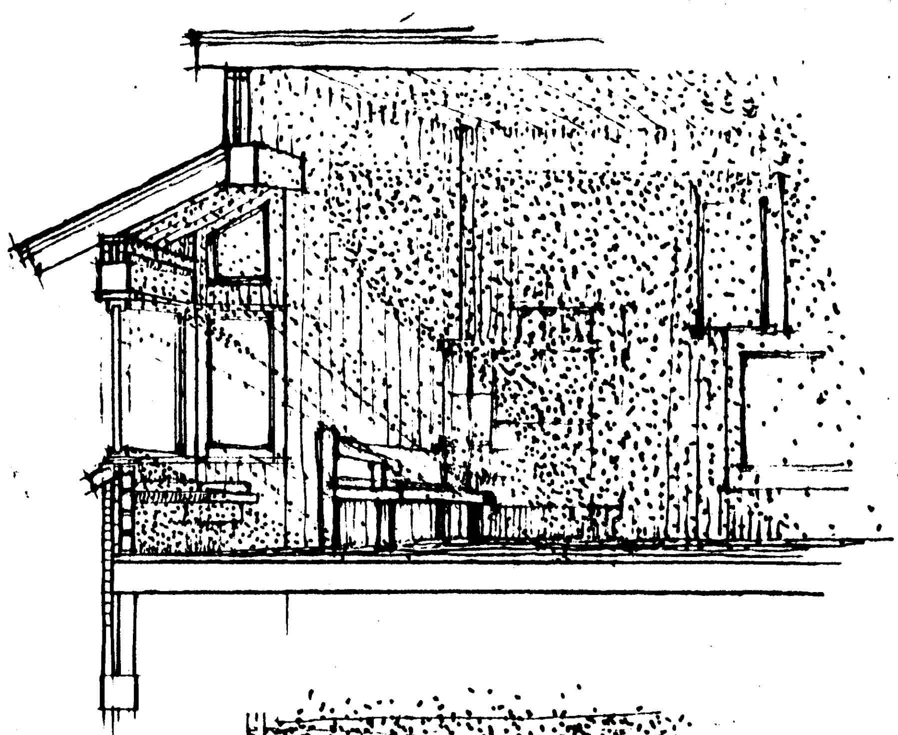
(A) SUN-SPACE-MASS

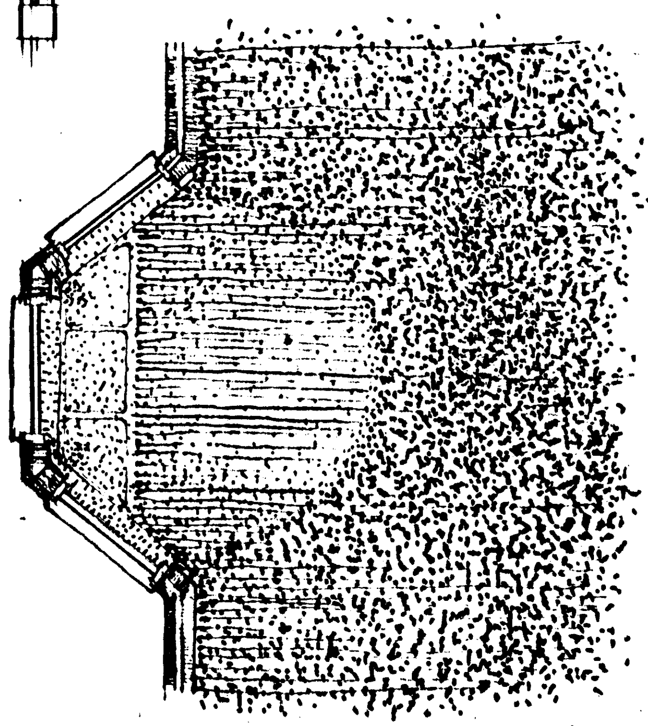


(B) SUN-MASS-SPACE



(C) SUN-COLLECTOR-MASS-SPACE





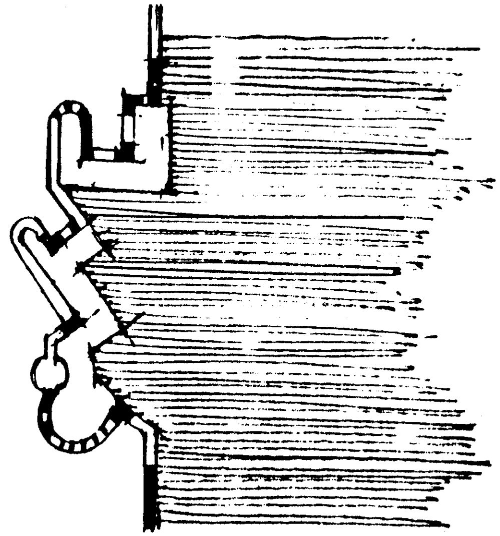
DIRECT GAIN

Bay Window

The Bay window makes up a thermal zone, different from that associated with the flat curtain wall (given the same ratio of window wall to wall surface area). Not only is the bay explicit in defining a use zone, but it provides a special light and thermal zone as well.

This architectural bump in an otherwise planar wall increases the surface area of the weather edge. At the same time it potentially allows more natural light to enter as greater heat loss is incurred.

The conventional bay window on a southern face is not as efficient in solar collection in winter as the window wall it replaces. The projected area of the bay sees slightly more of



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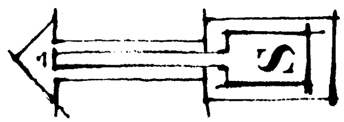

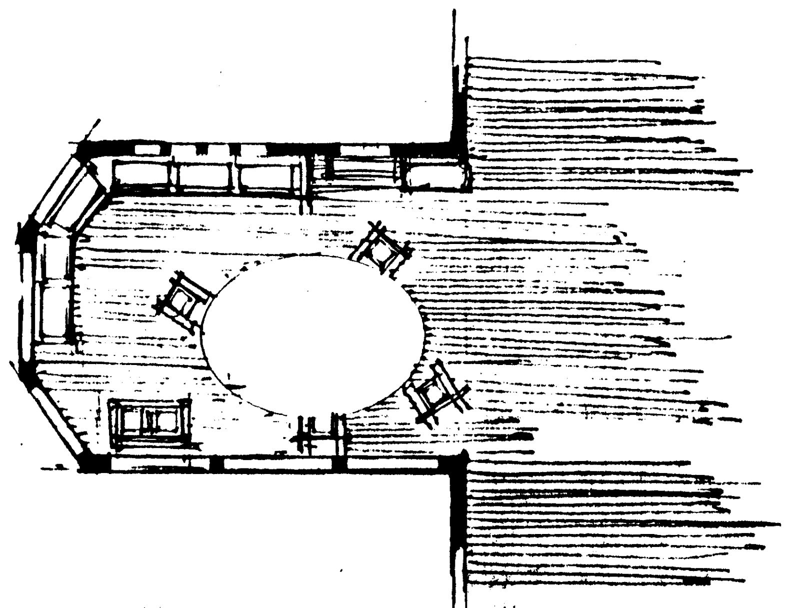

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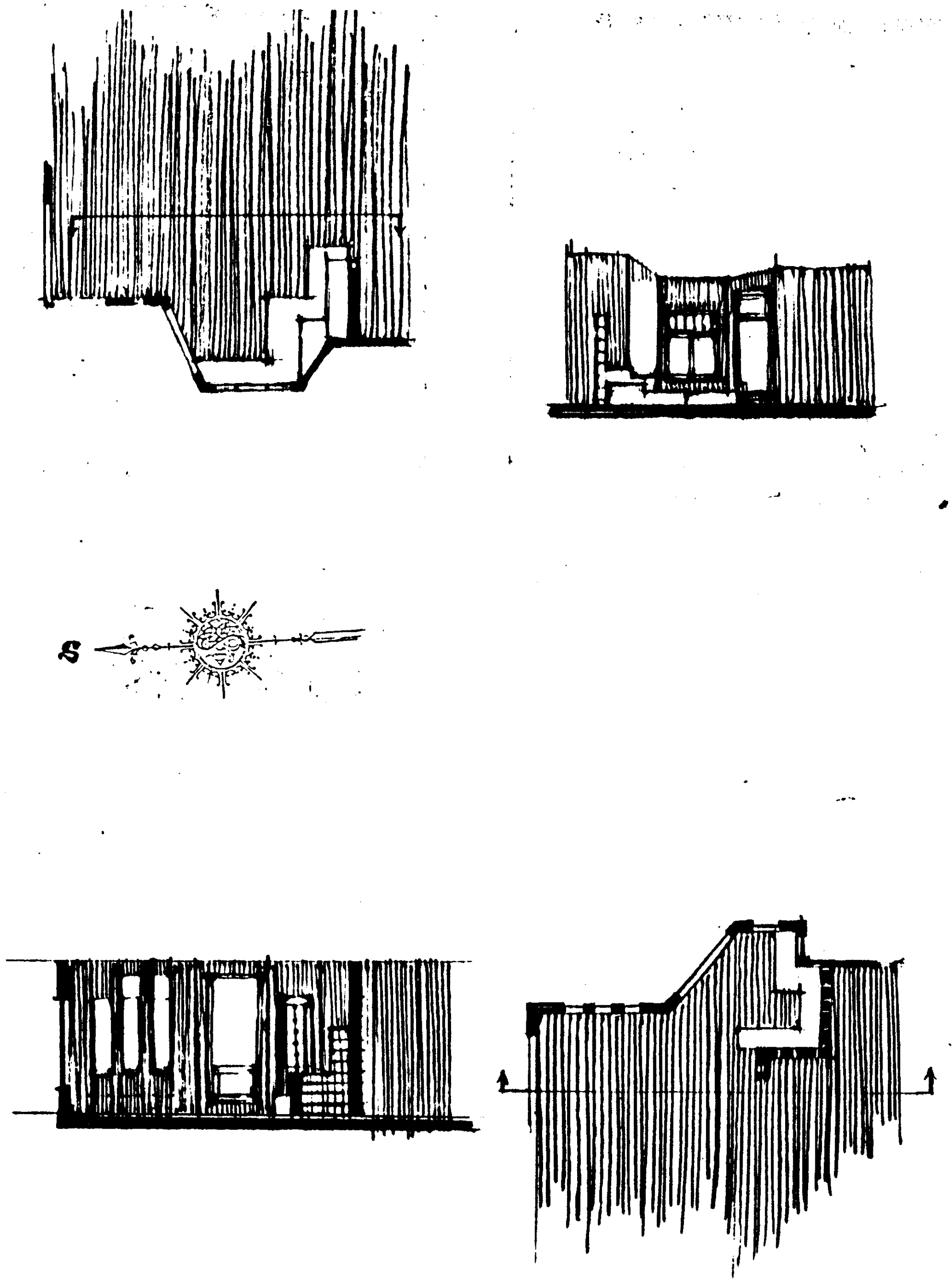
the sun, which increases the amount of radiation available to the bay. The heat loss for the added surface area, however, outweighs the heat gain. This is illustrated in the diagram by the use of the aperature effect (figure **30**). The interior zone of the bay window and adjacent space, however, undergo a more extensive range of thermal fluctuations over the course of the day. The rhythms are a scaled version of the thermal fluctuations of the entire building. This results from the changing insolation which impacts the various orientations. Assuming stable climate conditions, the heat gain of a flat south facing curtain wall tends to rise and fall evenly over a day's cycle.

The temperature excursions of the bay are in general more frequent and of less duration and hinge on the scaling factor



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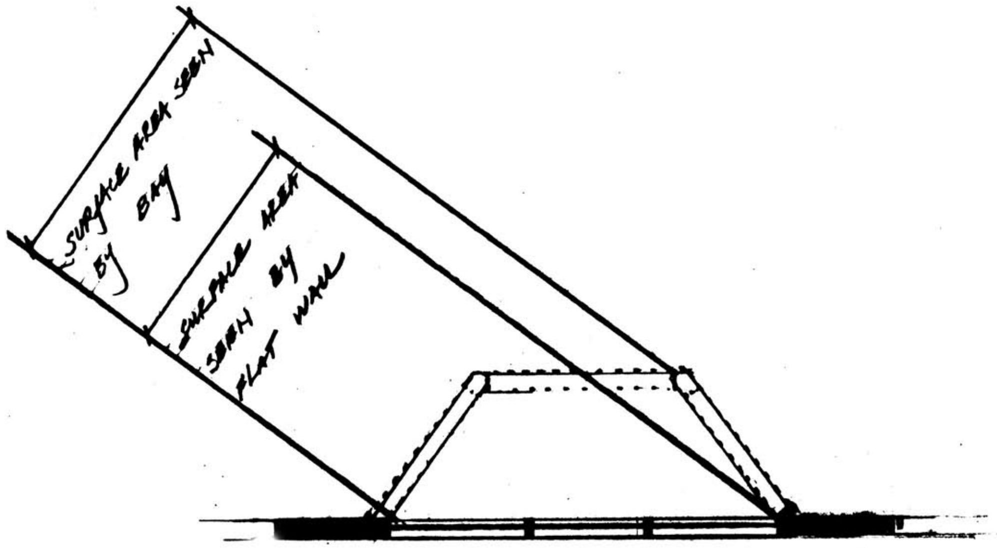
of the bay (surface area to volume ratio).

The scale factor and relative window wall to wall area will determine in part the thermal response of the zone. The bay is an architecturally spatial projection which can take on a range of use dimensions and thermal zones depending upon its form, shape, size, and the proportionality of sides. (See Diagram **27** .) The conventional bay relates closely to the individual human scale. One or two persons fill the spatial zone comfortably.

The extended bay, Diagram **28** , makes up a different spatial and thermal organization. The long narrow bay tends to heat up more quickly in the early morning hours. The south aspect, stabilizes the stronger insolation impacts because of the reduced surface area. And the space predictably heats up again as the sun moves into the westerly position. Adjustments




APERATURE EFFECT



of the window wall area for different orientations will also influence thermal variation. Reduced window wall area on the west aspect of the bay may significantly reduce the common overheating effects of the western orientation.

Temperature variations in the bay through the course of the day may range ten degrees or more. Considering the narrow temperature range of thermal comfort (6 degrees, according to the bioclimatic chart), this variation is significant.

Furthermore, the bay is subject to greater fluctuations over a 24-hour period. The use of insulating panels over glazing surfaces considerably alters this picture by reduction of backlosses at night. A bay construction of heavy materials (e.g. brick, concrete, stone) in conjunction with containment surfaces of high thermal mass will potentially warm the bay zone by re-radiation of heat.

The bay denotes another aspect of thermal flexibility, a result of its basic configuration, which allows good cross-ventilation.

If the bay is transferred to an east or west exposure, other design considerations surface on an east facing exposure. For example, thermal reasons might suggest the reduction or elimination of window wall openings on the north aspects. (Diagram 29 sketched in section and plan)

The increased wall surface provides an enlarged target area for solar energy within the bay zone. The window bay on the western exposure takes on a characteristic form response which attempts to ameliorate overheating conditions by limiting the amount of west facing windowwall and orienting a large percentage of glazing away from due west.

The incident angle effect is utilized beneficially to reflect a substantial percentage of insolation. For example, the southwest facing surface witnesses low glancing angles ( 55°), just after the sun passes the east-west compass line on its way to a setting position north of due west (its declination).

The articulation of the weather-edge is one method of creating and reinforcing thermal zones within a building. The bay example deals with a general thermal zone in close proximity to the weather edge. Generating a thermal zone does not necessarily depend on this edge condition. For example, wherever sunlight is allowed to penetrate into the building, a thermal zone can be enhanced by the placement, choice and geometry of materials. (Roof lights provide an excellent means of solar penetration.) Furthermore, thermal zones are not solely dependent on direct sun beam energy. Thermal zones and associated use areas can be defined by the design and placement of secondary thermal mass;° reinforced by the use of innovative wall systems, solid cabinetry, plants and heavy furniture.

In Diagram **31** , bookcases are backed up against the heavy masonry walls, providing partial containment. Although uncertain of the "U" value of books, novels may be higher than short stories, the encyclopedia Brittanica has undoubtedly a substantial "U" value. Nevertheless, the point is that a tightly stacked bookcase has thermal insulating properties which help control the heat flow from the masonry surfaces into the interior space.

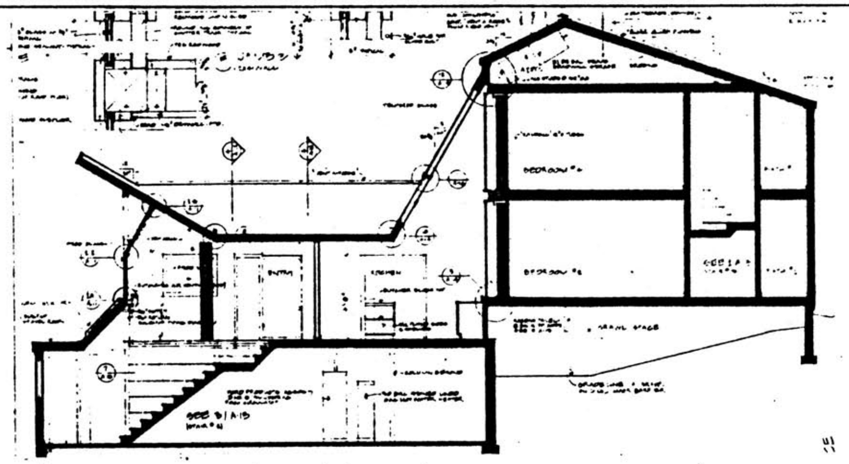
°A thermal storage rule of thumb states that 4 times the amount of secondary mass is needed to equal a given amount of mass directly impacted by sun.

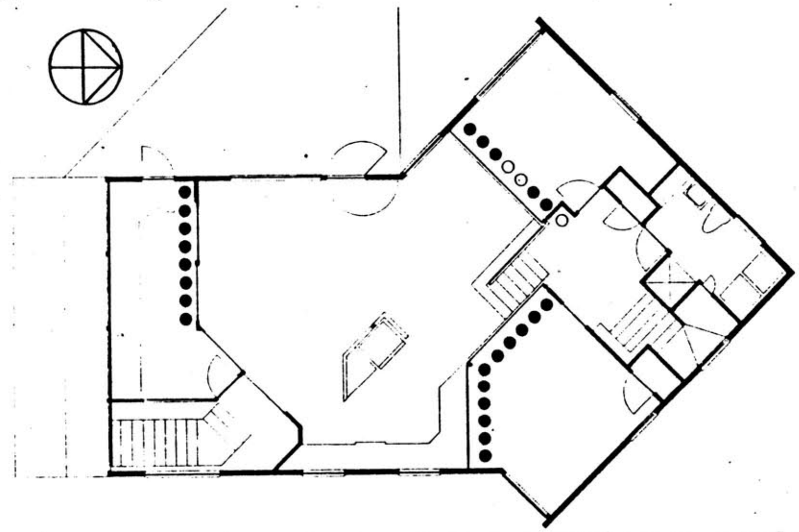
In considering thermal zones two important points should be emphasized.

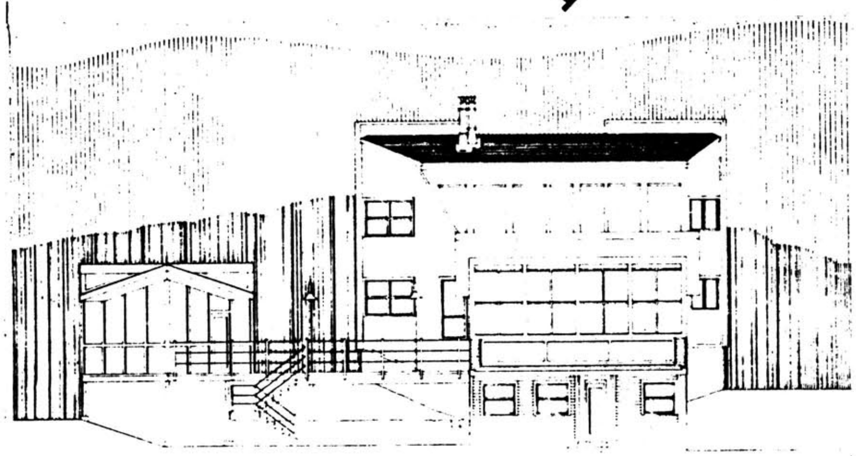
First, perimeter built thermal zones filter sunbeam energy penetrating interior spaces. This transition zone affords some control over convective heat exchange, radiant heat flow and helps regulate natural air flow. Bay windows have an excellent means of providing cross ventilation within the immediate thermal zone. The same surfaces that store solar heat can also become barriers to natural air flow, for the larger space. In this regard, some flexibility over the internal thermal regimes is desirable. For this reason, it might be reasonable to incorporate into the containment wall moveable shutters, screens and even interior openable windows.

Secondly, and perhaps the major point, concerns taking advantage of the mean radiant temperatures (M.R.T.) of containment surfaces. These surfaces allow a lower indoor air temperature due to their contribution to the local heat regime.

In general, the M.R.T. of localized surfaces and the impact of direct sunlight upon the body can effect what might be called "thermal dynamic mismatch." The pleasant sensation of warmth is attained by the combined effect of a cooler air temperature and radiant heat source(s). In some cases overheating may occur from, for example, direct sunlight. In these cases measures should be taken to provide for partial shading at window wall.







Water Walls

The Cook house designed by Dan Scully of T.E.A. utilizes an innovative approach to architectural thermal zoning.

> "The Cook house loosens up the stylistic constraints and usual preconceptions of what walls look like and then turns the partitions between the rooms into solar thermal mass."

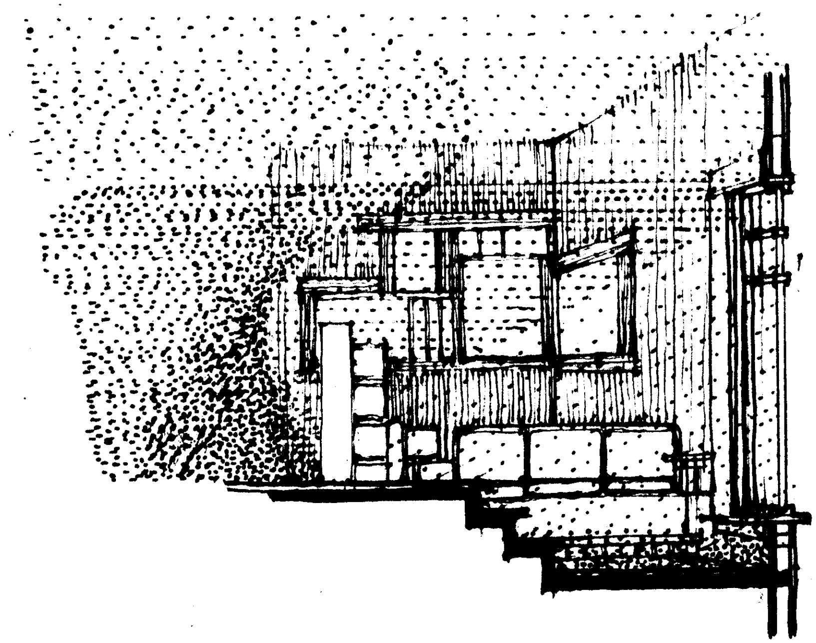
Kalwall tubes, 12" in diameter filled with water make up the wall partitions dividing the overall space into separate privacies and associated thermal zones. The storage mass is carefully placed within the building volume, creating balanced thermal zones. The translucent fiberglass tubes serving as target areas are designed to receive direct sunlight from south facing windows. The store is also appropriately located to provide heat to adjacent spaces, i.e. bedrooms, which most need the thermal mass for night time uses and can experience the greatest daytime temperature swings.

In addition, backlosses are reduced significantly because the majority of the store is placed well within the space. Unlike the trombe wall, the sun warmed surfaces are in radiant exchange with the interior space as opposed to exterior glazing.

The Cook house is an excellent example of the integration of high thermal mass materials into the fabric of the building while maintaining a direct relationship of sun to store.

Though water walls are not particularly good for mounting family portraits, they provide localized radiant sources of heat, a soft muted light, and reduce considerably the temperature fluctuations within the space.°

° Paper delivered by Dan Scully to Passive Solar Energy Conference, Philadelphia. 1978.



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Window Wall and Partial Containment

-- Gravity convection causes cold down drafts from window wall.

-- Zone pools air and reinforces horizontal stratification.

-- Zone cycles between day and night modes.

-- Gravity convection--prevalent during nighttime, cloudy conditions.

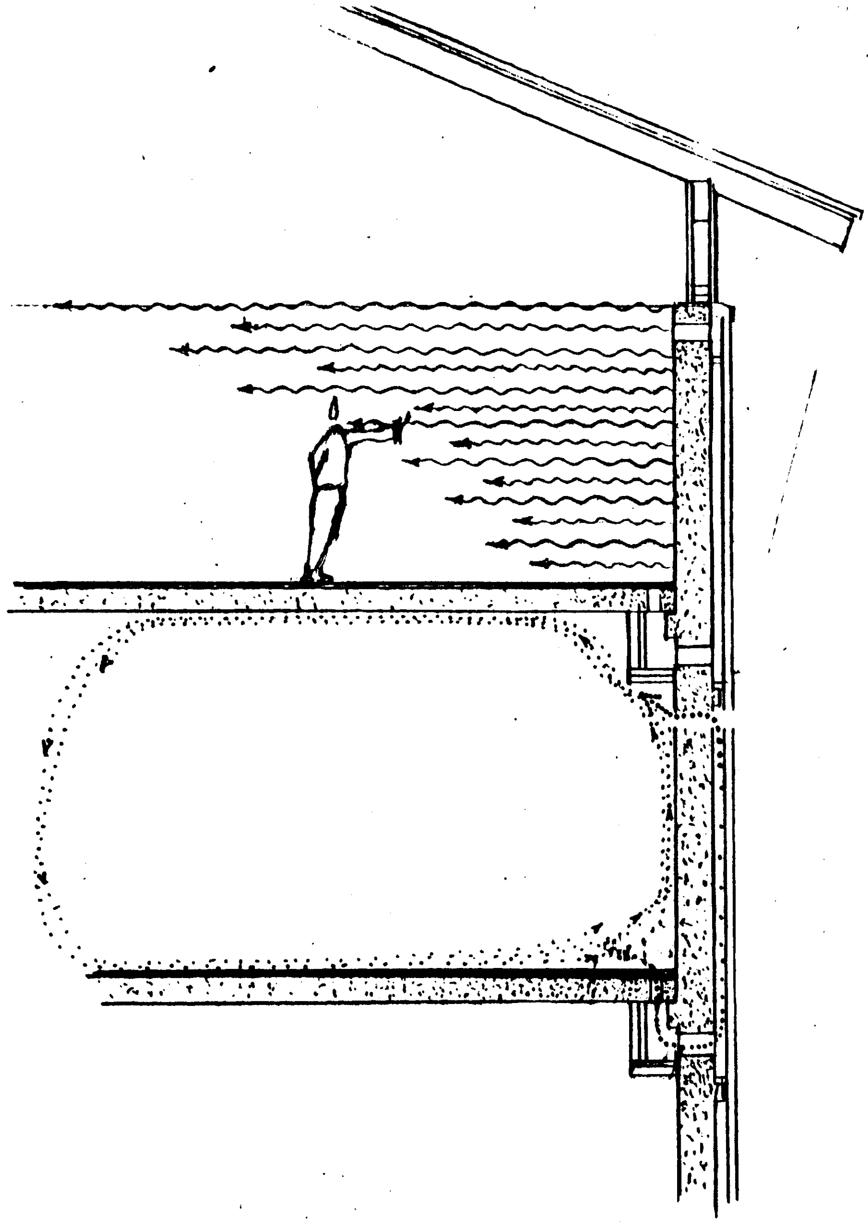
-- Step back section

-- stair faces

-- concrete block

absorb, hold heat; counterbalance cold pooling during direct gain hours and re-radiation times.

-- Lowered conversation area tends to create its own thermal zone (a convective loop). Air cooled by window surface falls due to gravity convection and moves slowly across the floor and is pulled up by warmed surfaces to the ceiling. The air moves across the ceiling to the exterior wall and continues its cycle.



INDIRECT GAIN MODIFIED TROMBE

Radiant Source

-- Provides vertical zoning dependent on direct line of sight.

-- Heat regime--varies evenly as a function of distance.

-- Radiant heat and back losses controlled by moveable insulated panels.

-- Sliding panels move across wall surface, closing and uncovering window wall openings.

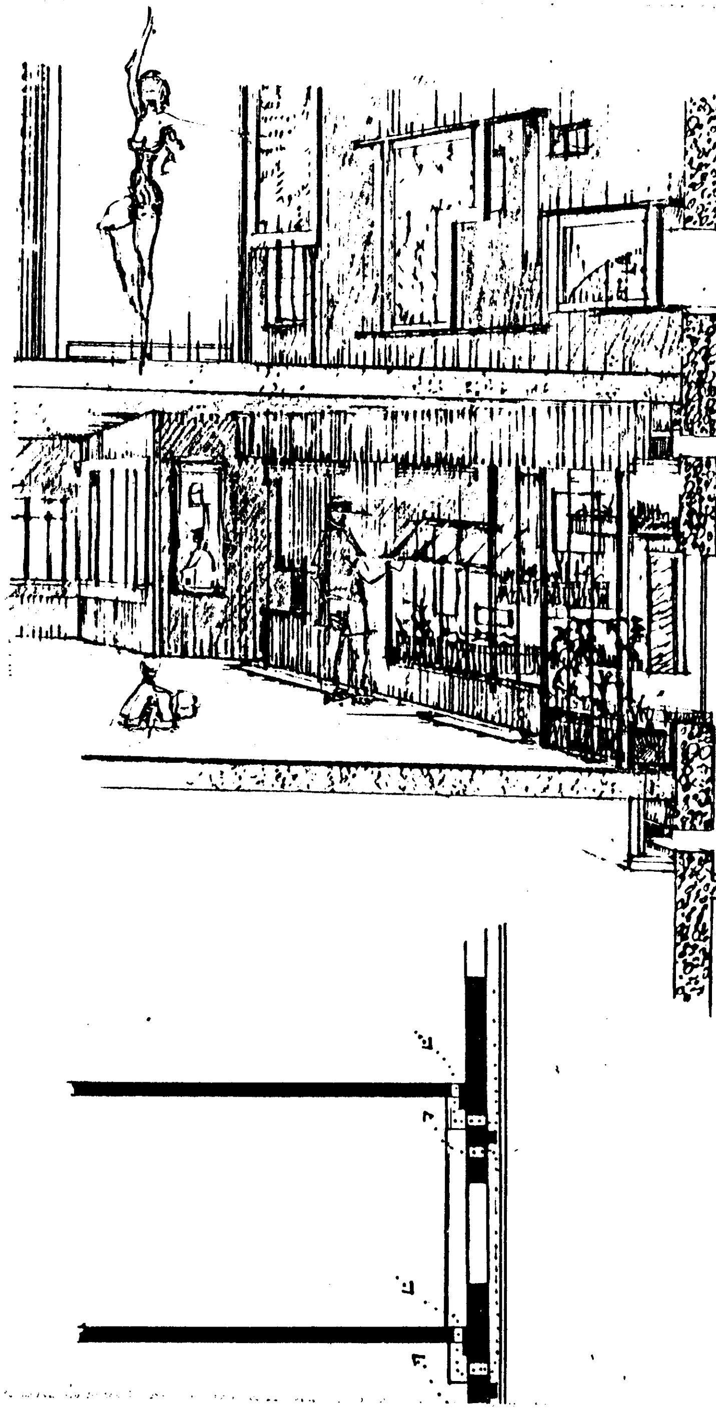
-- Hinged panels swing off of Trombe wall entirely frees up greater percentage of radiant wall surface.

-- Interior glassed enclosure also provides radiant heat source.

-- Interior hollow core wing wall--radiant source.

Convective Cycle

-- Heating mode of trombe circulates air --pulled in at floor level, heated



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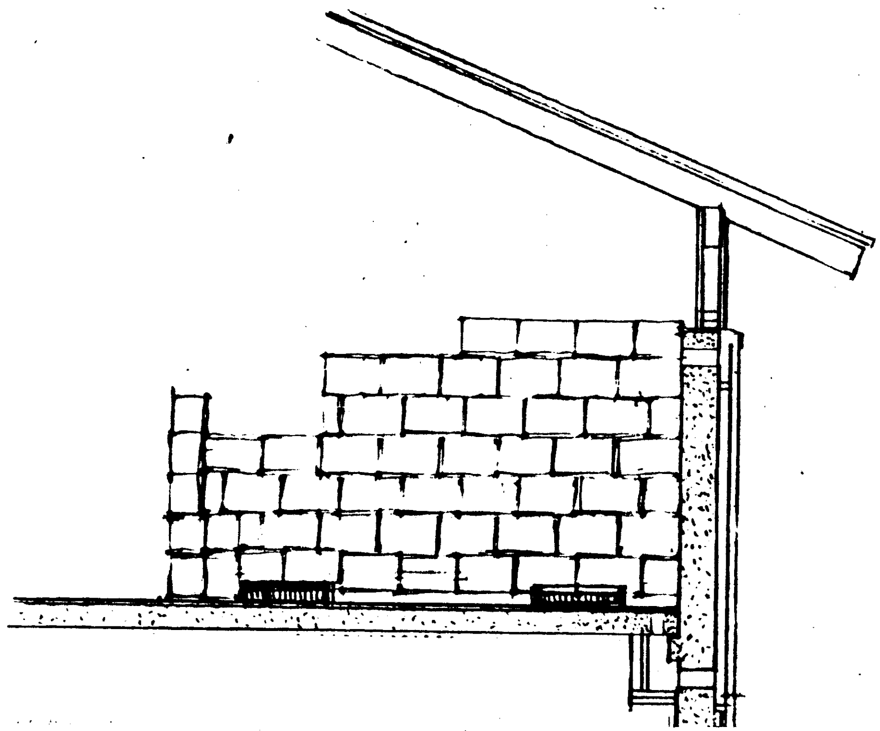
by exterior wall surface, pushed back into space.

-- Dampers or vents monitor heat retrieval dumped into space.

-- Alternate mode allows ventilation to outside, for cooling purposes.

-- Lowered cold air return off of floor monitor, prevents system reversal during sunless periods (overcast, cloudy, nighttime).

-- Temperature gradient of trombe wall reinforces interior thermal stratification (much higher temperatures at top third of wall), creates reverse gravity convection cycle pulling cool air from floor-up along interior surface of trombe to ceiling.



Interior Wing Wall

-- Interior hollow wing wall heats up (cools off) by means of one way loop from trombe. Outlet dampers regulate heat into wing wall and cooling of wall in alternate mode.

-- Hollow wing construction is of high thermal conductance material, e.g. painted sheet metal or high thermal mass material, e.g. concrete block.

-- Wing walls in conjunction with trombe wall--provide partial containment, define heat regimes and or thermal zones.

-- The wing wall actively ducts air in an attempt to counter thermal stratification by mixing air near floor level.

-- Two alternative designs for the wing wall are presented here:

Wing Wall - Radiant Source

-- Construction of wing wall channels heated air from top of trombe with the aid of small fan and pushes air down to bottom section of wing wall, in a closed inverted loop; circulating through the top and back out the bottom into trombe to be cycled again. Wing wall ties into trombe using reverse mode for cooling.

Wing Wall - Dual Mode - Hybrid

-- Wing wall performs as vertical duct, heated air is pushed into top of wall section with fan and vented out the bottom. The wall provides heat in a dual manner: natural forced air and radiant heat source. Reverse cycle can also be used for cooling.

Hybrid Window Wall - Greenhouse

-- This scaled down interior greenhouse enclosure is a source of heat, moisture, oxygen, (food).

-- Openable glass doors, adjustable grills allow heat buildup from direct gain through window wall openings and delayed heat flow from trombe wall to be vented into space.

-- Glassed plant enclosures act as an expanded form of thermopane. The zone is merely enlarged to accommodate a use dimension (for plants).

-- This edge enclosure tempers direct heat gain--entering through window walls. The multiple layers of glass (two), support framework, planter boxes and plants in themselves make up a collage of partial barriers which break up and filter direct sunlight. The quality of light which reaches the interior space takes on a character of its own; is more closely associated with light rendered mood of a Cezanne painting than an engineered solution.

-- The density of foliage, arrangement of planters, amount of soil, type of glass, e.g. stained, frosted, will influence thermal output and storage. Include an aquarium and one has an animated glass water wall, capable of storing roughly 2 1/2 times as much heat per volume as masonry.

-- The application of this hybrid window box is not bound to the trombe wall. It is not, however, recommended for east or west exposures (summer overheating problem) unless adequate shading is provided. The enclosure functions in a very different capacity on northern exposures (sunless). The major benefit of its placement on south facing aspects is reduction of high contrast glare. Back losses, heat sink effect associated with large areas of glass utilized for passive heating.

-- Those insulated panels introduced in Diagram 32 could easily be designed to slide between the glass enclosure and window opening to reduce backlosses at night.

-- Another advantage of the glass box is that it contains the heat in a convective trap and allows controlled release. Perhaps vents should be incorporated which allow venting to the outside via the trombe wall. Some cooling potential here too.

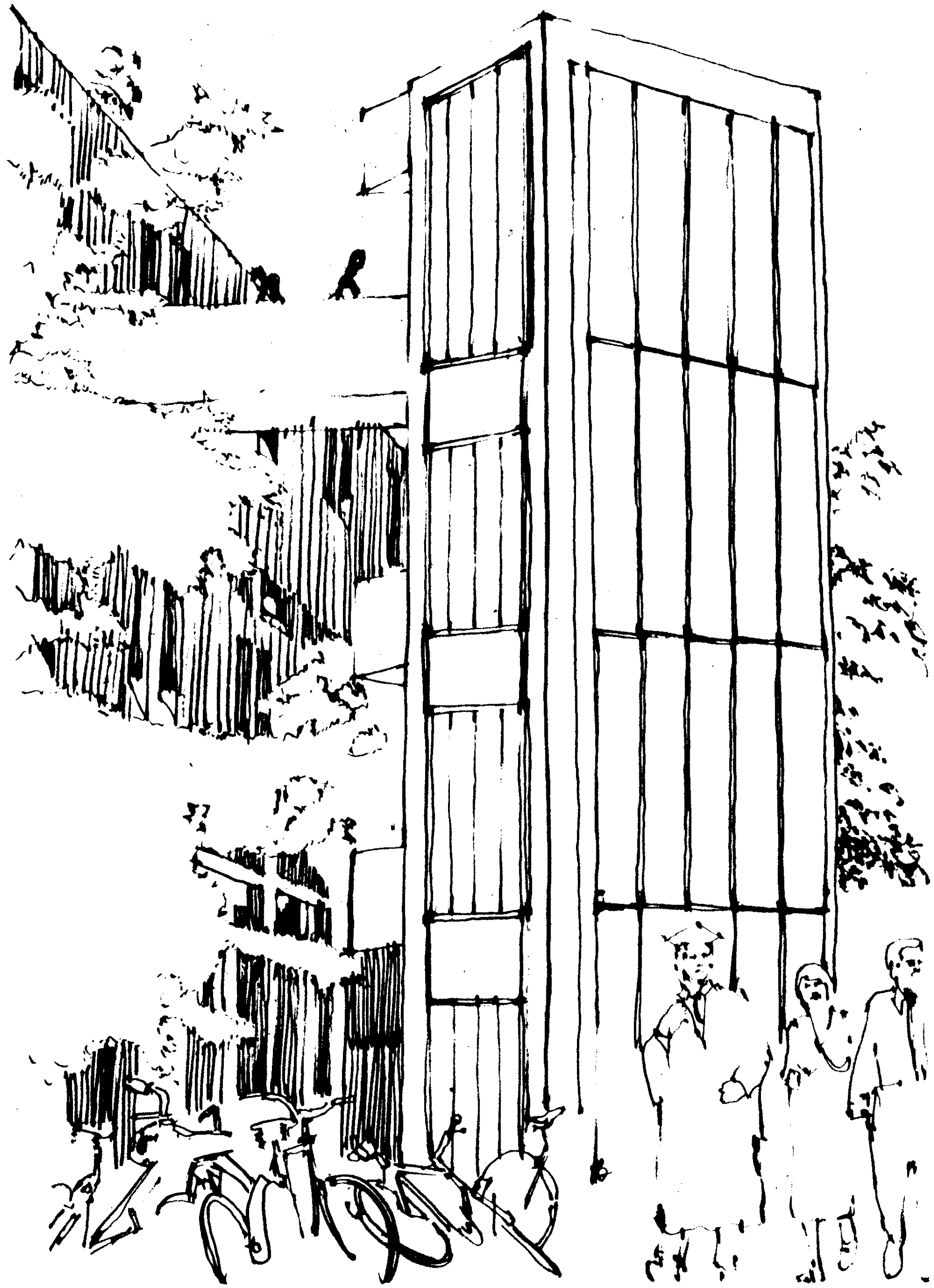
-- Attention should be given to the type of plants introduced. A hearty variety that can tolerate direct gain and reasonably high temperatures. A wide selection of garden vegetables can withstand relatively high temperatures, e.g. tomatoes, cucumbers, beans, etc.

Proprietors House at Allendale Farm, Boston
How much collection do we really need?

## Isolated Gain

Isolated gain systems fall somewhere in between the direct gain, low temperature "live-in" collection system, and the indirect gain, mass or water trombe types. This solar collection zone may vary from a minimal addition to a building connecting at one interface; or it may envelope a number of orientations. A collection zone might also be buried within the building.

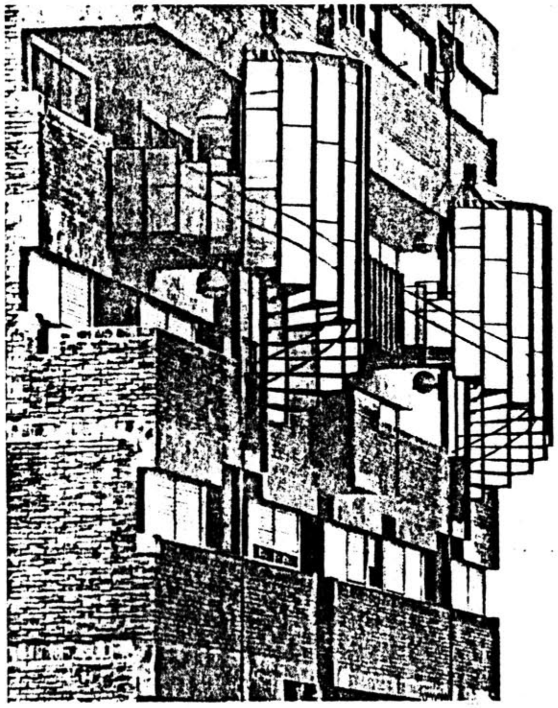
The usefulness of the collection zone is considerably extended when integrated with thermal mass. Materials of high thermal mass store heat for non-sunshine hours, help prevent overheating, and reduce extreme temperature fluctuations. Furthermore, collection zones will perform better as buffer zones if elevated air temperature of the transition space are maintained.

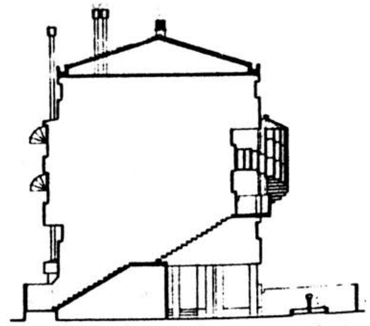


## Stair Towers

The use of conventionally placed stair towers at the weather-edge and detached stair towers are ideally suited as passive solar collection zones. Other use area and circulation zones, e.g. corridors, entries, atriums, porches, greenhouses, are also suitable for passive solar collection. The isolated or detached stair tower is investigated here.

In practice, stair cores act as smoke towers and are spaced (no more than 150 feet apart) throughout public buildings to provide for emergency egress. Heavy materials are often incorporated into the construction of the stair cores because of fire code regulations. High fire rated solid doors separate the stair tower from adjoining spaces. Stair and wall materials are





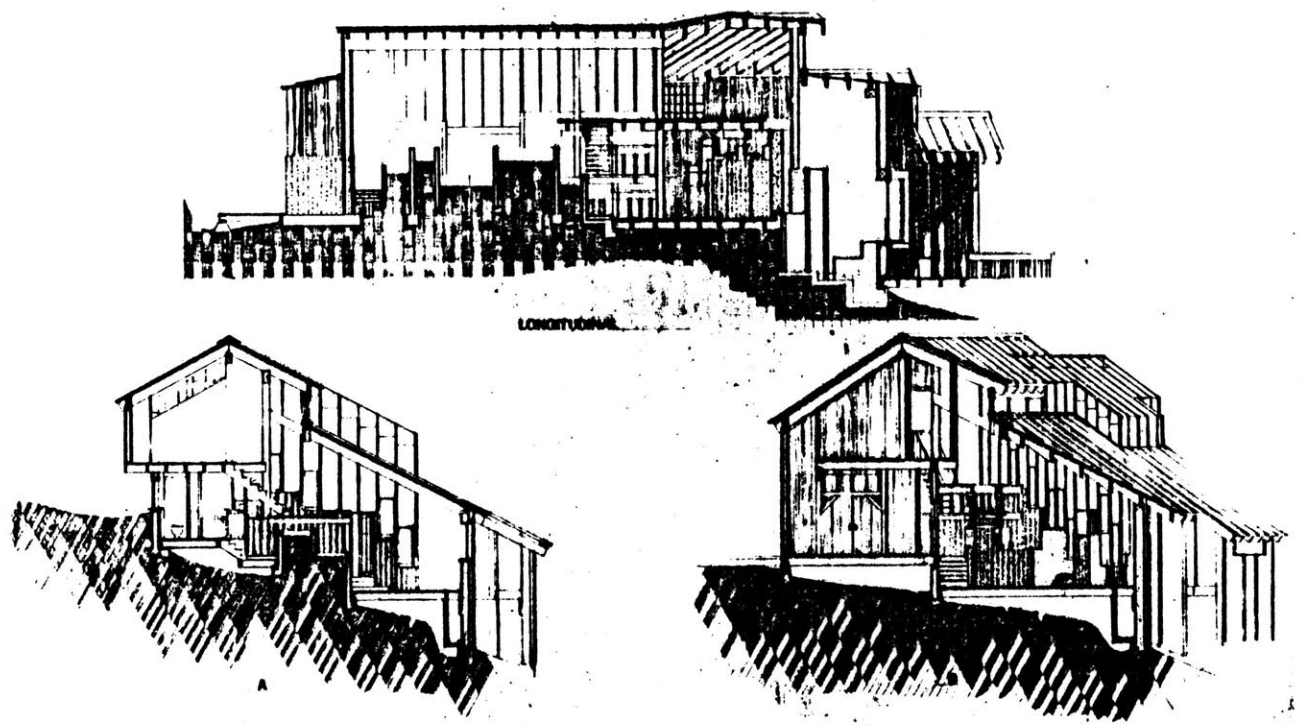
MBM: HOUSE FOR INSTRUCTORS,

in general built of masonry, concrete or steel. Because of the heavy construction the stair tower has high thermal storage capabilities.

Glazing the exterior sunlit surfaces transforms the stair tower into a solar collection zone. Because of its intermittent use it is allowed to reach high temperatures somewhat above the comfort zone. In winter, the heated air is either absorbed in the stair mass or ducted into isolated storage. In both cases the store is thermally isolated from the main structure. A more efficient use of the stair case ducts heated air into an insulated store for increased carry-over.

Because the stair case is solely heated by unconventional means, it is allowed to cool down during sunless periods. Incorporating thermal shutters to cover the large areas of glass may be economically prohibitive. Nevertheless, as part of the weatheredge, the stair tower does act as a thermal buffer zone.

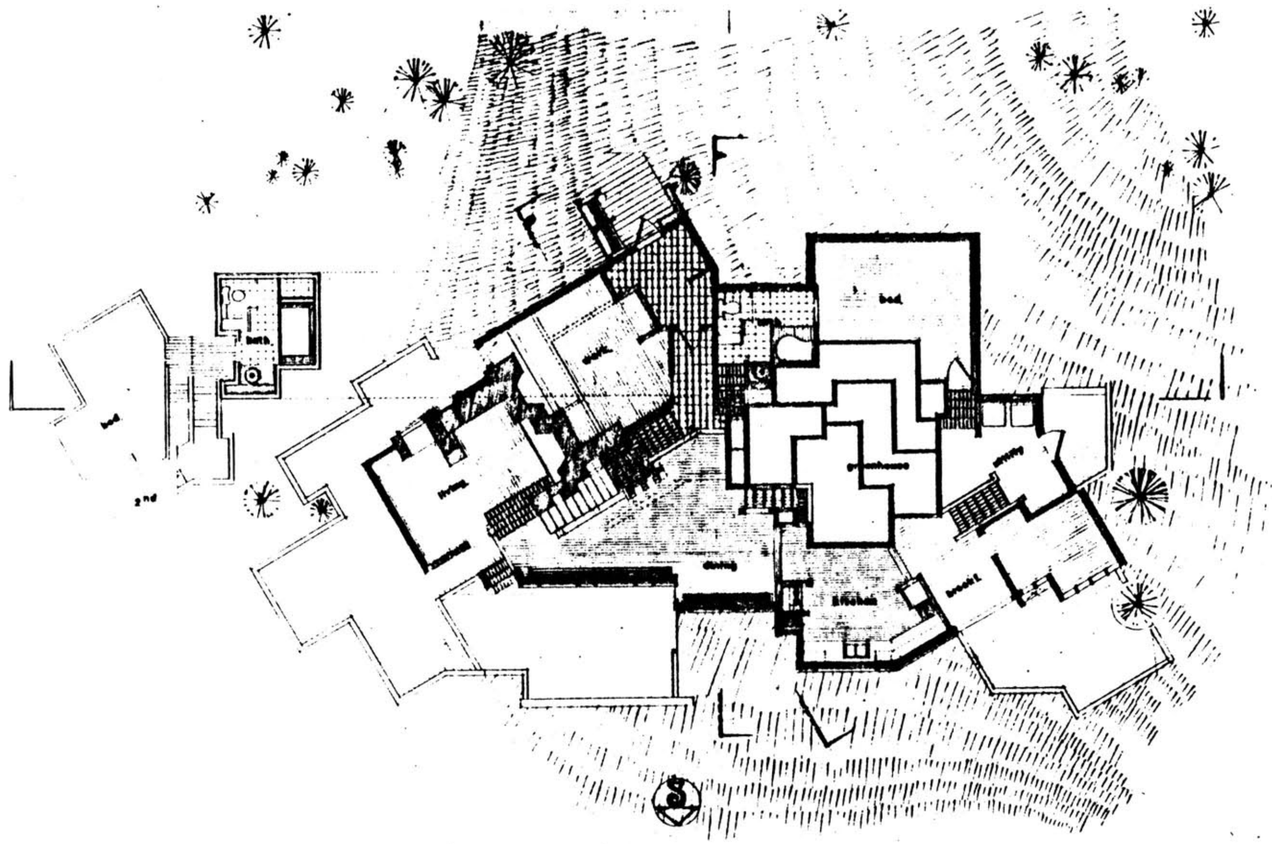
The stair core can also be useful in summertime for ventilation purposes, by accelerating the thermal chimney effect; pulling in warm building air and ventilating it to the outdoors. Stair cases buried in the building can provide a similar function by extending glazed areas above the roof line. The projected glazed roof provides for solar collection, ventilation and natural light. The large heat loss through the roof glass during non-sunshine hours can be reduced by double glazing the exterior surface and placing a third layer of glazing below the double glass. Openings in both the exterior and interior glazing would offer a number of operating modes providing controlled ventilation for seasonal use.




**BARNABE PASSIVE SOLAR HOUSE**

ROBERT BRUNKAN

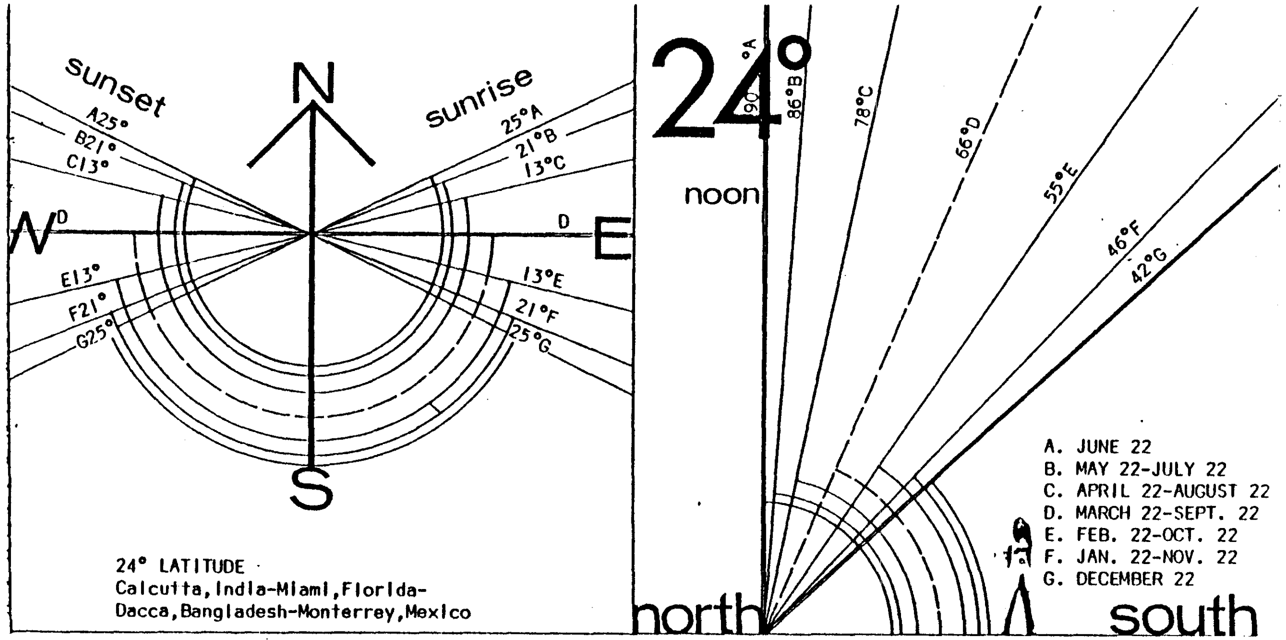
Work in Progress -- Marin County, California, 1978

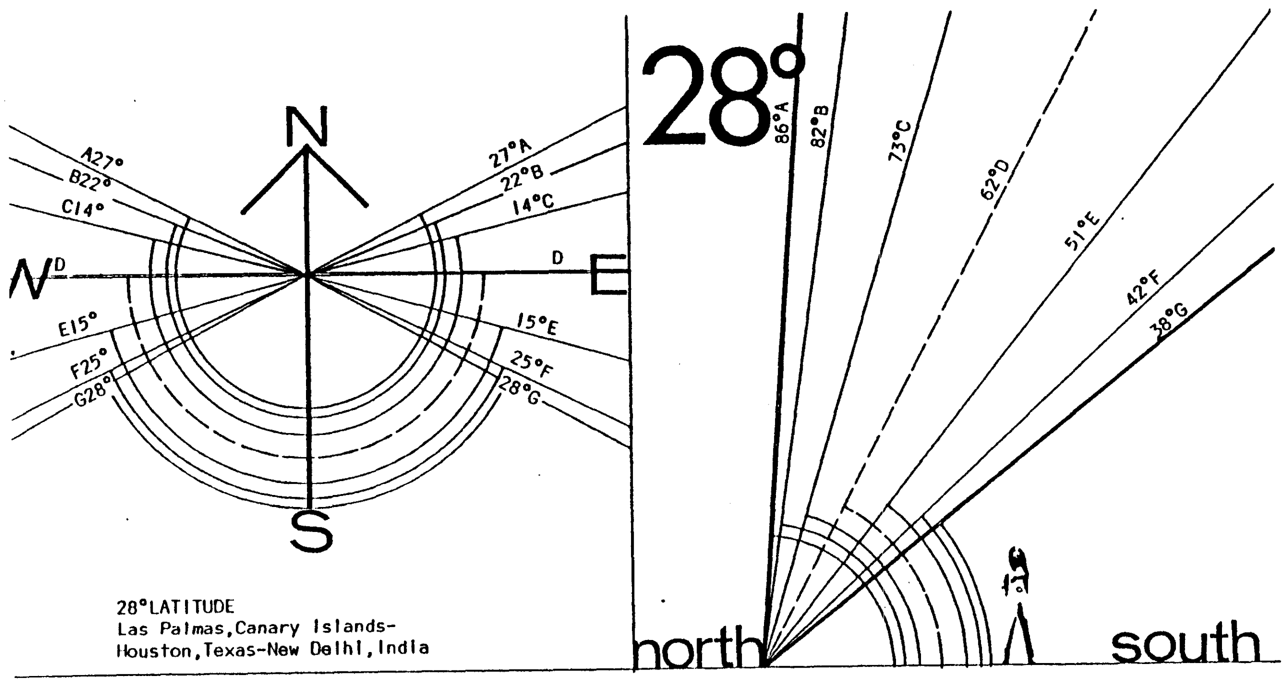


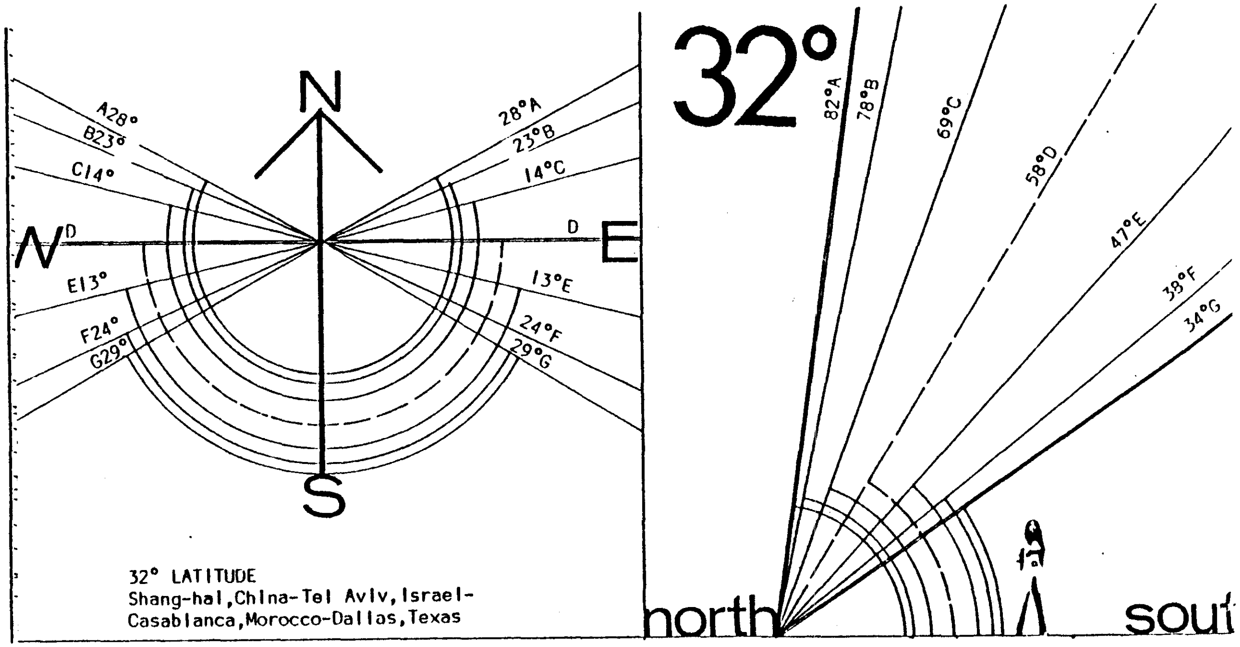

# BARNABE PASSIVE SOLAR HOUSE

ROBERT BRUNKAN

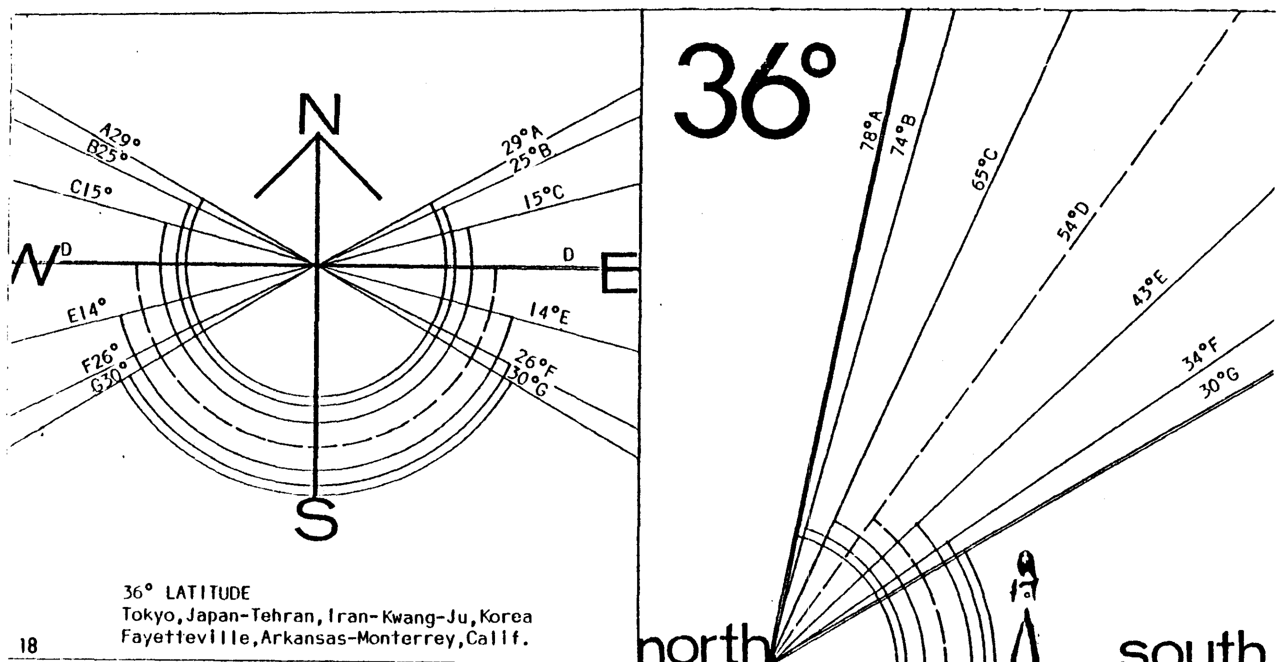
# APPENDIX


sunset
sunrise
N
W
E
S
A25°
B21°
C13°
25°A
21°B
13°C
D
D
E13°
F21°
G25°
13°E
21°F
25°G
24° LATITUDE
Calcutta,India-Miami,Florida-
Dacca,Bangladesh-Monterrey,Mexico
24°
noon
90°A
86°B
78°C
66°D
55°E
46°F
42°G
A. JUNE 22
B. MAY 22-JULY 22
C. APRIL 22-AUGUST 22
D. MARCH 22-SEPT. 22
E. FEB. 22-OCT. 22
F. JAN. 22-NOV. 22
G. DECEMBER 22
north
south

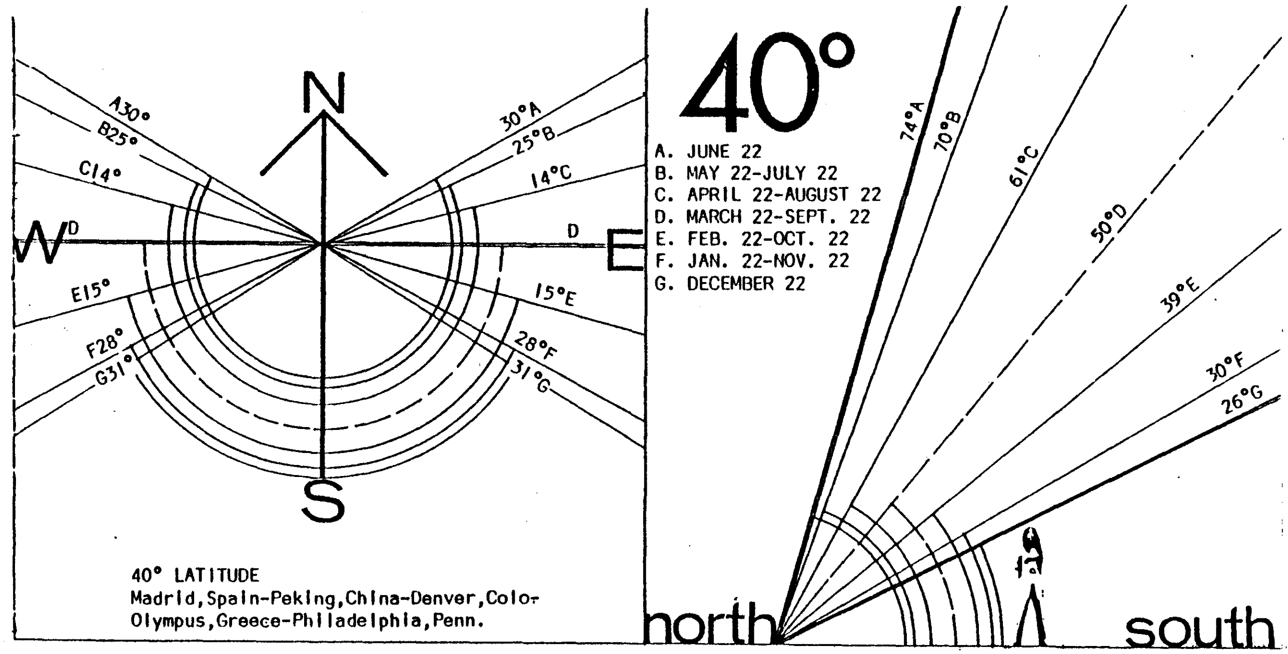

N
W
E
S
A27°
B22°
C14°
27°A
22°B
14°C
D
D
E15°
F25°
G28°
15°E
25°F
28°G
28°LATITUDE
Las Palmas,Canary Islands-
Houston,Texas-New Delhi,India
28°
86°A
82°B
73°C
62°D
51°E
42°F
38°G
north
south

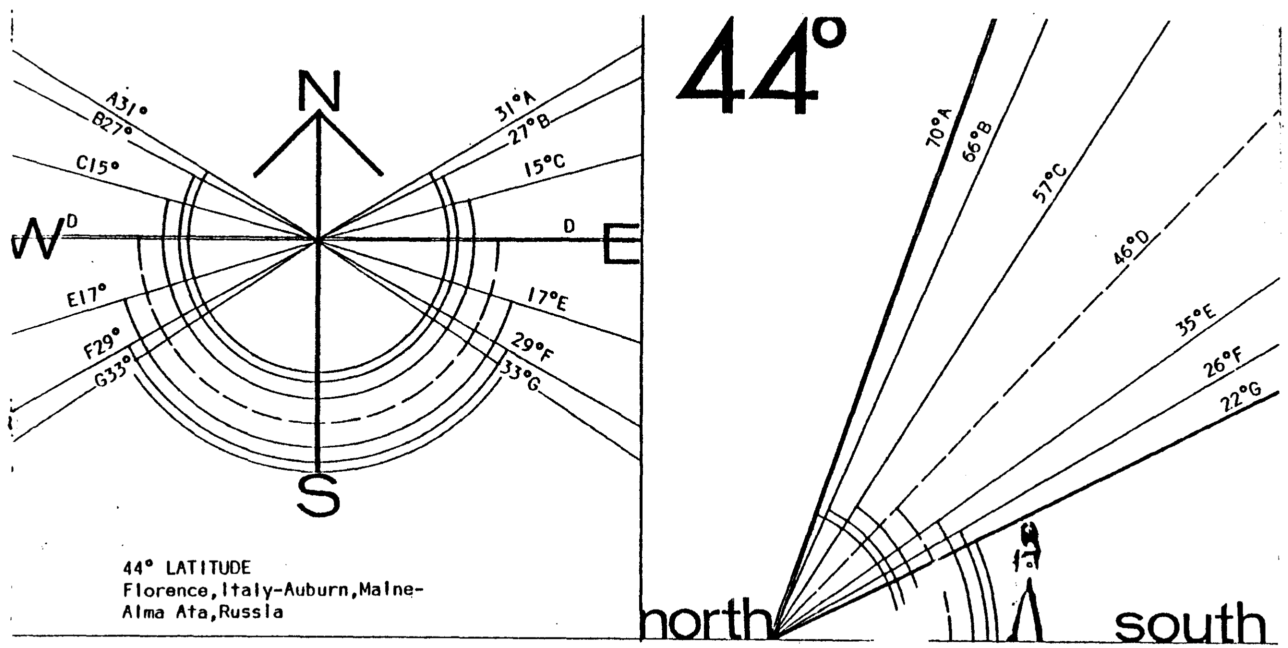



32° LATITUDE
Shang-hai, China-Tel Aviv, Israel-
Casablanca, Morocco-Dallas, Texas

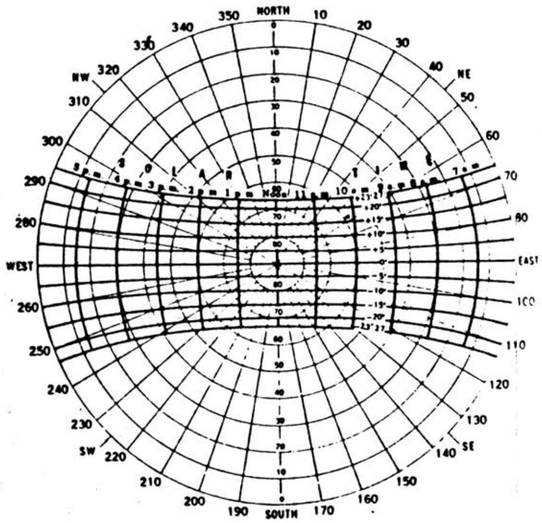



36° LATITUDE
Tokyo, Japan-Tehran, Iran-Kwang-Ju, Korea
Fayetteville, Arkansas-Monterrey, Calif.


40°
A. JUNE 22
B. MAY 22-JULY 22
C. APRIL 22-AUGUST 22
D. MARCH 22-SEPT. 22
E. FEB. 22-OCT. 22
F. JAN. 22-NOV. 22
G. DECEMBER 22
N
S
W
E
D
A30°
B25°
C14°
E15°
F28°
G31°
30°A
25°B
14°C
15°E
28°F
31°G
74°A
70°B
61°C
50°D
39°E
30°F
26°G
north
south
40° LATITUDE
Madrid,Spain-Peking,China-Denver,Colo-
Olympus,Greece-Philadelphia,Penn.

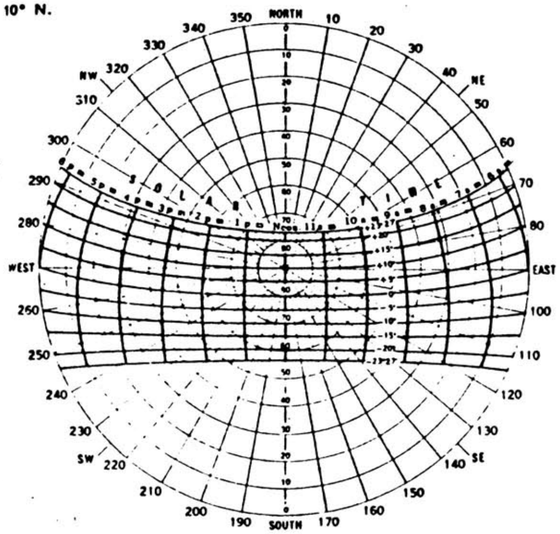

44°
N
S
W
E
D
A31°
B27°
C15°
E17°
F29°
G33°
31°A
27°B
15°C
17°E
29°F
33°G
70°A
66°B
57°C
46°D
35°E
26°F
22°G
north
south
44° LATITUDE
Florence,Italy-Auburn,Maine-
Alma Ata,Russia

0°



—Solar altitude and azimuth for selected days of the year at 0 degrees north latitude.

10° N.



—Solar altitude and azimuth for selected days of the year at 10 degrees north latitude.

20° N.

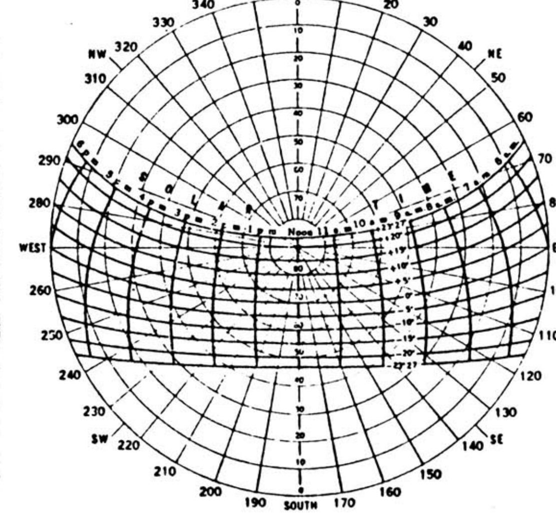
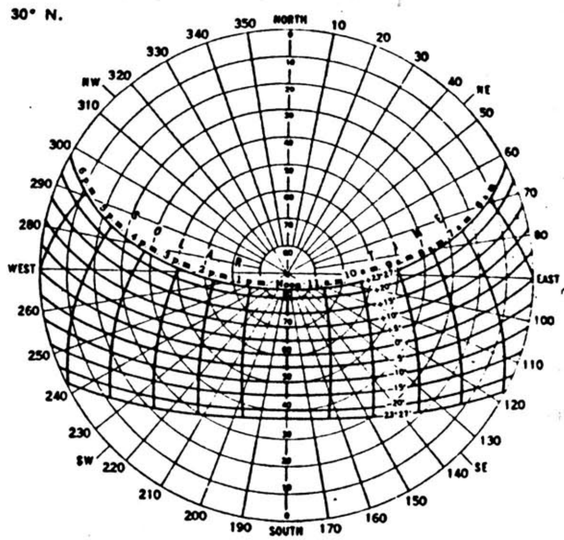


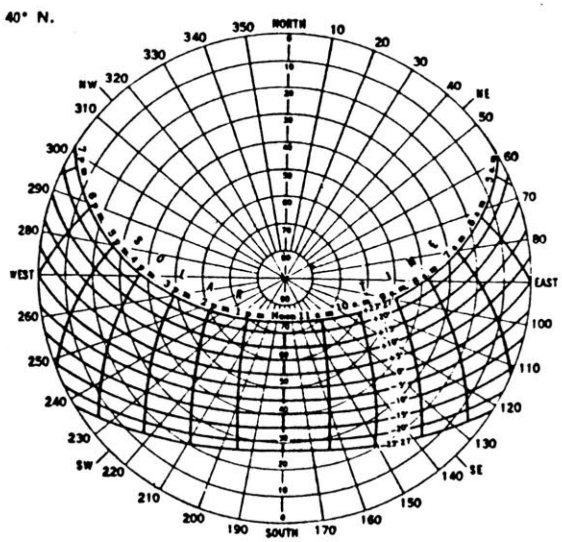
Figure 53.—Solar altitude and azimuth for selected days of the year at 20 degrees north latitude.

30° N.



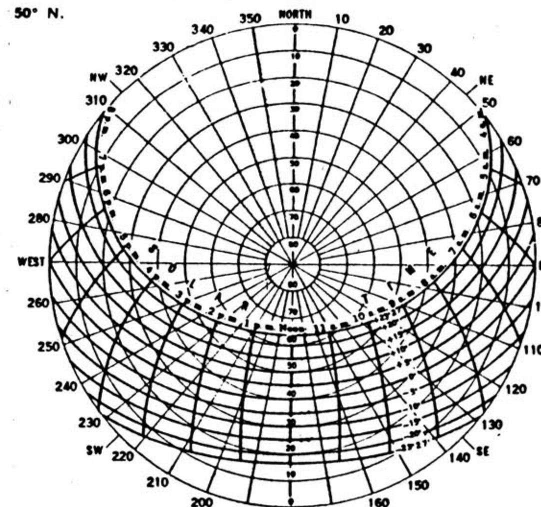
—Solar altitude and azimuth for selected days of the year at 30 degrees north latitude.

40° N.



—Solar altitude and azimuth for selected days of the year at 40 degrees north latitude.

50° N.



—Solar altitude and azimuth for selected days of the year at 50 degrees north latitude.

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