DESIGNING FOR CLIMATE AND ENVIRONMENTAL CONTROL

by 613-8302

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PART I

INTRODUCTION

PART I

INTRODUCTION

Climate and weather affect man's day-by-day life and activities. Safe navigation of ships and airplanes depend on the proximity and severity of turbulence, heavy rain, and thick fog. Farmers depend on the proper proportion of rain, sun, and temperature for successfully growing crops. Many of our social and cultural activities are also involved with both climate and weather.

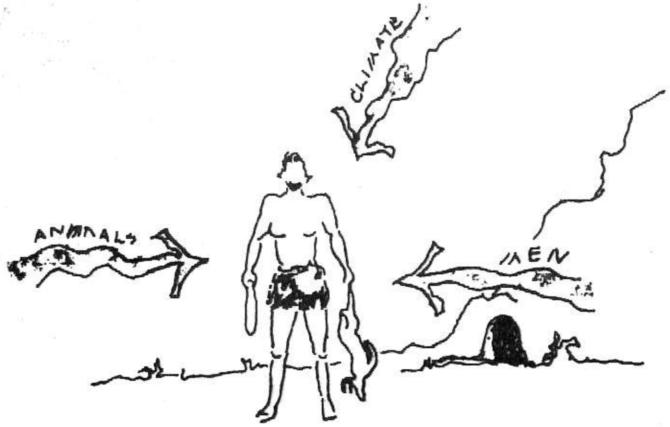
Weather and climate can be defined as the state of the atmosphere at a particular place with reference to the amount of precipitation, sunshine, wind, etc. However, weather is the local expression of climate, it changes from hour to hour and day to day, while climate varies only slightly over the centuries.

As man spread out into all parts of the world, he was forced to develop various methods of protection from the natural elements; heat, cold, rain, and excessive dryness, or a combination of these. He accomplished this by the design of his clothing and shelter (see Plate I).

As soon as the needs for survival were solved, man began to search for more comfort. For instance, through trial and error he found that if the temperature of his shelter remained somewhere between 74° and 78° F., his body felt more "comfortable." This was particularly true if he could maintain a relative humidity of 50 percent in the air surrounding him. Although it took him until comparatively recent times to translate his "feeling" for comfort into usable data, he attempted to experiment with and develop building materials and techniques that helped to over-

PLATE I

EVOLUTION OF MAN'S INTERNAL ENVIRONMENT

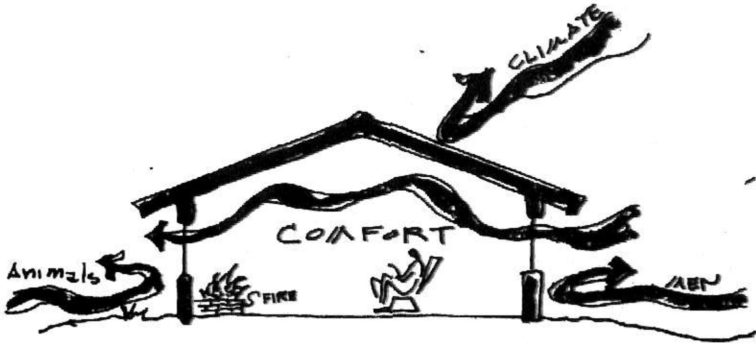


MAN HAD LITTLE PROTECTION
FROM MEN, ANIMALS, AND CLIMATE

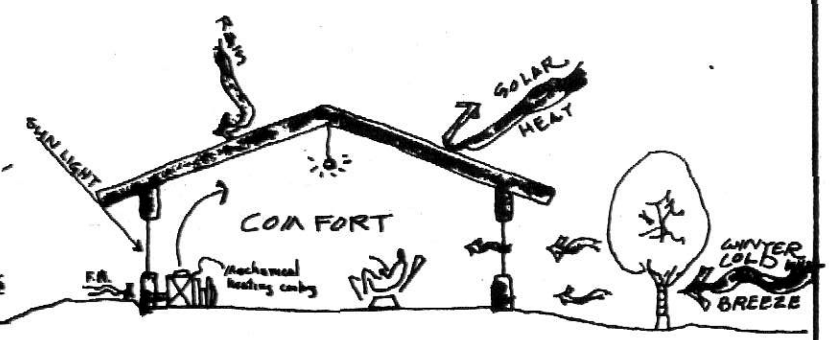
• MAN CAN PROTECT HIMSELF FROM CLIMATE BY <u>CLOTHING</u> • MAN CAN PROTECT HIMSELF FROM MEN AND ANIMAL WITH <u>WEAPONS</u> • BUT THESE ARE NOT ALWAYS ADEQUATE

WITH SHELTERS, MAN CAN BE PROTECTED FROM WILD ANIMALS,
MEN AND ADVERSE CLIMATE

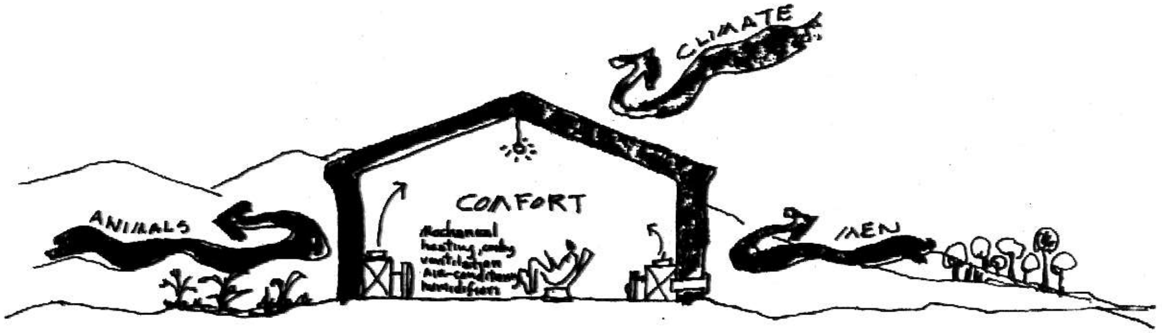
PLATE I (CONTINUED)



SHELTER BECOMES MAN'S CONTROL STATION FOR INTERNAL ENVIRONMENTAL COMFORT IN ADDITION TO PROTECTING AGAINST ANIMALS, MEN, AND CLIMATE.



MAN'S INTERNAL ENVIRONMENT IS FORMED IN CONJUNCTION WITH THE NATURAL ELEMENTS. EACH IS SOMEWHAT DEPENDENT UPON THE OTHER.



WITH NEW DEVELOPMENTS IN MECHANICAL COMFORT CONTROL SYSTEMS, MAN'S SHELTER IS ABLE TO BE TOTALLY DEPENDENT OF THE NATURAL EXTERNAL ENVIRONMENT.

come climatic variations that were "uncomfortable" to him. The development of these "systems" -- a combination of material, building techniques and crude mechanical devices -- continued until the very recent development of fairly sophisticated mechanical temperature control systems made it possible for him to "specify" the degree of comfort to be maintained in his home.

As a result of the availability of these merely effective mechanical devices, architects and builders tend to ignore design for comfort and rely on mechanical devices, to not only maintain temperature comfort, but also overcome the inefficiency of bad design.

In this study, special emphasis is placed on "natural" means of comfort control, however, basic principles of mechanical comfort control systems are also included. There are three main objectives in this study involved with climate and internal environmental comfort. The first objective of this study is to introduce the general nature of climate, the different climatic types in the world, and the effect of climate on man. The second objective is concerned with the development of an architectural approach to design for the various climates. The third objective is an approach to the design of residences that will help control objectionable natural elements and also use favorable natural elements to create a suitable and pleasurable environment.

Climate is one of the main elements effecting architecture and the development of internal comfort control (see Plate II). Houses in the past were designed and oriented according to climatic conditions. The use of various weather control elements such as sun shading devices, windbreakers, etc., the design of interior courts, and features such as the long deep arcades of Greek and Roman buildings were built to protect against adverse natural elements and help to provide necessary comfort.

In the design of shelters, if the building does not have a full mechanical comfort control system, it is particularly necessary to consider adverse climatic conditions and their influence on human comfort. The orientation of the building and the proper design of roof, overhangs, the use of natural wind-breakers and weather barriers, such as trees, shrubs, and vines, are some of the design considerations that are very important to help maintain comfort. However, the architect should always be aware that the utilization of such design devices will also significantly enhance the efficiency of well-equipped mechanical systems and provide considerable saving.

This study has been divided into four major parts. The first part defines the types of climate in the different parts of the world and the climatic factors involving human comfort. The second part of the study emphasizes the importance of climate on plants, animals and men. The third part is concerned primarily with comfort control with respect to climate, employing both mechanical and non-mechanical devices. Part four of this study illustrates schematic approaches to design, with respect to several climatic zones. These schematic design studies illustrate how "natural" and non-mechanical elements can be incorporated into the design of man's shelter to improve his comfort.

EXPLANATION OF PLATES II AND III

These plates show the elements which influence the shape and form of buildings. It consists of climate and other relative important elements (Plate II). Therefore, architects should study these elements in order to maintain relative comfort in the buildings as well as the aesthetic impression of their buildings (Plate III).

PLATE II

The Influencial Elements
on
The Shape and Form of Buildings

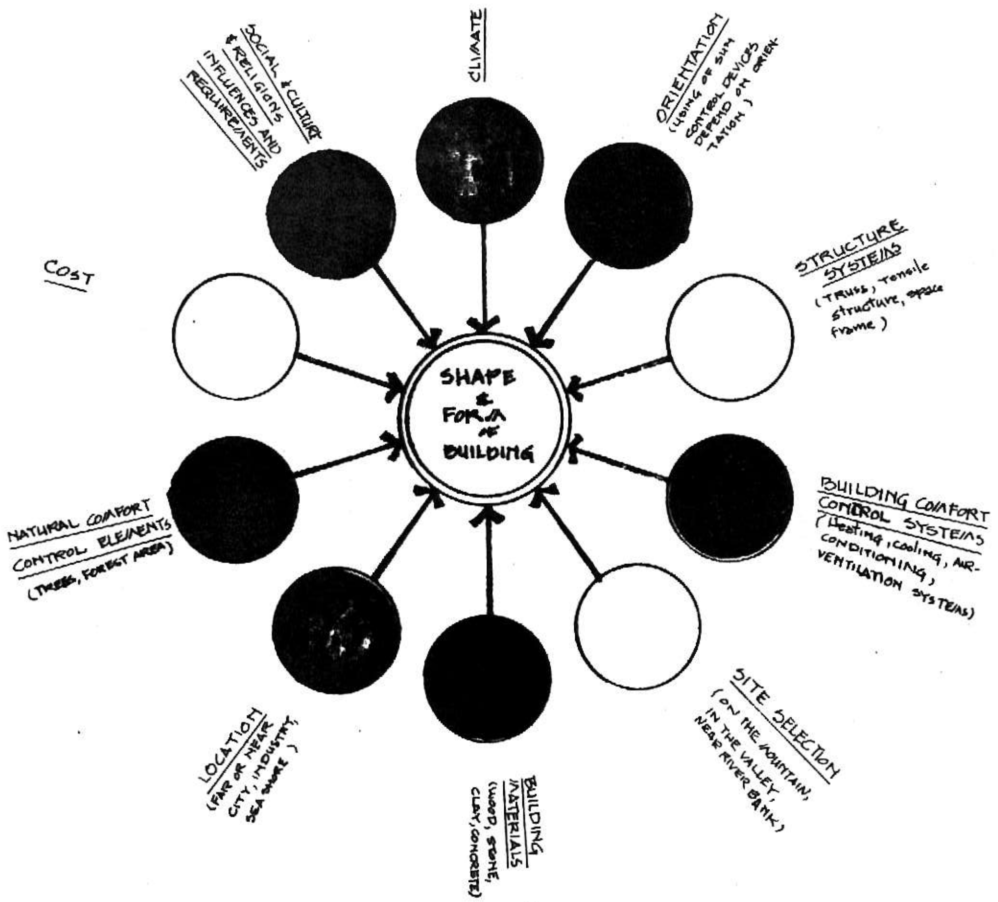


PLATE III

Architecture should encompass

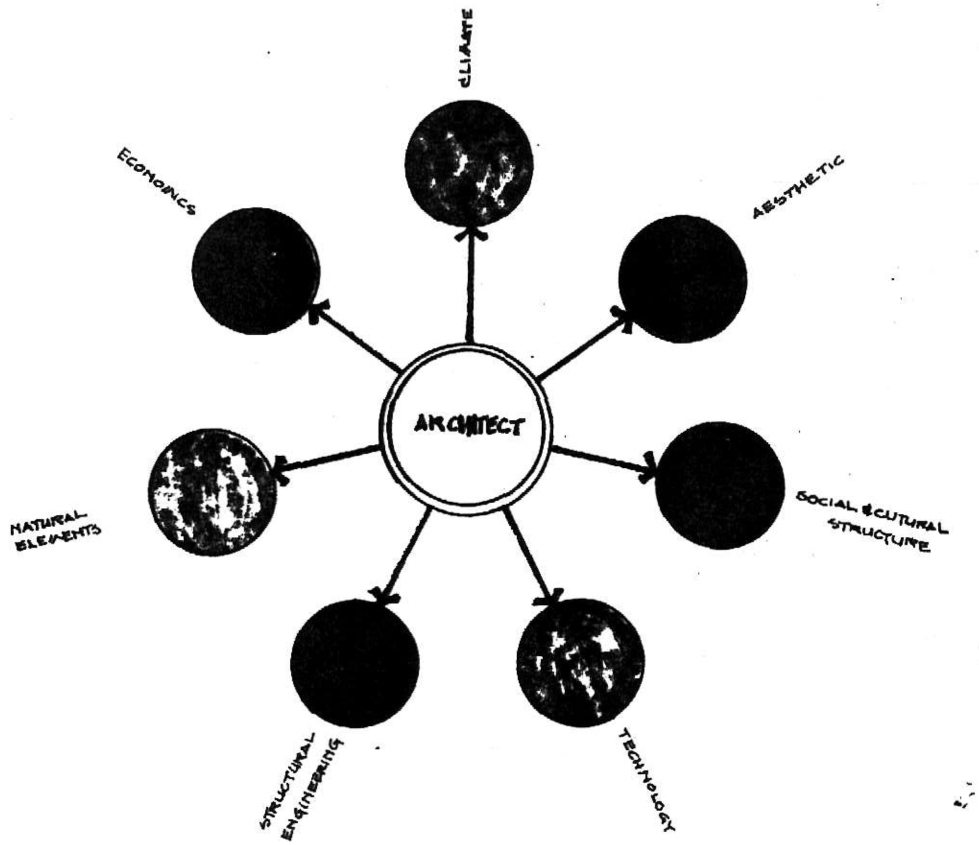
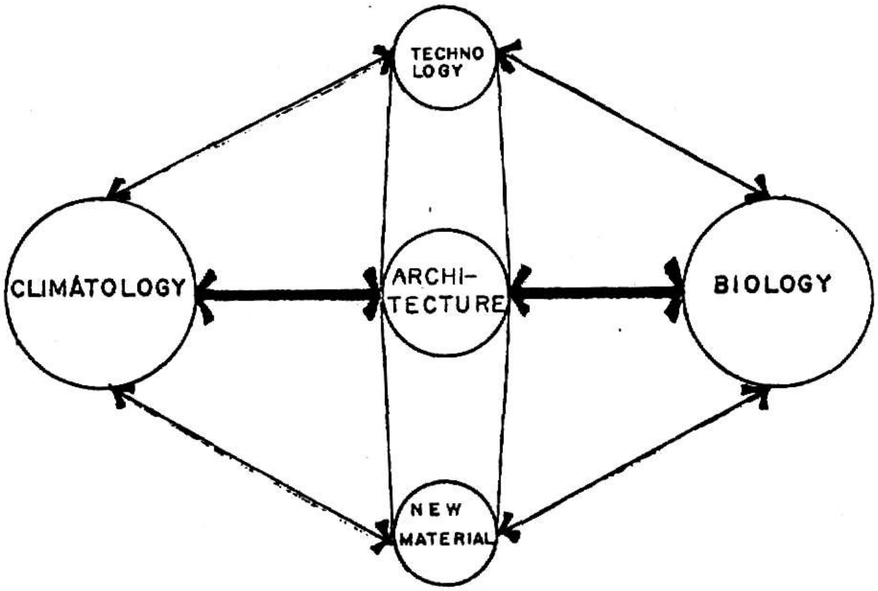


PLATE IV

CLIMATIC RELATIONSHIP WITH OTHERS ELEMENTS



CLIMATOLOGY : CLIMATE , MICRO-CLIMATE; RELATIVE HUMIDITY, TEMPERATURE, AIR MOTION, ETC.

BIOLOGY : RATE OF METABOLISM, LIVING WELL (COMFORT), ETC.

ARCHITECTURE: HOUSING LAYOUT DESIGN; HOUSING FORM DESIGN WITH ORIENTATION, SITE SELECTION, SITE LOCATION, ECT.

TECHNOLOGY : USING SUN CONTROL DEVICES, WIND BREAKER, NEW STRUCTURAL TECHNOLOGY, NEW TYPES OF MECHANICAL HEATING AND COOLING SYSTEM, ETC.

NEW MATERIALS: USING ALL AVAILABLE NEW MATERIALS TO IMPROVE LIVING COMFORT AND ARCHITECTURAL AESTHETIC, ETC.

PART II

CLIMATE IN GENERAL

PART II

CLIMATE IN GENERAL

I. TYPES OF CLIMATE IN THE WORLD

Climate in the world can be classified into six different zones:

1. hot,
2. monsoon (cold, dry winter, wet summer),
3. mediterranean (hot, dry summer, cold wet winter),
4. desert
5. temperate, and
6. cold.

But, for the purposes of human activities in different climatic zones, some modifications are needed. C.E.P. Brooks thus divides the world into nine climatic regions:[1]

1. Polar Regions and Tundras

These are inhabited, if at all, only by scattered hunting or fishing tribes; their chief economic product is fur. These regions are Greenland, the northern part of Canada, and the northern part of the Soviet Union.

2. Mountain Regions

According to C.E.P. Brooks, these generally have only a scattered population; success is difficult. These regions are important because of their healthfulness and winter re-

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[1] Charles E. P. Brooks, Climate in Everyday Life, (New York: Philosophical Library, 1951), p. 18.

creations.

3. Deserts (annual rainfall below 10 inches)

Apart from irrigated regions, such as the Nile Valley, and some mining centers, these also are very sparsely inhabited. These regions include the northern part of Africa, central Australia, and some parts of the southwestern United States.

4. Insolation Climates

These regions are where the main feature of life is the intense solar radiation. They are rather dry and dusty in summer, but generally have sufficient water for irrigation. Brooks pointed out that the high day temperatures in these regions can cause trouble with any materials which soften with heat, such as photographic films, confectionery, electrical insulation, etc. These troubles are aggravated by condensation at night, due to the very large daily range of temperature, and this causes powdered products to cake. These regions are often subject to strong winds carrying very fine, penetrating dust. He explained: "Activity is impossible during the hottest part of the day, and there is risk of heat stroke. In spite of all these disadvantages, they are often economically important, owing to the high crop yields under irrigation. Egypt is the outstanding example."[2]

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[2] Ibid.

5. Deterioration Climates

These are regions of high humidity combined with steady night temperatures which, however, are not extreme. The forests have been masters of these regions, and they are of great importance for the supply of tropical agricultural products. These regions include some parts of Brazil and the Congo, most parts of southeast Asia.

6. Typhoon and Hurricane Regions

These regions, such as the West Indies, southeastern United States, parts of the coast of India and China, and subequatorial islands, such as the Philippines, having climates which are on the whole favorable, but which are liable to destructive winds. All the permanent buildings in these regions must be specially built to withstand these forces.

7. Mediterranean Climate Regions

According to C.E.P. Brooks, these regions are very pleasant. The winter climate is ideal, but the summers are too hot for sustained energy. They are most extensive on the coasts of the Mediterranean Sea, whence they take their name, but they also occur in southern California and a few other parts of the world. They produce wine, olives, and similar deep-rooted crops.

8. Cyclonic-Temperate Climates

The main feature of these climates is their changeability. The passage of cyclonic depressions maintains a continuous series of rapid changes of temperature in all seasons. Rainfall is sufficient at all seasons; persistent extreme heat or cold is rare. The main regions included are parts of western and eastern United States and Canada, northwest Europe, Japan, parts of Chile, southeastern Australia and New Zealand. Brooks believed: "The climate is very stimulating, and the peoples of these regions are the most energetic and progressive in the world."[3]

9. Winter Frost and Snow Climates

These regions include the northern part of the United States, Canada, and the central portion of the Soviet Union. Their main characteristic is the long, cold winter, in which the ground is snow-covered for some months.

Although climate, unlike the weather, does not change from day to day, there are some evidences suggesting that climate does change slowly from century to century. One evidence was pointed out by Edwin H. Colbert of the American Museum of Natural History and Columbia University. He explained in his article called "Vertebrate Paleoecology" in the book, Climatic Change, that so far as past climates can be interpreted from the record of fossil vertebrates, it would appear that during much of earth's history, the world has enjoyed uniformly warm, equable climates over most of its surface. He believed that the earth's surface cools slowly, but each part of the surface has a different degree of cooling (or may be warmed differently by radiation

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[3] Ibid., pp. 18-21.

from the earth's surface or the sun).[4]

The relationship of these nine climatic regions and six climatic zones is that the different climatic regions represent the geographical characteristics of that certain area in each continent, while the climatic zones represent each country in general. The United States, for instance, is generally classified as a temperate climatic zone country, however, geographically, there are several others: cold climatic types in the northern part, hot humid in the southeastern and the south, hot and dry in the southwestern, and temperate in the western-central part of the country.

These are important to the architect in terms of a micro-climatic study, or the local climatic condition study, because each of the micro-climatic zones of each land is different, to some degree. The site in a hot, humid climate, for example, may differ greatly in temperature and humidity from other sites which are located on mountains or in valleys a few miles away, in the same climatic zone.

Therefore, the study of the different regional types, as well as the different zones of climate, is very important to the architect who wants to design and build shelters and who wants to take advantages of nature into consideration of climate and its influence into design. However, for the convenience of this study, we divide climate into four different types: hot humid, hot dry, temperate and cold.

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[4] Edwin H. Colbert, Climatic Change, (Cambridge: Harvard University Press, 1951), p. 269.

EXPLANATION OF PLATE V

Figure 1. Types of Climate of the World.

Figure 2. Areas of the World where temperatures for the warmest month do not exceed a mean of 75 F. and for the coldest month do not fall below a mean of 32 F, 20 or 10 F. Tropical area within these limits have been excluded because of the greater intensity of solar radiation.

(Taken from S.F. Markham, Climate and the Energy of Nations, (London: Oxford University Press, 1944), p. 98.

PLATE V

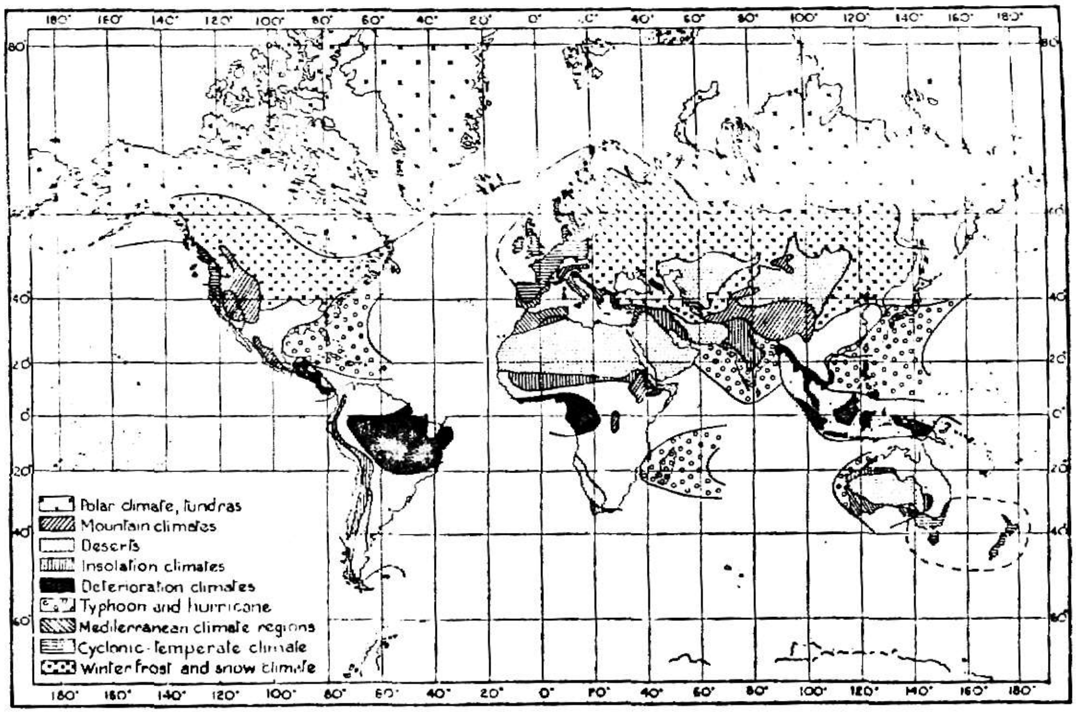

Fig. 1

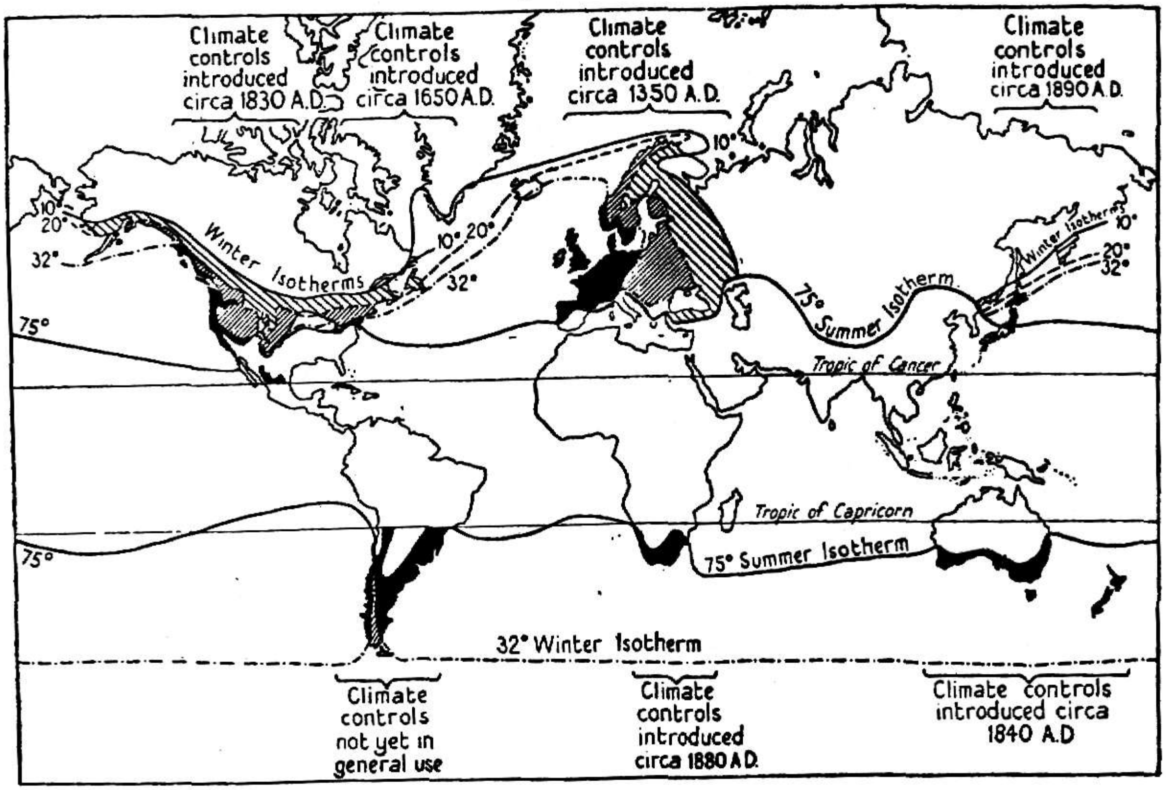

Fig. 2

II. CLIMATIC FACTORS

"The various atmospheric processes and conditions whose interactions determine the climate of any place, are called 'climatic elements' or 'climatic factors.' They are temperature, humidity, rain or snow, velocity and direction of the wind, etc.," said Dr. Julius Hann of the University of Vienna.[5] It is impossible to list all of the climatic factors, because the numbers can be arbitrarily increased. But, the following may be listed for the advantage of the architect:

1. Solar Radiation

The sun is the most important climatic factor because it influences the change in climate, and season; it causes the wind to blow. Temperature, humidity, and precipitation, are all influenced both directly and indirectly by the sun. It also has a great impact upon plants, animals, and human beings upon the earth. It is so important that Dr. Hann wrote in his book, Handbook of Climatology, "In so far as climate depends only upon the amount of solar radiation received at any place by reason of its latitude, it is called 'solar climate.'"[6]

Architects are trained to consider solar radiation as one of the major elements for coordinating into the total design. Site selection, orientation of the building, and the location of its openings, should be designed with respect to the sun's rays. Sun control, thus becomes a very important element in design.

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[5] Dr. Julius Hann, Handbook of Climatology, (New York: The Macmillan Company, 1903), p. 3.

[6] *Ibid.*, p. 91.

The solar constant is the amount of the sun's energy that falls in a unit of time on a unit of area 93,000,000 miles from the sun and perpendicular to its rays. According to Victor Olgyay, in Design with Climate, the mean value is 1.94 cal/cm^2/min. which is generally accepted as equivalent to 420 BTU/ft^2/hr.[7] The actual surface at ground level receives considerably less solar energy, because of a series of losses which occur when the radiation passes through the earth's atmosphere. Part of the incoming solar radiation is reflected by the surface of clouds, and part is absorbed by atmospheric ingredients.[8]

2. Temperature

An important climatic factor is temperature. According to Dr. Hann, when the term temperature is used in climatology, it means the total effect of the warmth of the air, and also of radiation. Out of doors, plants and animals are always under the influence of the temperature of the atmosphere which surrounds them, the heat due to radiation from the sun, the sky, the surface of the earth, etc.[9] It is known that on a clear day in the summer, air temperature is usually warmer than on a clear winter day. This is because of the earth receiving the sun's energy for a longer period of time in the summer than

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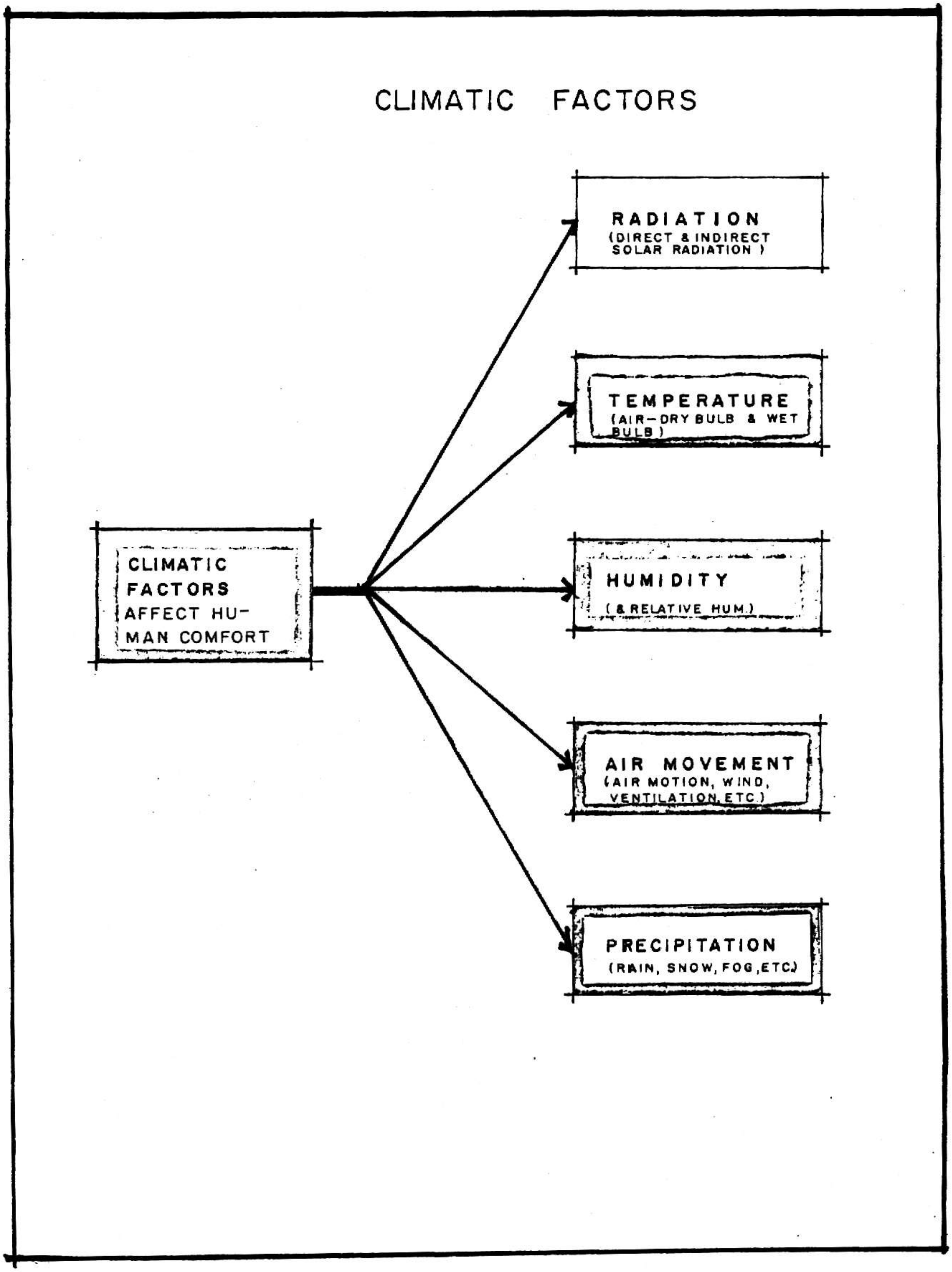
[7] Victor Olgyay, Design with Climate, (Princeton: Princeton University Press, 1963), p. 32.

[8] Ibid., p. 32.

[9] Dr. Hann, op. cit., p. 32.

PLATE VI


CLIMATIC FACTORS
CLIMATIC FACTORS AFFECT HUMAN COMFORT
RADIATION
(DIRECT & INDIRECT SOLAR RADIATION)
TEMPERATURE
(AIR-DRY BULB & WET BULB)
HUMIDITY
(& RELATIVE HUM.)
AIR MOVEMENT
(AIR MOTION, WIND, VENTILATION, ETC.)
PRECIPITATION
(RAIN, SNOW, FOG, ETC.)

it does in the winter. On a clear day in the winter, it is cooler than a cloudy one, because of the longer period of nocturnal outgoing radiation heat, which escapes more easily through the clear atmosphere.[10] Owens-Corning Fiberglass Corporation published a paper called the Economics of Sensible Heat Control, describing the duration of solar exposure in this manner:

> ...... the period of solar exposure is shortest at the winter solstice (Dec. 21) when the north pole is inclined furthest from the sun. At the perpendicular to the earth's orbital plane, the northern and southern hemispheres are illuminated for equal periods of time. Maximum exposure occurs at the summer solstice (June 21), when the north pole is tilted toward the sun, causing 15 hours of daylight at 40 north latitude, as compared with only 9 hours during the shortest day of the year...
>
> The magnitude of insolation will vary with the duration of solar exposure, and, in combination with meterological phenomena, will determine the actual number of hours of sunshine daily in any given period or locality...[11]

3. Humidity

Next to temperature, the climatic factor of the most importance is the measure of humidity. Humidity is the degree in which the air is charged with water vapor. The humidity of the air, according to Givoni, in Man, Climate and Architecture, (page 56), may be expressed in various ways; in terms of relative humidity, absolute humidity, specific humidity, or vapor pressure. He explains:

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[10] Victor Olgyay, op. cit., p. 32.

[11] ______, The Economics of Sensible Heat Control, (New York: Owens-Corning Fiberglas Corporation, 1970), p. 10.

> The humidity of the air does not directly affect the heat load operating on the body, but it determines the evaporative capacity of the air and hence the cooling efficiency of sweating. In extremely hot conditions, the humidity level determines the limits of the endurance time by restoring the total evaporation.

The water vapor, or moisture in the air, may cause a great deal of discomfort to some people. If, for instance, the humidity is too high, the rate of perspiration of our body will be small compared with the amount of evaporation, this may cause the feeling of clamminess and dampness until some air movement occurred. Humidity can also cause the wetness in buildings, which constitutes a potential hazard to health and comfort and is a source of aesthetic and material damage. Charles Franklin Brooks explained that if little water vapor is present in air and the relative humidity is low, as in our houses in winter, evaporation is rapid. Throats become dry and parched, skin chaps, bread and cake get dry and crumbly, leather cracks, and wall paper rattles.[12] S.F. Markham concluded the impact of humidity in his book, Climate and the Energy of Nations, as follows:

> The combination of heat and humidity, in particular, is one of which the human body cannot gladly endure, and humanity has devised little protection against such conditions. Since moist heat at 80 F. may cause sunstroke, while a dry heat of 100 F. can be safely endured, it is important that we should know the degree of moisture in the air...
>
> Like temperature, the relative humidity of the atmosphere changes every hour, but in spite of fluctuations it is almost as steady as temperature...[13]

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[12] Charles Franklin Brooks, Why the Weather?, (London: Oxford University Press, 1944), p. 23.

[13] S. F. Markham, Climate and the Energy of Nations, (London: Oxford University Press, 1944), p. 23.

4. Wind

"Atmospheric currents are important climatic factors for many reasons," said Dr. Hann. "As a general rule, climates with a considerable air movement have a stimulating effect upon man, which is conducive to active work; while climates where calms prevail have an enervating effect, which is conducive to inactivity."[14] Wind is simply air in motion. Air moves because of horizontal differences in atmospheric pressure, which results directly, or indirectly, from contrasts in temperature. According to Charles F. Brooks, of Harvard University, wind velocity depends, principally, on the pressure gradient, the air density, the latitude, and the friction.[15]

In the designing of a building with the advantage of prevailing wind, the architect should study the local wind directions, and its velocity, in order to place the openings to take advantage of them. He should also study the wind's behavior if a structure will be located on an unfamiliar site, such as on the top of the mountain, in the mountain valley; "Although, in general, valley sites offer protection, the wind speed is highest in the narrowest parts when the wind blows along the valley. Furthermore, the wind direction will be modified in narrow valleys and gorges, so that it is mostly up or down the valley."[16]

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[14] Dr. Hann, op. cit., p. 67.

[15] Charles Franklin Brooks, op. cit., p. 45.

[16] Neuberger and Stephens, Weather and Man, (New York: Prentice-Hall, Inc., 1950), p. 168.

They continue: "In flat, open plains, there is little difference in building lots so far as natural wind protection is concerned, with the possible exception of the protection offered by trees."[17]

In the United States, the wind direction was described by Thomas Morris Longstreth as follows:

> The west wind would rate highest in a country-wide poll. It is the temperate feature of our Temperate Zone. Its somewhat descending current clears the sky, tempers the summer heat, adds the cheerfulness of sun to the winter's cold ...
>
> The north wind can be simply frigid. Its vitality differs with the place. To the Great Plains and to Texas, the northerners bring violent gales, fog-thick with snow, with drops of 50 F. in temperature, the true blizzard. In the East a north wind is usually the waning stage of a northwest wind, and rarely strong...
>
> South winds receive some flattery that is not their due. In winter a south wind ends a cold spell and brings the damp of thaw, which is worse. In summer it increases the humidity in the east and the drought over the Great Plains ...[18]

5. Precipitation

Precipitation includes rainfall, snow, dew, hail, fog, and haze, etc. Haze is caused by dust, by salt blown from the ocean spray, or by tiny particles of water. All these things reflect light waves, sending them in every direction. This makes mountains, buildings, and trees look blue when we see them from far away. Fog is clouds that form near the earth's surface, according to Fenton, fog

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[17] *Ibid.*, p. 168.

[18] Thomas M. Longstreth, *Knowing the Weather*, (New York: Macmillan Co., 1942), p. 51.

droplets are at least twenty times larger than haze droplets. They absorb so many light rays that foggy days often become as dar as evenings.[19] Snow is formed by the condensing of the moisture of the air at temperatures below freezing.[20]

Rain is formed by the condensation of the moisture in the air. The rainfall is a very important climatic factor which Dr. Hann described as "the determination of the preductiveness of a country." He insisted that temperature and rainfall together are one of the most important natural resources of a country.[21] The rainfall and other precipitation are the greatest importance to vegetation.

However, the rainfall and other precipitation can cause some damage to plants, animals, and to men's property as well. Storms of large hailstones are destructive to crops, windows, and glass walls. A blizzard, which is a combination of very strong wind, very cold weather, and dry "powdery" snow cause numerous property destructions, and is extremely dangerous to highway travel. Fog, when mixed with smoke from factories, will become a dangerous and harmful smog. Therefore, factors should be carefully located where there is less concentration of fog in the surrounding area.

The rainfall directly, and indirectly, effects floods. There is an

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[19] Carroll L. Fenton and Mildred A. Fenton, Our Changing Weather, (Garden City, N.Y.: Doubleday and Company, Inc., 1954), p. 57.

[20] Charles Franklin Brooks, op. cit., p. 228.

[21] Dr. Hann, op. cit., p. 57.

important matter for architects who survey the site for the new structure. Charles Franklin Brooks explained that the risk of flooding by heavy rain depends on the nature of the ground, as well as the amount of rain. He warned that a valley with a small catchment area is more liable to sudden floods than a river system with a large basin. He also pointed out that in any particular situation, the heights of floods in the past are the best guide, provided that the bed of the river has not changed.[22]

There are other ways that architects can find out about the flood level in the past. Brooks suggested that it can be found from natural marks on the banks, marks made on buildings or bridges to record the height of floods. "However, natural marks are not always safe guides because for one thing, capillary action may raise the water level considerably inside the porous stones," said Brooks, "therefore, the best basis for estimating the probable height of future floods is in actual records, either of the depth of water or of the volume of flow."[23]

In the design of buildings, it is essential for architects to take into account rainfall, water table, and the flood condition on the site. Since most buildings have basements, therefore, they are involved with the problems of sewage disposal, drainage, soil condition, etc.

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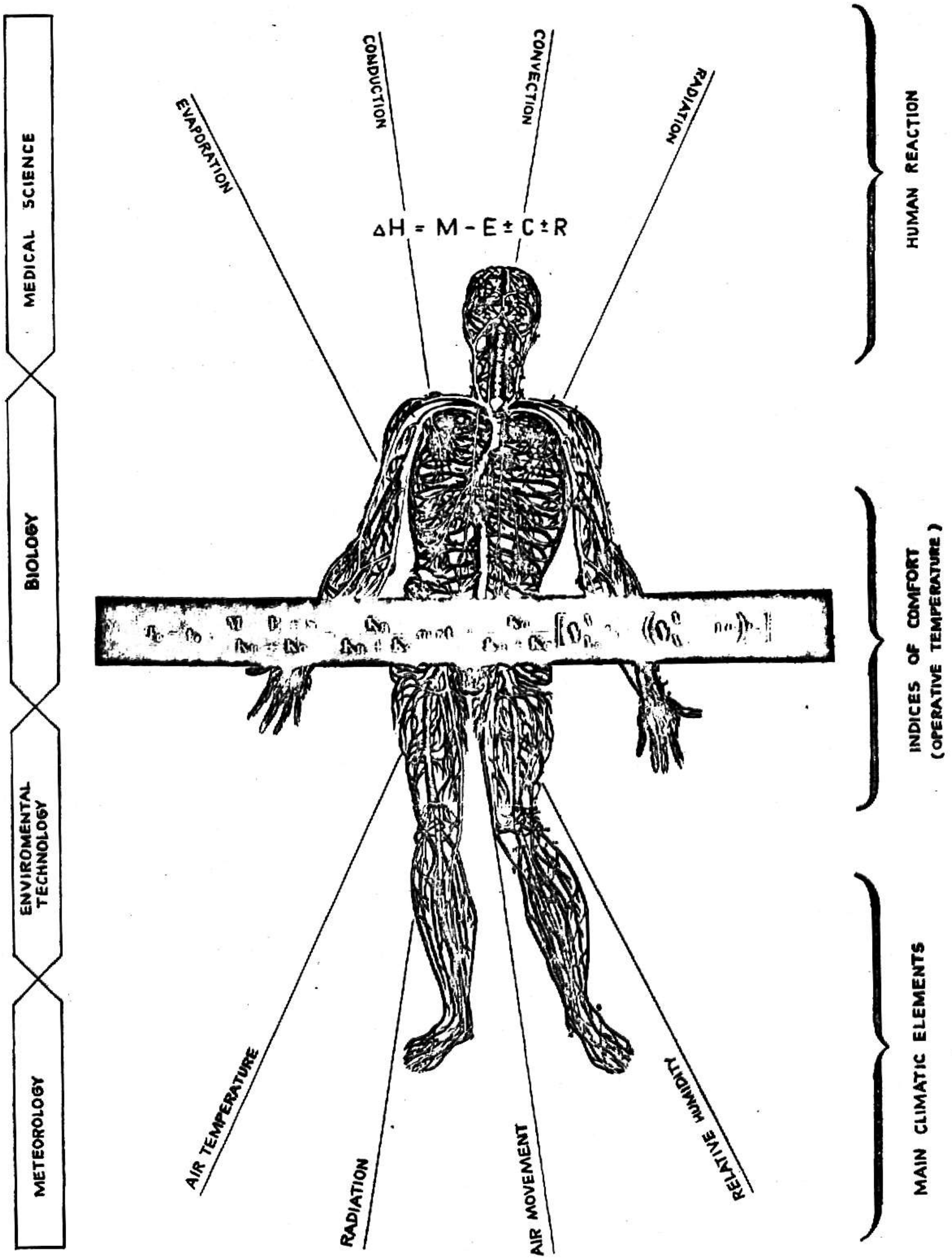
[22] Charles F. Brooks, op. cit., p. 208.

[23] Ibid., pp. 208-209.

PLATE VII

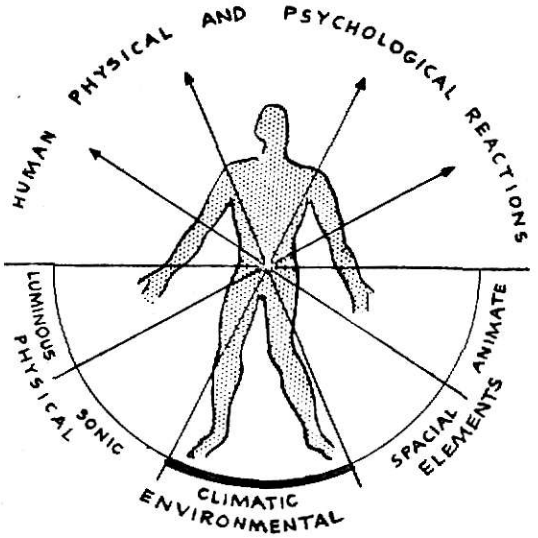


—RELATION OF HUMAN BODY TO CLIMATIC ELEMENTS

PLATE VII (CONTINUED)

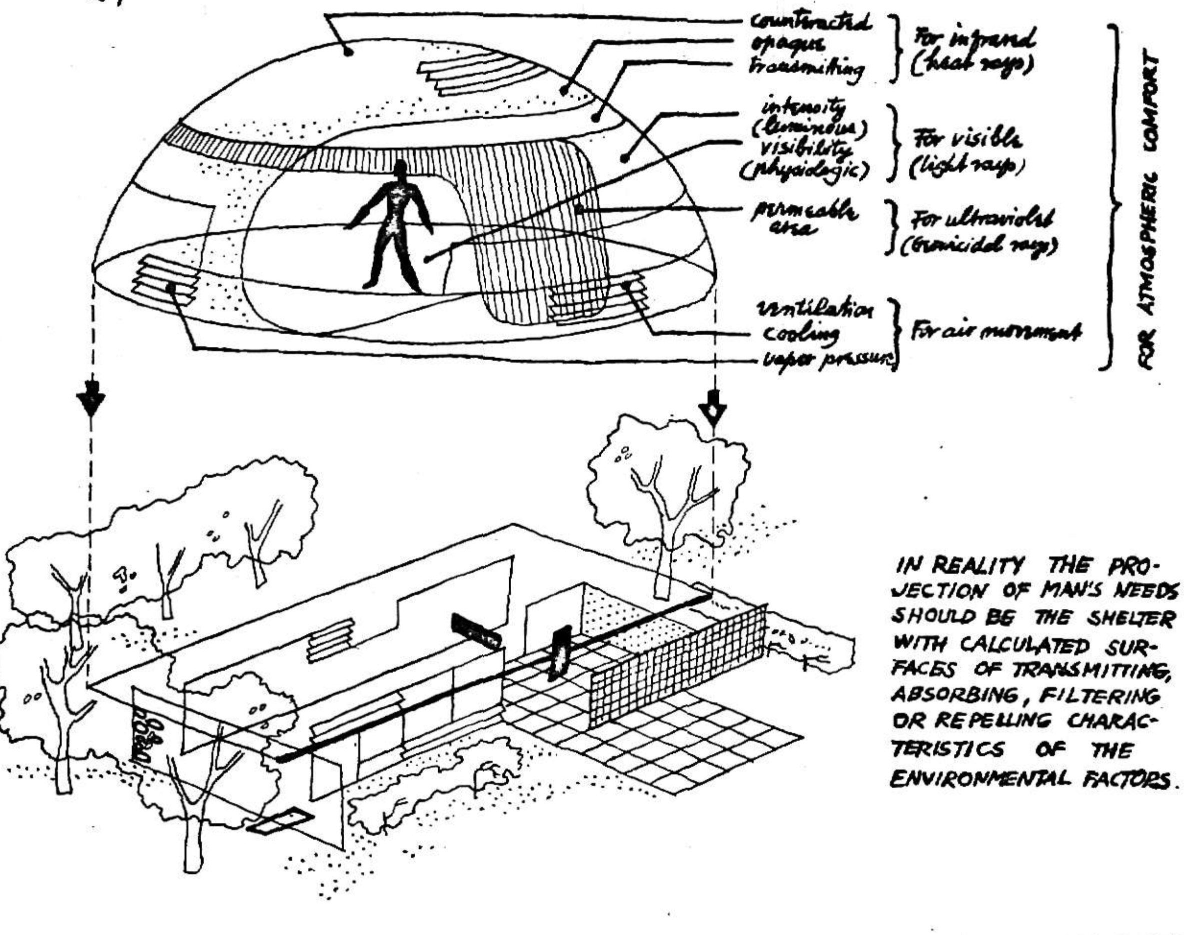
THE CENTRAL MEASURE OF ARCHITECTURE IS THE MAN

a)



ANALYSES OF ALL THE ENVIRONMENTAL ELEMENTS SHOULD BE THE BASIC APPROACH

b)



IN REALITY THE PROJECTION OF MAN'S NEEDS SHOULD BE THE SHELTER WITH CALCULATED SURFACES OF TRANSMITTING, ABSORBING, FILTERING OR REPELLING CHARACTERISTICS OF THE ENVIRONMENTAL FACTORS.

PART III

CLIMATE AND NATURE

PART III

CLIMATE AND NATURE

III. CLIMATE AFFECTS PLANTS, ANIMALS, AND MEN

1. Climate Affects Plants and Animals

Climate has long been the most important element which affects the life cycle of plants and animals, especially since almost all plants are extremely sensitive to climate. Plants can give the indication of changing in weather, which can be learned by watching the time of budding and blooming in the spring.

Rainfall is extremely important to all kinds of vegetation, including desert plants. Plants get food from soil which consists of three major elements: the soil substance, water, and air.

Snow is also useful in piling moisture upon the ground, where it can melt slowly and sink into the soil. Loose snow also makes a fluffy blanket which covers low plants and the ground. Dew often protects vegetation from freezing at night.

Plants also affect our environment. They act as an absorbent material in the landscape, blotting up heat, light and sound. Giving off moisture, they actually destroy a large portion of the heat which falls upon them. Hence, in addition to their shading effect, plants have a definite cooling effect and are of great importance in ameliorating the micro-climate, especially during the summer.[1] James J. Nighswonger, extension specialist in Landscape Architecture at Kansas State University, published a booklet called Plants, Man and Environment, clearly explaining about plants as an "Atmospheric Purification" agent in the following manner:

> Plants cleanse and purify existing air as well as manufacture clean air. Plants use sunlight, water, carbon dioxide, and other atmospheric gases to produce the food they need (the photosynthetic process). During photosyntheses they release oxygen to the atmosphere as a by-product....
>
> Ornamental plants cleanse and purify air by at least four methods:
>
> 1. They dilute bad air by mixing clean air (which they produce) with the bad air....
>
> 2. Growing plants transpire or give off large quantities of water to the air.... Under certain climatic conditions, this moisture also condenses on leaves and twigs. These wet surfaces then serve as effective traps for air-borne particles.
>
> 3. Trees also slow air movement considerably, allowing heavier dust particles and pollutants to settle down....
>
> 4. Fumes and odors may be partially controlled by masking; that is, by covering up or replacing the obnoxious odor with a stronger, more pleasing smell....[2]

James Nighswonger also explained that a plant's ability to modify temperature is a result of a sun control, wind control, and precipitation control. He stated that trees not only give off moisture, but the overhead canopy of leaves tends to prevent the moisture-laden air from

---

[1] ______. Microclimate, the Architectural Forum, March, 1947, Vol. 86, pp. 114-122.

[2] James J. Nighswonger, Plants, Man and Environment, Cooperative Extension Service, Kansas State University, Manhattan, Kansas, 1972.

moving away. According to him, trees are very effective devices for shielding the sun's radiation. About wind control by plants, he pointed out:

> Wind can significantly reduce the effect trees have on temperature reduction. During windy conditions in the summer, moisture-laden cool air within the tree canopy is replaced by dry, warm air carried by the wind. Thus, trees are most effective in modifying summer temperature, especially during relatively calm days when the sun is shining. Since trees screen sunlight and transpire moisture, the area below the tree canopy can be as much as 25 F. cooler on a still day in the summer than an area out in the open ....
>
> Plants intercept precipitation in the forms of rain, snow, of fog. Fog, for example, condenses on the leaves of plants and falls to the ground. Not all rain or snow that falls on a tree reaches the ground.[3]

With this basic knowledge about climate and plants, architects and landscape architects should be able to utilize the use of plants to coordinate with the design.

Unlike plants, animals have freedom of movement, they are able to avoid an unfavorable micro-climate, and can search for suitable conditions. However, they highly develop their adaptibility to certain climatic conditions. Rudolf Feiger gave an example of the adaptability of some animals as follows:

> According to W. Mosauer, the sand lizard can stand the extreme temperatures of desert sand by raising the body a little above the heated ground when running fast. The African cricket, according to F.S. Bodenheimer, turns its body in the

---

[3] *Ibid.*

> direction of the sun's rays about noon, so as to present the smallest possible cross-sectional area to it, but lies broadside to the sun in the cool of the morning.[4]

There is another interesting example of the animal's survival in the extreme climatic conditions, as Geiger pointed out:

> In the desert near Salt Lake City, there lives a type of rabbit that is unable to find water, and can therefore obtain its supplies of liquid only from its scanty nourishment.... it was proved that the animal was able to maintain its fluid balance without ever drinking a drop of water, because of the surprisingly high relative humidity of itw burrow, where it remained for long periods.[5]

With their instincts, animals build homes in which they can bring up a new generation. The necessary micro-climate conditions are taken into account. Geiger, once again, brought up a very interesting example of another kind of rabbit on the North Sea island of Sylt:

> I have always been amazed at the way rabbits on the North Sea island of Sylt arranged their burrows. One had its entrance, for example, on the upper slope of a sand dune, so that when there was heavy rain it collected below, and none came through the opening. An overhanging growth of heather roofed over the entrance and protected it from rain and dripping water. It had a southerly exposure, so that the entrance was sunny, and shielded from north winds. A very large bush to the west provided additional protection from the stormy west winds.[6]

---

[4] Rudolf Geiger, <u>The Climate Near the Ground</u>, (Cambridge, Mass.: Harvard University Press, 1966), pp. 471-472.

[5] <u>Ibid.</u>, p. 475.

[6] <u>Ibid.</u>, pp. 475-476.

Animals, like the example of rabbits on the North Sea island, bees, and so on, have some ability to control their environmental comfort. However, this may depend on their instincts, and their adaptability.

2. Climate Affects Men

Man has the poorest protection against climate in terms of body protection. However, it is believed that man has a better brain than animals. Man can design better protection for his body in the form of clothing and dwellings. He established "culture" and "civilization" which then draws a sharp line between man and animal.

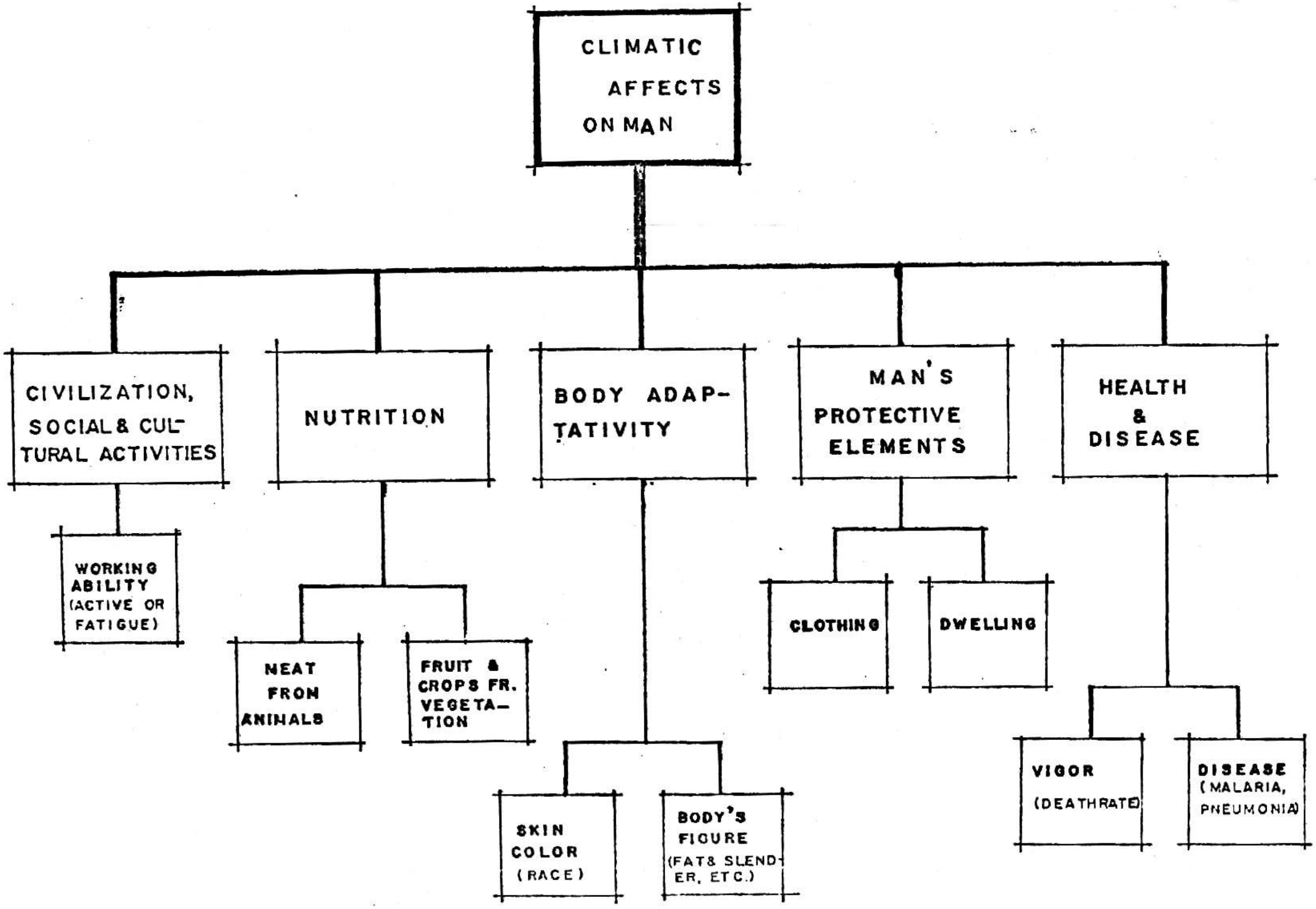
Climate affects man in many respects. It influences, both directly and indirectly, the way of our lives, our social and cultural activities, our health and our food supply (see Plate VIII).

a) Civilization, Social and Cultural Activities

Climate is believed to have a great effect on the birth of any civilization. Climate has a degree of stimulating effect, or retarding effect, upon human activities and the ability to distribute civilization. For example, in the insolation climate, Indian people in India are less active than German people in the temperate climate. In Civilization and Climate, Ellsworth Huntington of Yale University believed that the periods of high civilization had apparently been toward cool, but not extremely cold, and toward the areas of frequent changes of temperature. He also believed that temperature is the climatic factor which has an

PLATE VIII

GENERALIZED CLIMATE / MAN DIAGRAM



especially strong effect on the distribution of civilization.[7]

b) Nutrition

Climate affects the growth of different types of vegetation in different parts of the world. Fruits, such as oranges, and grapes, grow abundantly in the "Mediterranean" climates, while mangos, spices, and pineapples, etc., grow very well in equatorial zones. Rice, tea, coffee, and other kinds of crops also grow in certain climatic zones.

c) Body Adaptability

There is evidence that the human body does have some ability to fight against disease and the adaptability to extreme climatic conditions. In order for man to be able to live comfortably in his own part of the world, his body and his skin has naturally adapted to the local climatic conditions. The color of skin, the color of hair, and the size of people, are all different climatic types and geographical environments. E.C. Semple explained that in the case of the Negro, the dark skin is associated with a dense cuticle, diminished perspiration, smaller chests and less respiratory power.[8] Huntington also pointed out that the Negro's deep pigment is a protection against heat. He continued that Eskimos, Tibitans, and other inhabitants of cold climates tend

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[7] Ellsworth Huntington, Civilization and Climate, (New Haven, Conn: Yale University Press, 1924), Third Edition, pp. 12-13.

[8] Ellen C. Semple, Influence of Geographic Environment, (New York: Henry Holt and Company, 1911), p. 38.

to have a stocky body built with a considerable layer of fat. "People in hot climates, like that of India, tend to be slender, with a relatively large surface of skin compared with their weight. Thus, the evaporation of sweat has a more effective cooling power than in fat people."[9]

d) Man's Protective Elements

Man constructed clothing and shelter to help him maintain a certain temperature level for comfort. According to C.E.P. Brooks, the insulating power of a thickness of cloth is almost proportional to the thickness of the layer of "dead air" between the surface of the outer layer of cloth and the body.[10]

The danger from actinic sun rays which cause inflammation of the skin (erythema) and sunburn, is greatest in dry and tropical countries such as Egypt, India, Africa and Southeast Asia. Therefore, wearing hats, caps or helmets, and waring light colors of clothing became the customs of these countries. It is not surprising when the westerner went to such countries and found that many women use unbrellas when the sun is shining and there is not a drop of rain.

e) Health and Diseases

Climate may have both direct and indirect effect on a human's health, causing some kinds of disease such as malaria, pneumonia

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[9] Ellsworth Huntington, <u>Mainsprings of Civilization</u>, (New York: John Wiley and Sons, Inc., 1945), p. 267.

[10] Charles E.P. Brooks, <u>Climate and Everyday Life</u>, <u>op. cit</u>., pp. 254-257.

and the common cold and hay fever. In Man Adapting, René Dubos claimed that cold, heat, and humidity naturally influence health and disease in many different ways, even under conditions far less extreme. He explained that stormy weather, either warm or cold, is widely assumed to have pathogenic effects. Lung embolism, thrombophlebities, and hemorrhage are said to occur predominantly in warm, damp weather.[11]

Health, or vigor, is a basic factor in determining the rate of human progress, and deathrate is the determination of a country's health and vigor. According to Ellsworth Huntington, among the factors which influence health, climate plays an especially significant part in setting the geographical pattern.[12]

The effects of climate on man are tremendous. Many inventions, from the past to the present time, have also been directly and indirectly connected with climate and the way to control climate. S.F. Markham concluded:

> After a full consideration, I am convinced that one of the basic reasons for the rise of a nation in modern times is its control over climatic conditions: that the nation which has led the world, is that nation which lives in a climate, indoor and outdoor, nearest to the ideal, provided always that its numbers are large enough to resist invasion by its rivals. Civilization to a great degree depends upon climate control in a good natural climate.[13]

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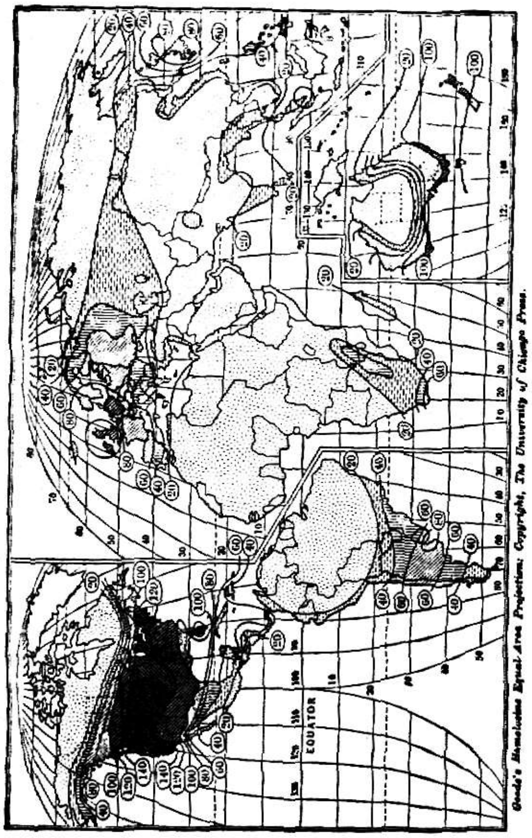
[11] René Dubos, Man Adapting. (New Haven, Conn.: Yale University Press, 1965), p. 60.

[12] Ellsworth Huntington, Mainsprings of Civilization, op. cit., p. 251.

[13] S.F. Markham, Climate and the Energy of Nations, op. cit., p. 20.

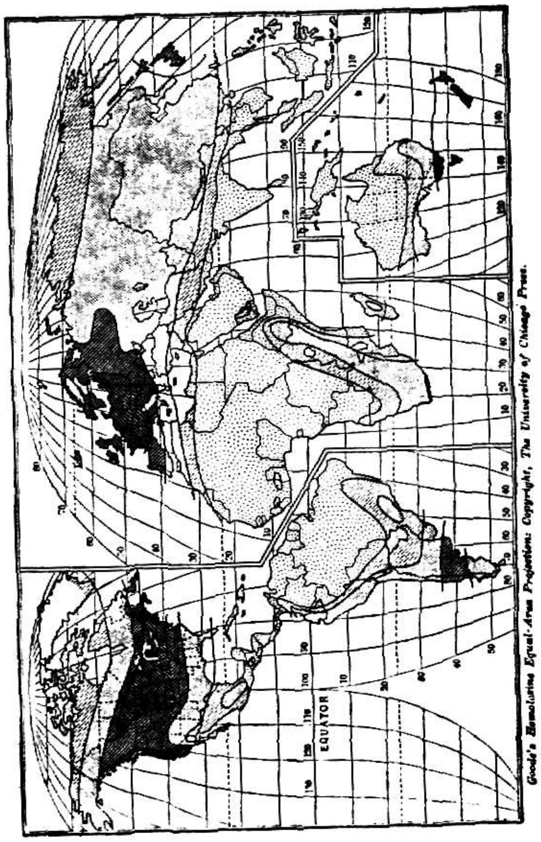
The study of climate control, therefore, is relatively important to architects and builders in providing the necessary internal comfort environment. The utilization of various methods of controlling climate depends on the types and size of dwellings, as well as the location. In this study, we divide the control of climate into two major areas, namely: climate control by mechanical means, which is widely used in the industrial countries, such as America, Europe, etc., and non-mechanical countries, such as Egypt, India, Southeast Asian countries, etc.

PLATE IX



Goode's Homolosine Equal-Area Projection: Copyright, The University of Chicago Press.

World Distribution of Education. From *Principles of Human Geography*, Fifth Edition.



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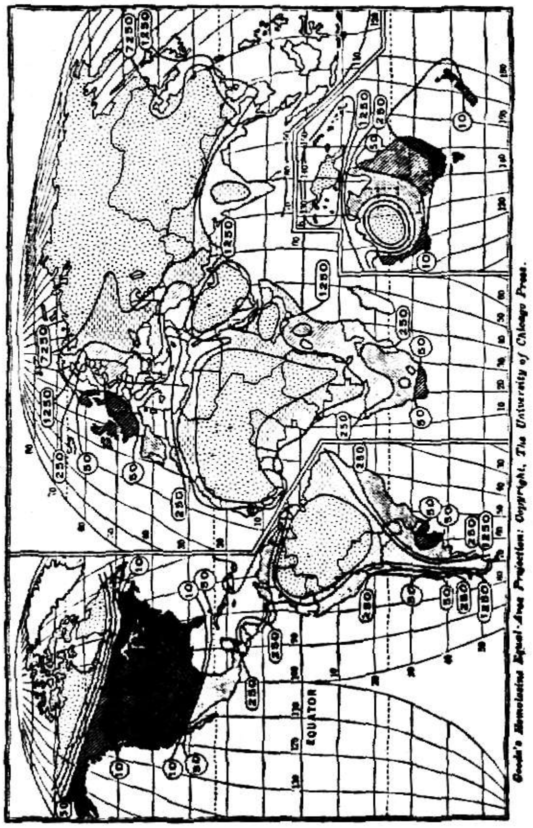
World Distribution of Climatic Efficiency. From *Principles of Human Geography*, Fifth Edition.



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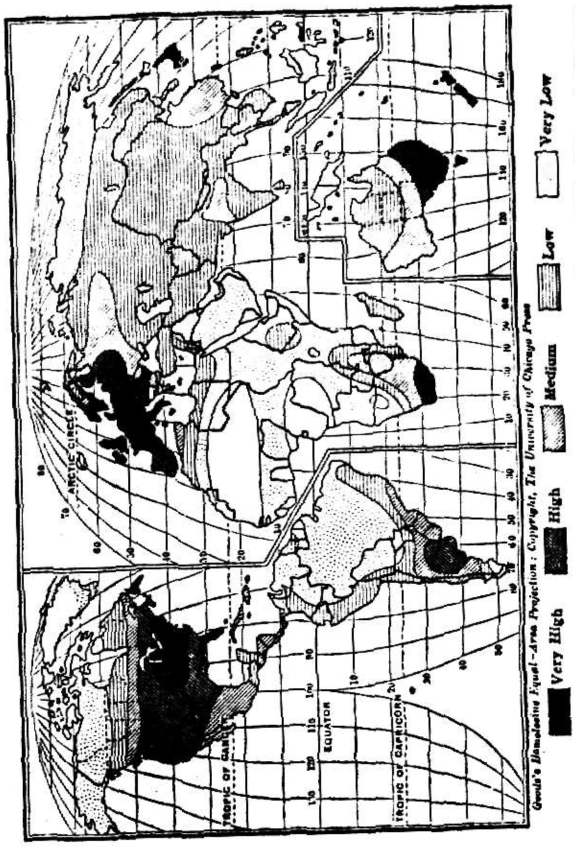
World Distribution of Automobiles. From *Principles of Human Geography*, Fifth Edition.



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World Distribution of General Progress. From *Principles of Human Geography*, Fifth Edition.

PART IV

CLIMATE CONTROLS

PART IV

CLIMATE CONTROLS

IV. CLIMATE CONTROLS BY MECHANICAL MEANS

1. Introduction

Climate control by mechanical means is the art of using science and modern technology to make our living more comfortable without depending on nature. Today, it almost becomes necessary to have mechanical systems controlling our indoor environment, wherever a large number of people are involved. Mechanical systems such as heating, air conditioning, and ventilation overcome many problems in our buildings, such as too hot in the summer or too cold in the winter. This is one of the main causes of our discomfort.

In 1971, the Department of Economic and Social Affairs of the United Nations, published a book called Climate and House Design; it states that the extreme hot and cold climatic conditions make the maintenance of a steady body temperature difficult.

> The phsyiological rhythm of work, fatigue and recovery is disturbed by high body temperatures. Fatigue accumulates and efficiency in the performance of mental and physical tasks declines. Neither acclimatization nor adaptation can completely overcome the disadvantages of an unfavorable climate. It is, however, possible to provide relief from climatic stress in well-designed houses....
>
> This can be achieved through mechanical air-conditioning -- heating or cooling as necessary. In fact, the extension of human settlements to the colder latitudes is dependent entirely on the availability of mechanical means to keep houses and their occupants warm. In warm climates, too, mechanical cool-

> ing is an effective and direct way of creating a favorable indoor climate, but it is expensive and out of the reach of many millions who live remote from the necessary sources of power....[1]

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) describes that man learns how to survive and becomes acclimatized during a cold period, but "exposure of men to extreme high temperature is limited by two different physiological responses: (1) elevated skin temperature resulting in pain and tissue damage, and (2) elevated body temperature and the associated syndromes of heat exhaustion, heat cramps, and heat stroke...."[2]

Man endlessly searches for a better way to deal with the indoor climatic condition. F.T. Andrews writes:

> From the time when men lived in caves and huts until the early part of the 19th Century, homes were heated with a fireplace in the living room. But the drawbacks of smoke, ashes, wood storage and uneven heat distribution caused man to seek better means of heating. With the advent of better fuels -- coal, oil, gas and electricity -- new heating methods that did not have the disadvantages of the fireplace were developed.[3]

Since the invention of air conditioning by Dr. W. H. Carrier, father of the air conditioner in 1902, we have air conditioning to re-

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[1] Department of Economic and Social Affairs, United Nations, Design of Low-Cost Housing and Community Facilities, Vol. I, Climate and House Design, (New York: United Nations Publications, 1971), p. 15.

[2] The American Society of Heating, Refrigeration and Air Conditioning Engineers, ASHRAE Handbook of Fundamentals, (New York: 1967), p. 114.

[3] F.T. Andrews, P.E., The Architect's Guide to Mechanical Systems, (New York: Reinhold Publishing Company, 1966), p. 1.

move the heat from our living space in the summer. And in the winter, after Benjamin Franklin designed a half-fireplace, half-stove in 1735, we have the heater to warm up the air in our house. Therefore, mechanical systems such as heating and cooling become more and more important systems in our environmental comfort.

2. Physiological Principle of Thermal Environment

a) Metabolism

Man is a constant-temperature animal, unlike snakes, fish, or frogs. The inside temperature of his body is about 98.6° F. This body temperature depends upon the balance between heat production and heat loss. Heat resulting from oxidation of food elements in the body (metabolism) maintains the body temperature well above that of the surrounding air in a cool or cold environment. At the same time, heat is constantly lost from the body by radiation, convection and evaporation.[4]

According to physiologists, at rest, a human being generates about 410 BTU; 300 BTU are given off by radiation and convection and 65 BTU by evaporation (46 BTU is lost through respiration), (see Plate X)[5]. Joseph Olivieri explains, in the book called <u>How to Design Heating-Cooling Comfort Systems</u>:

> If this heat loss is accelerated, we feel cold; and if it is retarded, we feel hot. The correct humidity is also im-

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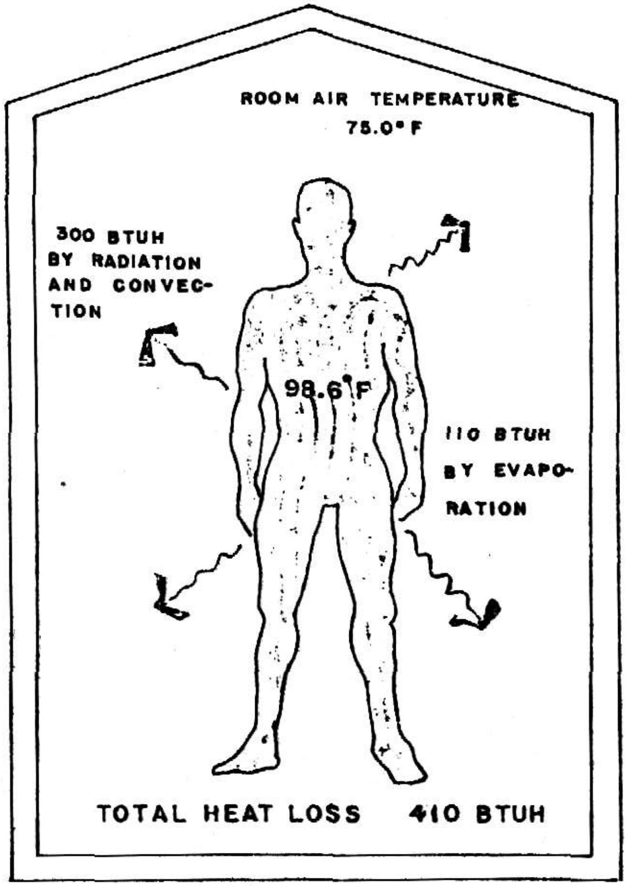
[4] <u>ASHRAE Handbook of Fundamentals</u>, <u>op. cit</u>., p. 112.

[5] Joseph B. Olivieri, <u>How to Design Heating-Cooling Comfort Systems</u>, (Birmingham, Michigan: Business News Publishing Company, 1970), p. 6.

PLATE X

BODY HEAT LOSS



SUMMER

FOR COOLING EFFECT, THE BODY HEAT LOSS IS SPEEDED UP BY MAINTAINING:

1. LOW AIR TEMPERATURE
2. LOW SURFACES TEMPERATURE (RADIANT COOLING)
3. RELATIVELY DRY AIR
4. ACTIVE AIR MOTION

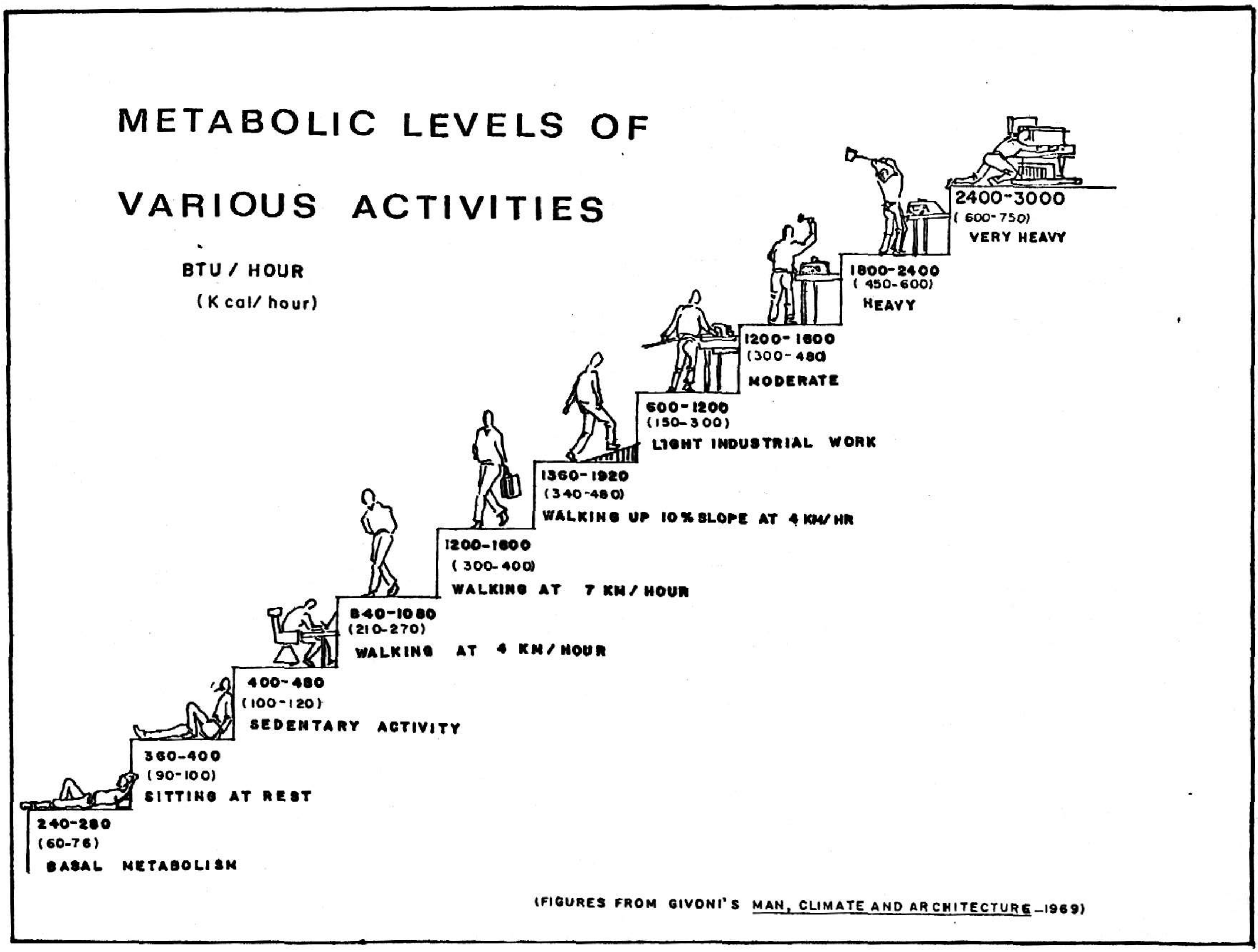
WINTER

FOR HEATING EFFECT, THE BODY HEAT LOSS RATE CAN BE RETARDED BY MAINTAIN:

1. HIGH AIR TEMPERATURE
2. HIGH SURFACES TEMPERATURES (RADIANT HEATING)
3. RELATIVELY MOIST AIR
4. SLOW AIR MOTION

Source: McGuiness, William, Mechanical and Electrical Equipment for Buildings, (New York; John Wiley & Sons, Inc., 1967).

PLATE XI



METABOLIC LEVELS OF VARIOUS ACTIVITIES

BTU / HOUR
(K cal/ hour)

(FIGURES FROM GIVONI'S MAN, CLIMATE AND ARCHITECTURE -1969)

> portant for comfort because too dry an environment will increase the evaporation of perspiration, causing us to feel chilled. Conversely, if an environment is too humid, the evaporation is retarded and we feel hot and flushed. Because of our average skin surface temperature is about 80° F., our bodies will radiate heat to any object at a lesser temperature and absorb heat from any object at a higher temperature.[6]

Man protects himself from excessive heat or cold by elaborate clothing and buildings. The Greeks and Romans warmed all buildings with open fires and braziers. Since then, man has begun to develop many different types of mechanical systems to provide human comfort, such as heaters, air conditioning, and so on. In dealing with heating and cooling, there are four physical factors involving human comfort which must be taken into consideration. They are: air movement, air temperature, humidity and radiation.

b) Four Physical Factors Affecting Human Comfort

1. Air movement: Air movement or air motion is singificant to body heat transfer by convection and evaporation. According to Bertram Kinzey, Jr., for both methods of transfer, the faster the motion the greater the rate of heat flow.

2. Air temperature: Air temperature, or dry-bulb temperature, is the second factor that affects the rate of convective and evaporative body heat losses. Dry-bulb temperature is the temperature of air taken with a thermometer not in contact with water.

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[6] Ibid.

3. Humidity: Humidity, or moisture content of surrounding air, influences the evaporative loss. Air already laden with moisture cannot absorb more from the skin. The drier and warmer the air, the greater will be the rate of heat flow from the skin by evaporation of perspiration into the air.[7]

4. Radiation: Radiation or surrounding surface temperature, is the last factor that affects heat loss. The body loses heat by interchange of radiant energy which related to the difference between the skin temperature and the Mean Radiant Temperature (MRT) of the surfaces that the body "faces." A person will fell warmer in a room of better construction with a higher MRT and a lower temperature differential between the body and its surrounding surfaces. Air motion does not affect this.[8] Mean Radiant Temperature is a weighted average of the temperature of all the surfaces in the direct line of sight of the body.

c) The Equivalent Temperature Scale and the Effective Temperature Scale

The Equivalent Temperature Scale and the Effective Temperature Scale (ET), have the same purpose, according to T.C. Angus, namely, to provide an easily understood measurement of physical conditions which

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[7] Bertram Kinzey Jr. and Howard Sharp, Environmental Technologies in Architecture, (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1965), p. 13.

[8] William J. McGuiness and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, (New York: John Wiley and Son, Inc., 1971), Fifth Edition, p. 97.

will define and average a person's thermal sensation. He describes the Equivalent Temperature Scale: "This is especially suited to the evaluation of the effects of heating appliances in any climate where such appliances are needed. It takes account of dry-bulb temperature, rate of air movement, and radiation from or to surroundings."[9]

About the Effective Temperature Scale (ET), Angus clearly describes:

> This is especially valuable where high temperatures prevail and the evaporative cooling of the body assumes great importance. Its essential difference from the Equivalent Scale is that it takes account of humidity, i.e. it requires measurements of wet-bulb temperature as well as of dry-bulb. The effective temperature is widely used in America for the evaluation of thermal sensations.[10]

According to Angus, the Effective Temperature Scale was developed in the United States of America (Houghton and Yaglou, 1923; Yaglou, 1928). This scale stresses the importance of humidity in influencing human thermal sensation; this is particularly true at the higher temperatures, such as are found in certain industries, and in the tropics, where the physiological cooling of the body is so largely dependent upon sweating (see Plate XII).[11]

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[9] T. C. Angus, The Control of Indoor Climate, (Oxford, England: Pergamon Press), p. 9.

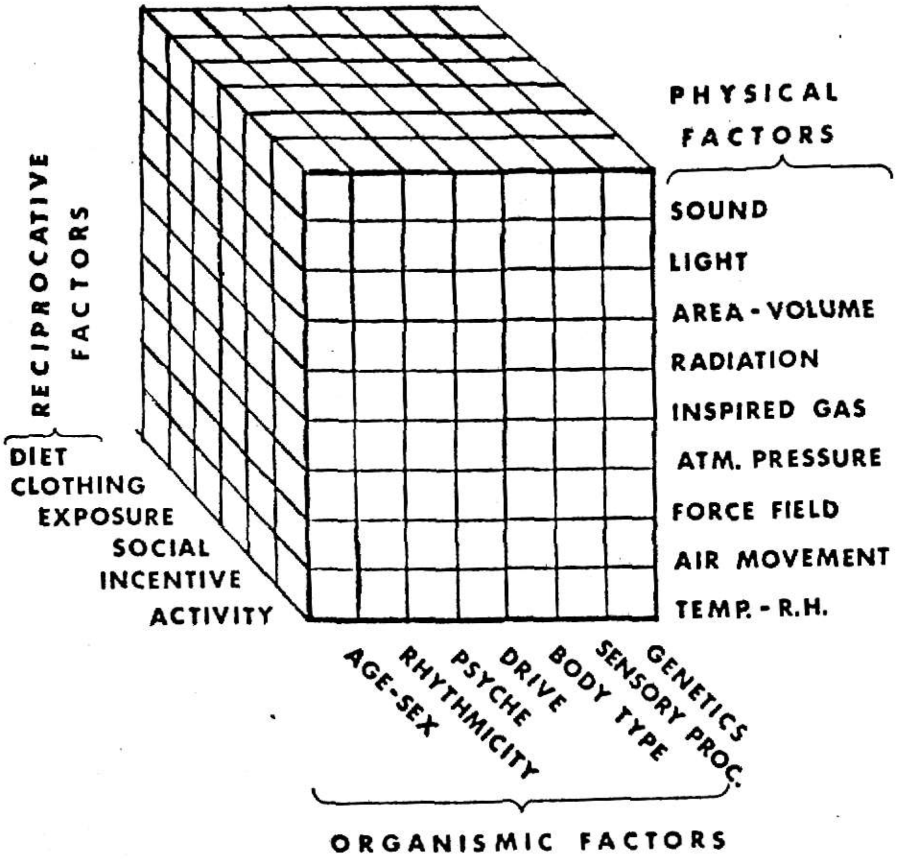
[10] Ibid.

[11] Ibid., p. 18.

d) Comfort Zone

In 1936, Bedford established "comfort zones" or ranges of the temperature within which a large proportion of the persons concerned say that they are comfortable. He found that in terms of dry-bulb temperature, the winter comfort zone for light workers in factories ranged from 60° F. to 68° F.[12]

Figure 5



Three-dimensional representation of various factors to be accounted for in seeking thermal comfort

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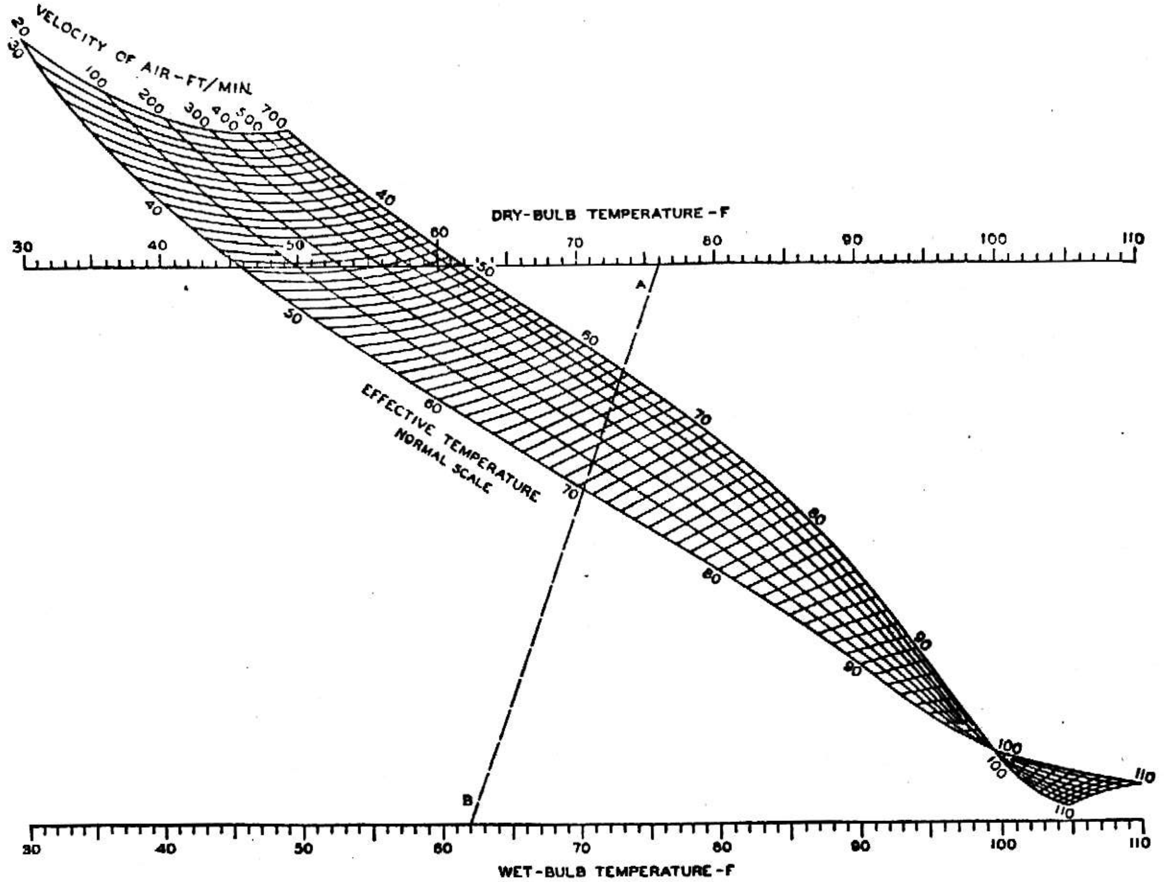
[12] Ibid., p. 14.

PLATE XII



HOW TO USE THE CHART: *Draw line A-B through measured dry-bulb and wet-bulb temperature. Read effective temperature or velocity at desired intersections with line A-B.* **EXAMPLE:** *Given 67 F db and 62 F wb, read: 69 ET at 100 fpm velocity, or 340 fpm required for 66 ET.*

.... Chart for Determining Effective Temperature for Sedentary Individuals, Normally Clothed, from Measurements of Dry-Bulb Temperature, Wet-Bulb Temperature and Velocity of Air

With regard to air temperature, relative humidity and air motion, the ASHRAE has conducted experiments to determine the relationship of environmental conditions which human subjects consider to be comfortable. The ASHRAE comfort chart for still air is published in the <u>ASHRAE Guide and Data Book</u> for 1961 and 1965. The comfort chart is useful for determining design conditions to be met by the building envelop and its thermal equipment (see Fig. 3, Plate XIII). In regard to the comfort chart, Kinzey writes;

> Women prefer higher effective temperatures than men, older persons higher values than the young, and persons living in southern climates higher temperatures than those in northern regions. Since the comfort chart is the result of observation of healthy clothed sedentary subjects, spaces to be conditioned for very active, ill, or nude persons may require vastly different conditions for comfort than those indicated....[13]

Flynn and Segil concluded that the winter optimum for normally-clother people appears to be near 67-68 ET. This ET range is achieved with an environmental air temperature of 74° F. (dry-bulb) and 30 percent RH, with relatively still air moving at a rate of 15-25 ft./min. The summer optimum for normally-clothed people appears to be near 71 ET. To achieve this, a common target is 76° F. (dry-bulb) and 50 percent RH, when air is also moving at a rate of 15-25 ft./min.[14]

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[13] Bertram Kinzey and Howard Sharp, <u>op. cit</u>., p. 15.

[14] John E. Flynn and Arthur W. Segil, <u>Architectural Interior Systems</u>, (New York: Van Nostrand Reinhold Company, 1970), pp. 81-82.

PLATE XIII

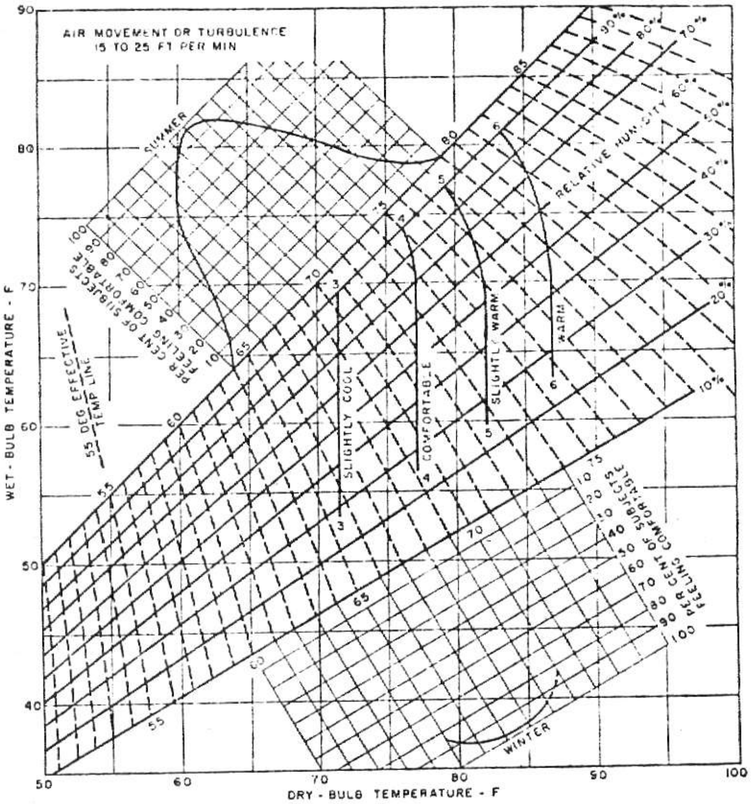


Fig. 3 Revised ASHRAE Comfort Chart

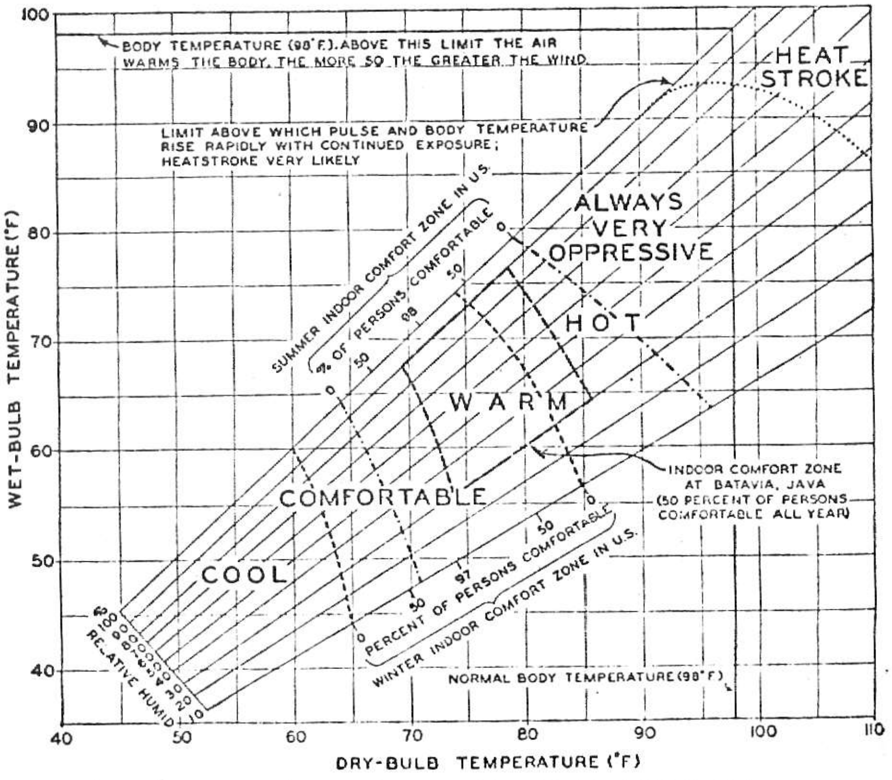


Fig. 4 Comfort zones in terms of humidity and temperature.

The sensation of comfort was described in terms of the Ecosystem Complex by Professor F.H. Rohles, Jr. of the Institute for Environmental Research, of Kansas State University. He explained that a three-dimensional paradigm is suggested for defining the relationship between an organism and its environment. Called the Ecosystem Complex, its constituents fall into three main classes: Physical Factors, Organismic Factors, and Reciprocative Factors (see Plate XIV and Fig. 5). Regarding these factors, R. G. Nevins, Head of the Department of Mechanical Engineering and Director of the Institute for Environmental Research wrote in Criteria for Thermal Comfort, that some of these factors such as air temperature, exert a large influence on comfort, while others affect comfort only slightly. He explained that the factors having the greatest influence on comfort are dry-bulb air temperature; air motion; and relative humidity and mean radiant temperature, or the temperature of surrounding surfaces. "These factors define the thermal environment and affect the heat exchange of people. To achieve thermal comfort, the thermal environment should be such that the body is in thermal equilibrium, a necessary but not sufficient condition."[16]

e) Heat Loss

An extremely important consideration in warming a building in the winter, is determining the amount of heat loss. Heat is lost in two

---

[15] Frederick H. Rohles, The Ecosystem Complex, Institute for Environmental Research, Kansas State University, IER Reprint No. 35, (December 1971).

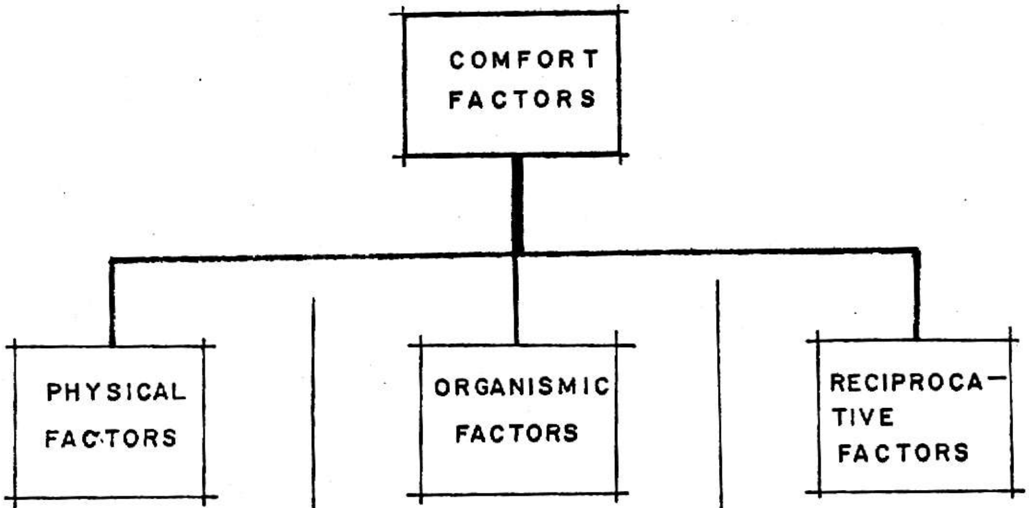
[16] R. G. Nevins, Criteria for Thermal Comfort, Institute for Environmental Research, Kansas State University.

PLATE XIV

Comfort Factors

(THE ECOSYSTEM COMPLEX)

THE SENSATION OF COMFORT IS A COMPLEX, SUBJECTIVE ONE WHICH RESULTS FROM A COMBINATION OF PHYSICAL, PHYSIOLOGICAL AND PSYCHOLOGICAL FACTORS. THE FACTORS WHICH AFFECT COMFORT CAN BE SEPARATED INTO THREE GROUPS



THESE FACTORS ASSOCIATED WITH THE PHYSICAL ENVIRONMENT INCLUDE LIGHT, SOUND, AIR MOVEMENT, TEMPERATURE, ECT.

THESE FACTORS ASSOCIATED WITH THE PERSON INCLUDE AGE, SEX, ETC.

THESE FACTORS ASSOCIATED WITH MAN'S BEHAVIORS INCLUDE SOCIAL VARIABLES, AND ACTIVITIES, ECT.

(FROM "CRITERIA FOR THERMAL COMFORT" BY R.G. NEVINS, HEAD DEPT. OF MECHANICAL ENGINEERING AND DIRECTOR OF INSTITUTE FOR ENVIRONMENTAL RESEARCH, KANSAS STATE UNIVERSITY, MANHATTAN, KANSAS) ways:

a) by direct transmission through the walls, roof and floor of a building; and

b) by air leakage through doors, windows or other interstices between the inside and outside of a building.

The total heat loss is the sum of the heat lost by direct transmission and by air leakage or infiltration.[17]

Heat introduced to and extracted from a structure flows at a rate which is measured in BTU per hour. However, the rate of flow changes constantly. "Since the heat does not flow constant rate, it is often necessary to find the time of day and year when the rate of flow is a maximum for a given situation," says Kinzey.[18] The amount of heat lost, or gained, through a wall is determined by multiplying the area of the building component by its heat transmission coefficient and temperature difference. The heat transmission coefficients "U" are factors which tell us how much heat is transferred per unit area, per unit time, per degree of difference.[19]

$$Q = AU (t - t_o)$$

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[17] Charles M. Gay and Charles De Van Fawcell, Mechanical and Electrical Equipment for Buildings, (New York: John Wiley and Sons, Inc., 1948), 2nd Edition, p. 99.

[18] Bertrain Kinzey, op. cit., p. 21.

[19] Joseph Olivieri, op. cit., p. 10.

Heat Loss or Gain in BTU = Area in sq.ft. × coefficient of heat transmission × temperature difference in degrees Fahrenheit

The lower the value of U-coefficients of the heat transmitting rates, the better the material is for insulation purposes. For instance, glass which has a U-value of 1.13 transmits heat faster than an eight inch masonry wall which has a U-value of 0.41. A U-value of 0.06 is considered an excellent heat insulation material. Therefore, "... a reduction in the rate of heat loss can be achieved by the use of insulating materials having slow conduction rates, the interposition of one or several air spaces and the reduction of radiant transfer by the use of reflective linings in air spaces, " explains McGuinness. Another factor is the tight construction retaining warm air and resisting the entry of cold air during windy times.[20]

f) <u>Heat Gain</u> (see Table I)

Heat gain in the winter has caused no serious problem for our buildings, but in the summer, it causes quite a problem in cooling the building. W. P. Jones divided heat gain into two categories:[21]

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[20] McGuinness, <u>op. cit</u>., p. 112.

[21] W. R. Jones, <u>Air Conditioning Engineering</u>, (Glasgow, England: Edward Arnold (Publishers) Ltd., 1967), p. 124.

External Gains (see Fig. 6)

1. Direct and scattered solar radiation through windows.
2. Heat transmitted through the glass and also through the non-glass fabric of the room enclosure, by virtue of the air-to-air temperature difference. Such gains are often termed 'transmission gains.'
3. Solar radiation eventually causing a heat gian to the room through the non-glass fabric of the walls.
4. Sensible heat gain arising from the infiltration of warm air from outside.

Table I

HEAT GAIN FROM PEOPLE

DEGREE OF ACTIVITY	TYPICAL APPLICATION	Metabolic Rate (Adult Male) Btu/hr	Average Adjusted Metabolic Rate* Btu/hr	ROOM DRY-BULB TEMPERATURE									
				82 F		80 F		78 F		75 F		70 F	
				Btu/hr		Btu/hr		Btu/hr		Btu/hr		Btu/hr	
				Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Seated at rest	Theater, Grade School	390	350	175	175	195	155	210	140	230	120	260	90
Seated, very light work	High School	450	400	180	220	195	205	215	185	240	160	275	125
Office worker	Offices, Hotels, Apts., College	475	450	180	270	200	250	215	235	245	205	285	165
Standing, walking slowly	Dept., Retail, or Variety Store	550											
Walking, seated	Drug Store	550	500	180	320	200	300	220	280	255	245	290	210
Standing, walking slowly	Bank	550											
Sedentary work	Restaurant†	500	550	190	360	220	330	240	310	280	270	320	230
Light bench work	Factory, light work	800	750	190	560	220	530	245	505	295	455	365	385
Moderate dancing	Dance Hall	900	850	220	630	245	605	275	575	325	525	400	450
Walking, 3 mph	Factory, fairly heavy work	1000	1000	270	730	300	700	330	670	380	620	460	540
Heavy work	Bowling Alley‡, Factory	1500	1450	450	1000	465	985	485	965	525	925	605	845

*Adjusted Metabolic Rate is the metabolic rate to be applied to a mixed group of people with a typical percent composition based on the following factors:
Metabolic rate, adult female = Metabolic rate, adult male × 0.85
Metabolic rate, children = Metabolic rate, adult male × 0.75

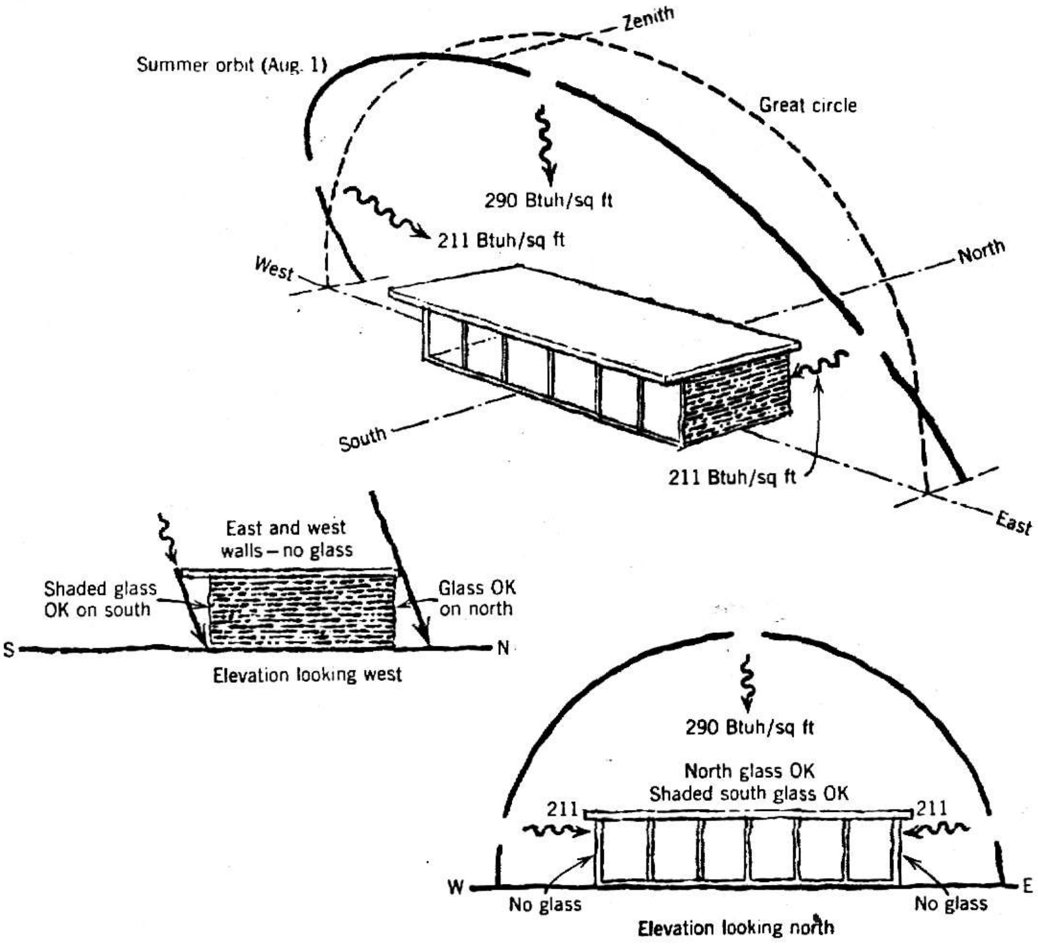
†Restaurant—Values for this application include 60 Btu per hr for food per Individual (30 Btu sensible and 30 Btu latent heat per hr).

‡Bowling—Assume one person per alley actually bowling and all others sitting, metabolic rate 400 Btu per hr; or standing, 550 Btu per hr.

Internal Gains

1. Electric lighting;
2. People;
3. Equipment; and
4. Process work.

Figure 6



Protection against heat gain. Shielding the interior from the radiant effect of the sun by insulated construction or heavy masonry is the first step. Glass is not a good choice within this orbit. When used it should be in full shade of trees or outside baffles. *Values are approximate and* for conditions on August 1st at 40° north latitude.

Included in the term 'process work' are such diverse activities as cooking by gas or oil, the evaporation of any water and lighting by gas or, conceivably, by oil.

In order to reduce the load from heat gain, an architect must incorporate elements into his design which will reduce the heat caused by these heat producers. Orientation, the shape of the building, shading of glass and the use of an overhang, may reduce a great deal of heat gain. The use of fluorescent lighting, instead of incandescent, will reduce the wattage by approximately half, while maintaining the same lighting level. Another item which can be reduced is the heat load caused by the sun on the roof. According to Oliviere, flooding the roof with one inch of water will cut the load by 60 percent, and the use of sprays will reduce the load by 80 percent,[22] however, because of the better insulating materials for the roof, this practice becomes less popular.

The knowledge and calculations of heat loss and heat gain are very important in designing a heating and cooling system, and insulation as well. The architect should know how large the mechanical systems should be for use in a certain space, and what types of systems may be suitable for such a job in order to have full advantage from this system. If the architect designs the system too large, it probably is just a waste of money in the cost of operating and maintenance.

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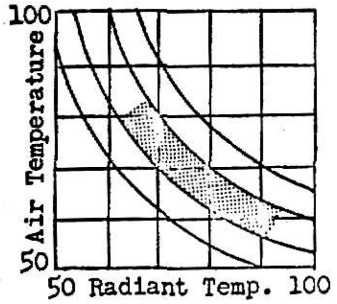
[22] Joseph Olivieri, op. cit., p. 23.

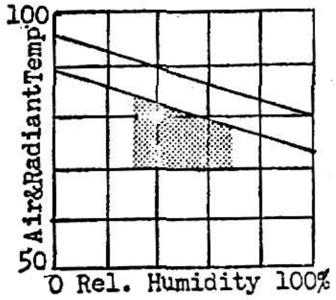
PLATE XV

NOTE:
Dotted areas indicate schematically the positions of comfort areas.



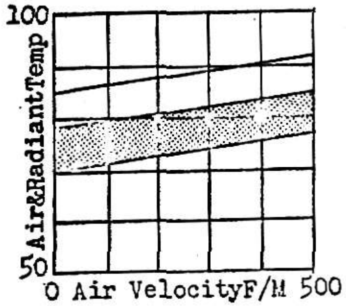
A

INTERRELATIONSHIP OF RADIANT AND AIR TEMPERATURE



B

RELATIVE HUMIDITY AND ITS EFFECT ON COMFORT RANGE



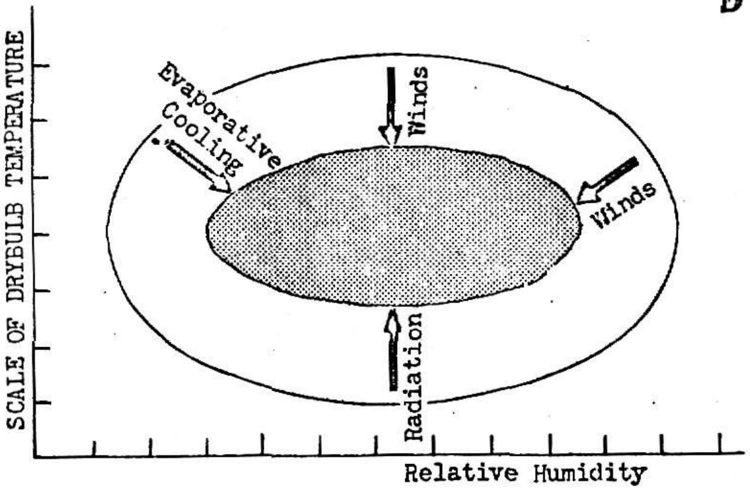
C

AIR MOVEMENT AND BODY COOLING RELATIONSHIP

D

DIAGRAMMATIC
PRESENTATION OF
COMFORT ZONE

Basic objective: To modify existing climatic conditions by natural means in such a way that they conform with conditions prevailing in the comfort zone. If natural means are insufficient, mechanical means will have to be employed to establish comfort conditions.



DIAGRAMMATIC PRESENTATION OF THE COMFORT ZONE

EXPLANATION OF PLATE XVI

The schematic bioclimatic index shows the corrective measures needed to restore the feeling of comfort. For example, at dry-bulb temperature, 75° F., relative humidity, 50%, the need is none, the point is already in the comfort zone.

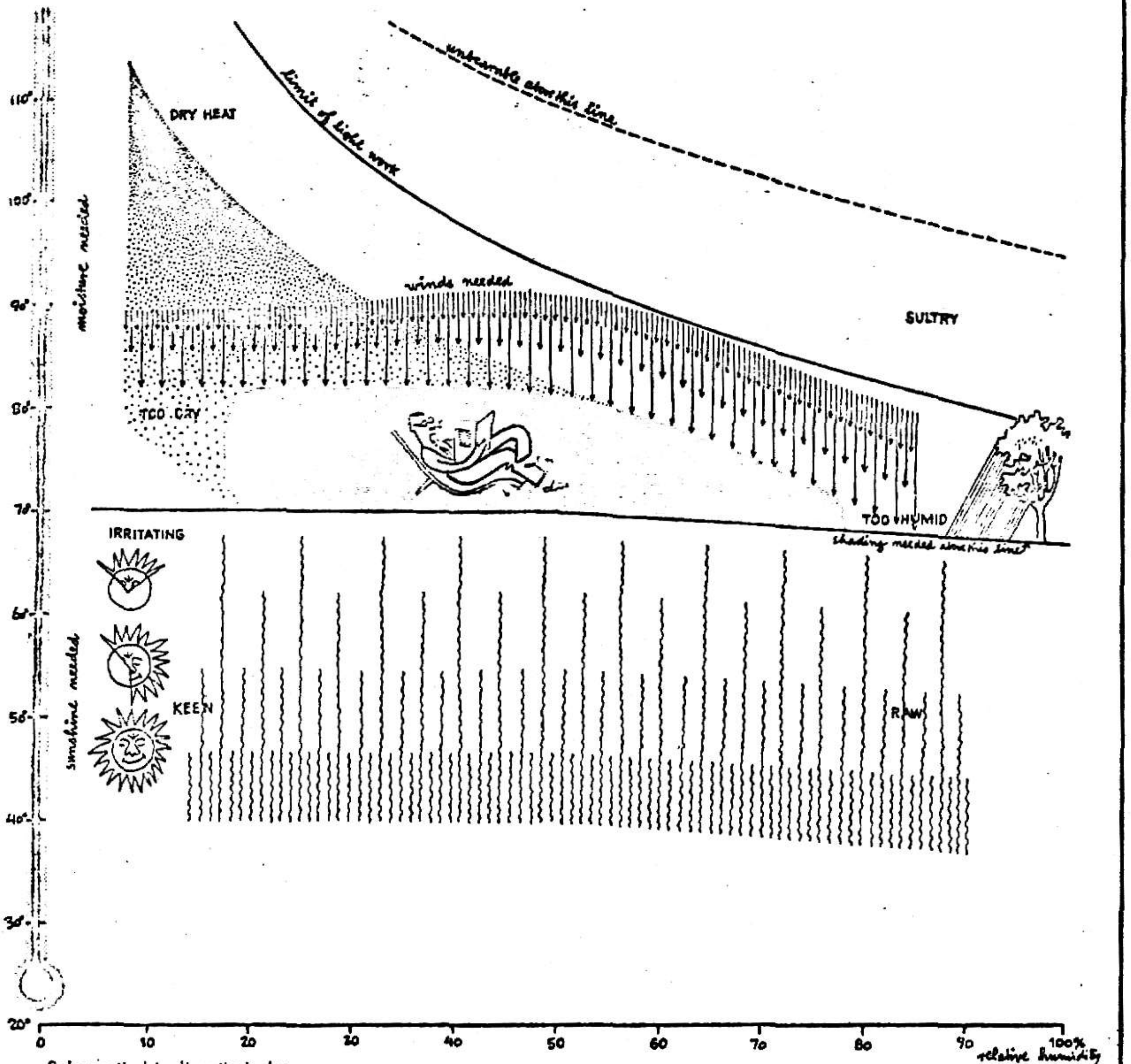
At dry-bulb temperature, 75° F., relative humidity, 70%, Need: wind to counteract vapor pressure.

At dry-bulb temperature, 50° F., relative humidity, 56%, Need: sun radiation.

At dry-bulb temperature, 87° F., relative humidity, 30%, Need: counteraction by either of two means: 1) wind; or 2) evaporative cooling.

(Taken from Victor Olgyay, Design with Climate, Princeton, N.J.: Princeton University Press, 1963), p. 23.

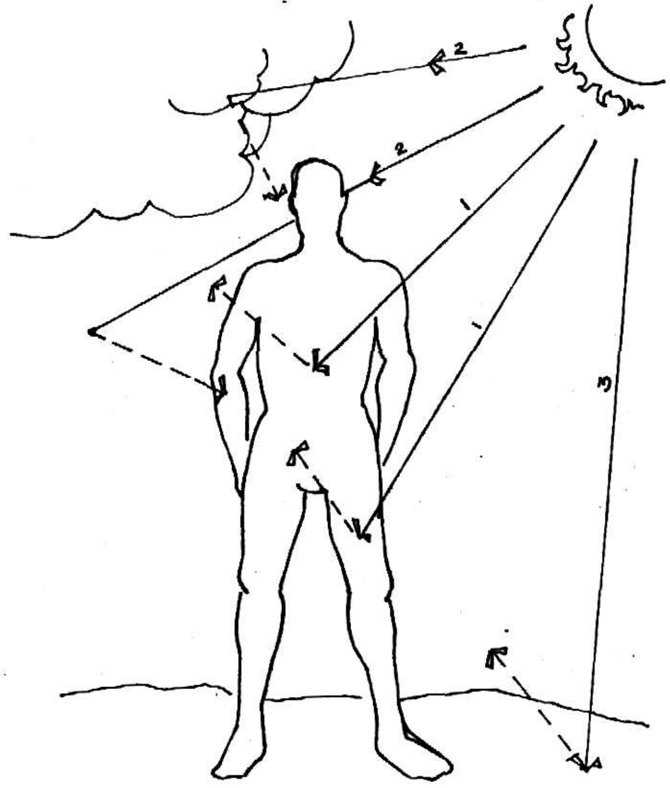
PLATE XVI



Schematic bioclimatic index.

PLATE XVII

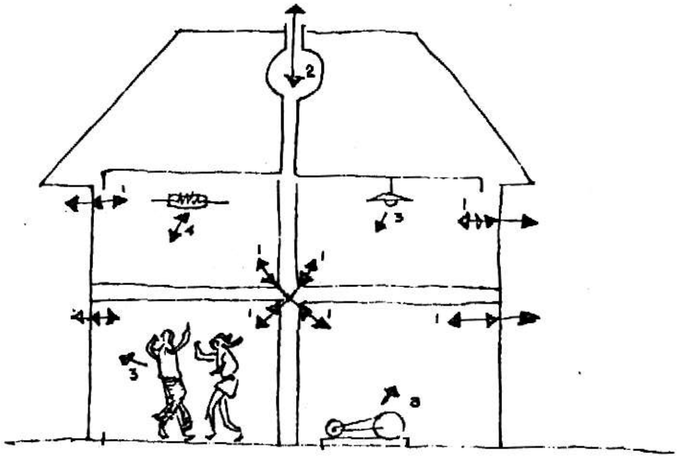
Man's Radiation Exchange



RADIATION EXCHANGE BETWEEN MEN AND SURROUNDINGS

1 DIRECTLY FROM SUN
2 AFTER REFLECTION FROM CLOUDS AND ATMOSPHERE PARTICLES
3 AFTER REFLECTION FROM THE GROUND

Building Heat Exchange



THE HEAT BALANCE IN THE BUILDING

1 HEAT EXCHANGE THROUGH AND WITH THE FABRIC (ANY PART OF THE STRUCTURE)
2 HEAT EXCHANGE BY VENTILATION
3 HEAT GAIN FROM INTERNAL SOURCES
4 HEAT EXCHANGE WITH THE FUNCTIONAL PLANTS (HEATING AND COOLING PLANT)

(FROM WINDOW AND ENVIRONMENT, 1969)

PLATE XVIII

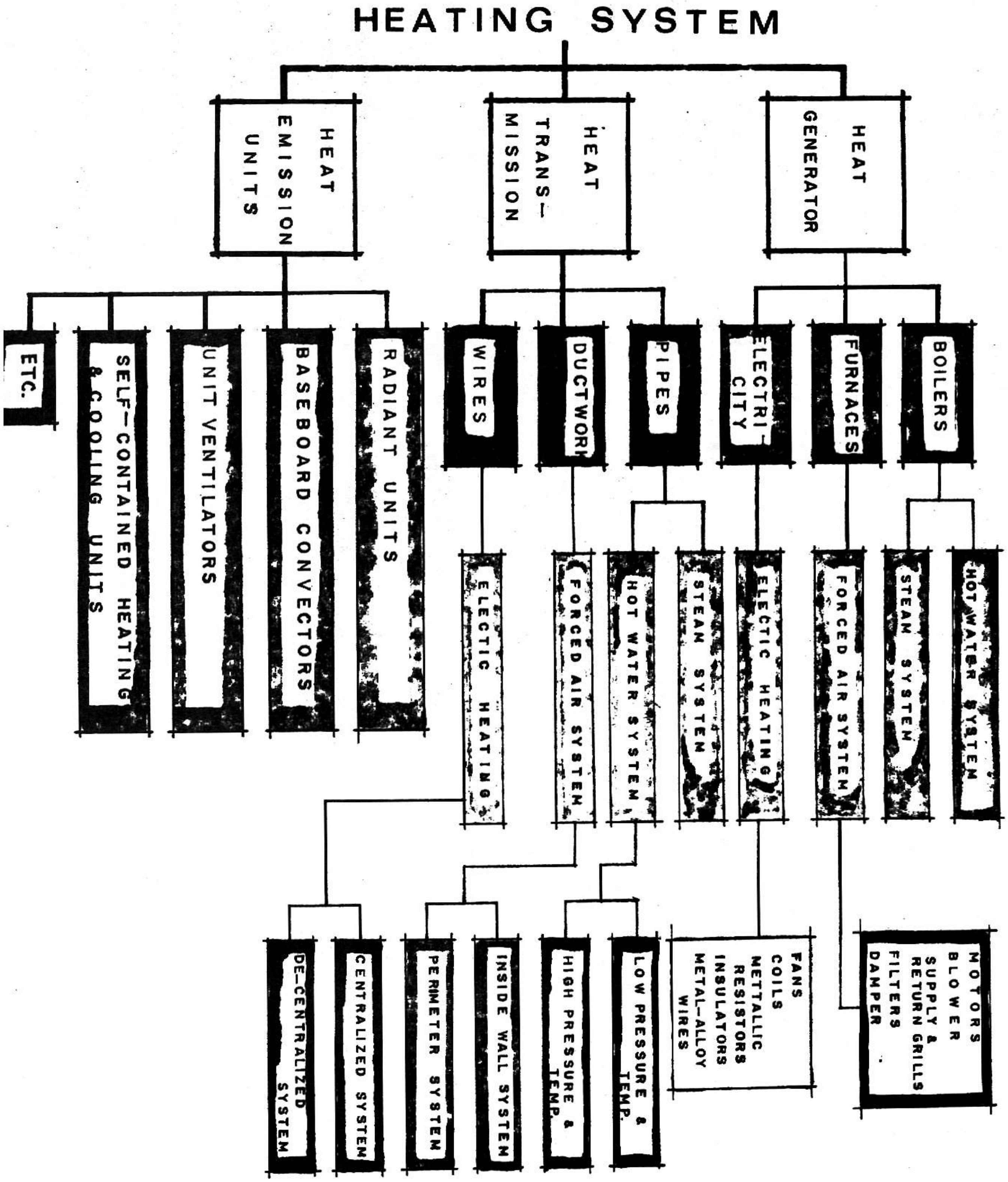

HEATING SYSTEM
HEAT EMISSION UNITS
HEAT TRANS-MISSION
HEAT GENERATOR
ETC.
SELF-CONTAINED HEATING & COOLING UNITS
UNIT VENTILATORS
BASEBOARD CONVECTORS
RADIANT UNITS
WIRES
DUCTWORK
PIPES
ELECTRICITY
FURNACES
BOILERS
ELECTIC HEATING
FORCED AIR SYSTEM
HOT WATER SYSTEM
STEAN SYSTEM
ELECTIC HEATING
FORCED AIR SYSTEM
STEAM SYSTEN
HOT WATER SYSTEM
DE-CENTRALIZED SYSTEM
CENTRALIZED SYSTEM
PERIMETER SYSTEM
INSIDE WALL SYSTEM
HIGH PRESSURE & TEMP.
LOW PRESSURE & TEMP.
FANS
COILS
NETTALLIC
RESISTORS
INSULATORS
METAL-ALLOY
WIRES
MOTORS
BLOWER
SUPPLY &
RETURN GRILLS
FILTERS
DAMPER

TABLE II

Comparison of Heating Systems

		Generation Equipment Requirements				Distribution Equipment Requirements		
	Fuel Cost	Condenser-Evaporator Equipment	Furnace or Boiler	Chimney Action	Fuel Storage	Ducts or Pipes for Supply and Return	Fans or Pumps	Con-vectors or Panels
Noncombustion Heat Sources:								
1. Utilization of condenser heat (including heat pumps)	high	yes	—	—	—	piping for water or refrigerant	yes	yes
2. Thermoelectric	high	—	—	—	—	electric wiring	—	yes
3. Utilization of interior waste heat	—	—	—	—	—	air or water cycle	yes	yes
4. Electric resistance units	high	—	—	—	—	electric wiring	—	yes
Combustion-Type Heat Sources:								
1. Natural fuels (wood, peat)	low	—	yes	yes	yes	air or water cycle	yes	yes
2. Fossil fuels coal gas oil	low med. med.	—	yes	yes	yes	air or water cycle	yes	yes

Source: John E. Flynn and Arthur Segil, Architectural Interior Systems, (New York; Van Nostrand Reinhold Company, 1970) p. 221.

In the next section, the mechanical air-conditioning systems and their controls will be briefly introduced for both residences and non-residence buildings.

3. Heating Systems

In recent years, the heating of buildings has been developed by merely raising the temperature within them, as measured by a dry-bulb thermometer, according to Charles Gay. Heating systems now embrace considerations of moisture and air movement quite as completely as warmth, and is based upon maintaining an effective heat which depends upon temperature, relative humidity, and the movement of the air.[23] Heating systems have been developed every since the first fireplace was used as the main heating system for the whole building. Today, our heating systems are far more efficient in providing, not only warm air, but also, better air movement, and so on. There are various types of heating systems which we can select from, depending on what kind of fuel we have. Kinzey explained; "Appropriate equipment selection involves many considerations which include fuel to be used and its storage and method of firing.... Equipment efficiency and economics of first cost are important aspects of heat source selection."[24]

However, fuel selection is one of four factors in selection of the heating system. Other factors in choosing a heating system are:

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[23] Charles Gay and Charles Van Fawcett, op. cit., p. 96.

[24] Bertram Kinzey, op. cit., p. 84.

1. zoning requirements;
2. building size; and
3. costs.

a) Types of Fuel

In the past, people used wood as their primary heat source. Then came the discovery of coal, gas, oil and, finally, electricity to heat their places of shelter. Today, people have a variety of fuel to heat their buildings. The use of natural growth such as wood and peat has been proven to be inconvenient, in that it is dirty and difficult to handle. But, "proximity to the source of supply is still a strong factor in the choice of a fuel in spite of the development of pipe lines for gas and oil which often cross many states."[25]

According to William McGuinness, if cost were not a consideration, it is likely that most people would select fuel in this order:

1. electricity;
2. gas;
3. oil; and
4. coal.

He gives the reason; "... electricity offers easy thermostatic control in each room. It is almost instantaneous in response and, since there need be no combustion on the premises, assures a measure of fire safety if the electrical system is carefully installed in accordance with prescribed regulations and good practice." With other

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[25] McGuinness, op. cit., Fifth Edition, pp. 211-212.

types of fuel, he explains; "Gas eliminates fuel storage problems, and both gas and oil involve no labor for handling as coal does. Electricity is the cleanest, but with good combustion there should be little difference in the cleanliness of the other three, though coal dust rising from that fuel prior to burning may be unpleasant."[26]

However, the type of fuel for a heating system will also be determined by cost, cleanliness, convenience and availability. According to J.R. Kell, the total cost includes other items, and is made up of:

1. fuel consumption;
2. running of auxiliaries;
3. labor;
4. maintenance and reparis;
5. interest and depreciation, and
6. insurance.

"Cleanliness and convenience," says Kell, "are equally important. Conditions of cleanliness which might be quite satisfactory, for instance, in a factory or workshop would probably be intolerable in a bank of office building."[27]

b) Principles of Heating Systems

The first step in the design of a heating system is to determine the heat loss that the building will sustain from external

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[26] Ibid.

[27] J. R. Kell and Oscar Faber, Heating and Air Conditioning of Buildings, (London: Architectural Press, 1968), Fourth Edition, p. 358.

conditions. This heat loss calculation is an important step before we are able to select any heating system suitable to our job. Then, we should understand the principle of the heating system. Heating systems consist of three different parts (see Plate XVIII):

1. Heat generator - can be generated in boilers as hot water or steam, in furnaces as warm air, and as electricity in a power plant.
2. Heat transmission - steam and hot water are transmitted in pipes, warm air in ductwork, and electricity in wires. Steam, water and air systems can be subclassified by the piping or ductwork arrangement, or pressure conditions.
3. Heat emission unit - this part of our system is the part most associated with comfort because it is in the space to be controlled. Steam or hot water can be circulated through cast iron radiators, convectors, finned pipe radiation, and baseboard radiators.[28]

c) Types of Heating Systems

Heating systems, for our simple understanding, may be divided into four basic systems: steam, hot-water, forced air, and electric.

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[28] Joseph Olivieri, op. cit., p. 76.

1. Steam

According to the ASHRAE Guide and Data Book Systems 1970, a steam heating system uses the vapor phase of water to supply heat to a conditioned space or a process, connecting a source of steam, through piping, with suitable terminal heat transfer units located at the interior space. They operate from 218° F., or higher, during winter to conditions of 125° F. in mild weather, so that the average temperature of the radiation may vary in direct relation to heating demands.[29]

The flexibility and versatility of control of modern steam systems, make the steam heating systems readily adaptable to a wide range of system sizes and process applications. Accordingly, steam systems are often preferable to water systems, where excessive static water pressure is encountered.

Other advantages of steam systems, according to ASHRAE, are:

1. Optimum comfort, from the ability to vary terminal equipment temperature, to balanced heat loss, which ranges from coldest to mildest weather requirements, and is due to the capability of resetting steam temperatures to balance outdoor temperature conditions. Space temperature fluctuations are reduced, although demand varies. The heat may be continuously introduced along the entire outdoor perimeter by finned-tube, baseboard, or wainscot radiation.

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[29] ASHRAE Guide and Data Book System, 1970, (ASHRAE, 345 East 47th St., New York, N.Y.), Chapter 10, "Steam Heating System," pp. 125-126.

2. Application is flexible as to purpose and equipment, and first cost is nominal, occasionally less than for water. Piping may change vertically, up or downward, as required to accommodate architectural or structural requirements.
3. Building costs are somewhat reduced, since the building framing is not required to support the water contents of expansion tanks and piping, in addition to the weight of the piping.
4. Pumping costs, for maintaining circulation, are usually drastically lower than for a water system.
5. From a maintenance standpoint, costs are low. The small difference of pressure the system components operate under, reduces wear and maintenance expense to a minimum.[30]

2. Hot-water

Water systems have supplanted steam systems for residential heating applications, and are now used in a majority of large building heating systems, according to ASHRAE. In addition, hot water is now being used in a significant number of industrial process distributions and district heating applications. This increase may be gained in properly designed hot water systems.

1. Resetting system supply water temperatures with respect to provides:
   a) an economic means of matching system heat out-put to load

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[30] _Ibid._

requirements, thus minimizing overheating, pipe losses and fuel waste;

b) greater comfort produced by uniformity in surface temperatures of heating equipment, in turn made possible by maintained water flow rates at varying temperature;

c) better automatic control valve operation, since nearly all closed port positions are minimized; and

d) possible reductions in piping insulation, otherwise needed to prevent overheating caused by pipe losses.

2. Forced circulation of water used as a heating media affords an economic opportunity by:

   a) providing a simple means of introducing heat along entire outdoor exposures, through the use of baseboard, finned radiation, or radiant ceiling panels;

   b) providing faster, but uniform, response to load changes, utilizing minimum pipe sizes;

   c) permitting piping to be run at any pitch or level, up or down, as desired to match building or site configuration;

   d) providing, in the total water mass, the desirable inertia effect which aids in balancing diverse system load requirements with uniform input at fuel burnes;

   e) requiring fewer specialties; and

   f) permitting practical air elimination, thus minimizing corrosion and maintenance.[31]

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[31] <u>Ibid.</u>, Chapter 12, "Basic Water Systems Design," pp. 181-182.

PLATE XIX

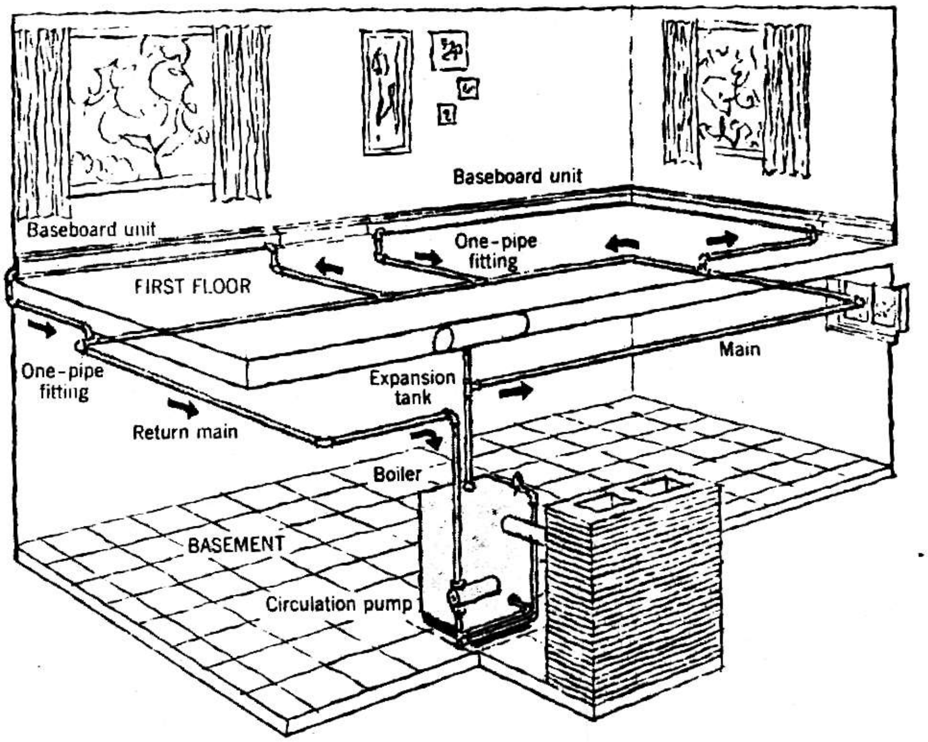


Fig. 7 Forced hot-water system using the one-pipe principle with special one-pipe fittings to divert water to the baseboard units. Reprinted by permission of the University of Illinois Small Homes Council from its copyrighted publication G 3.1 HEATING THE HOME.

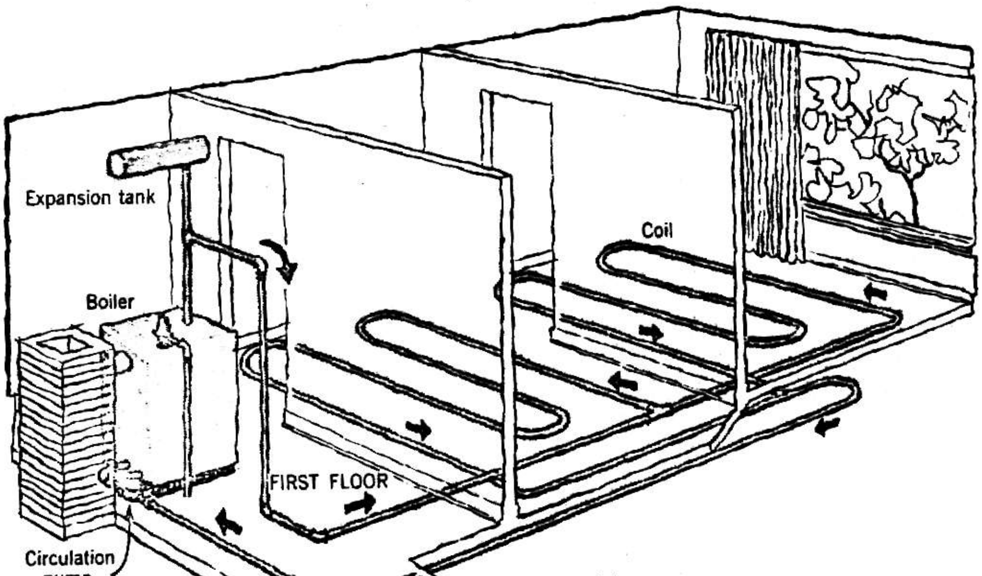


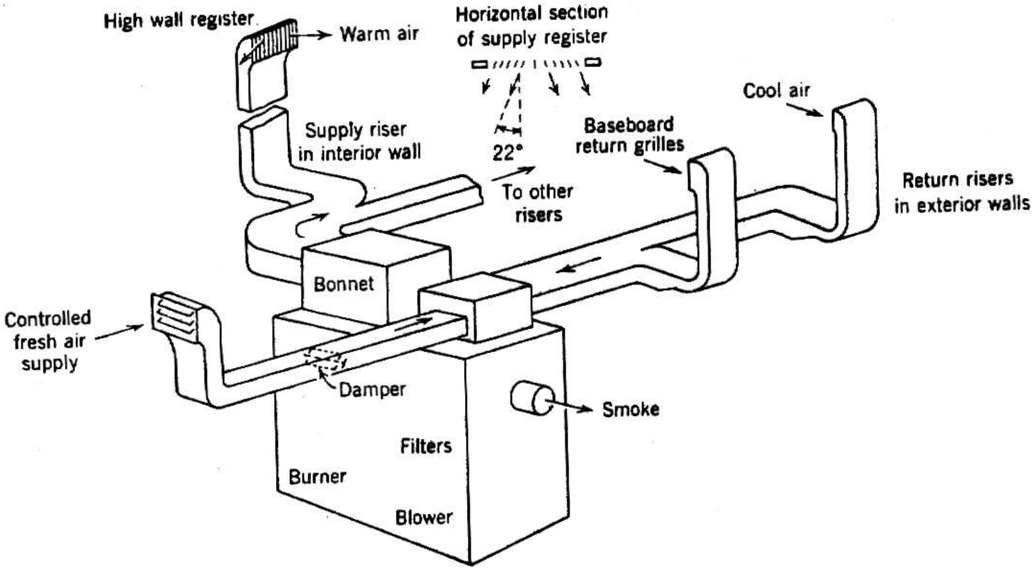
Fig. 8 Forced-hot water, floor-type radiant heating showing 2 coils. Reprinted by permission of the University of Illinois Small Homes Council from its copyrighted publication G 3.1 HEATING THE HOME.

3. Forced Air

In forced air systems, the air circulation is affected by motor-driven centrifugal fans, commonly referred to as blowers. The advantages of forced air systems, according to ASHRAE Guide and Data Book 1970, are:

1. The unit may be placed in any part of the structure.
2. Distribution ducts can be made small enough to be inconspicuous and out of the way, or be completely concealed from view, where desired.
3. Circulation of air is positive, and in a properly designed system, can be controlled in such a way as to give a comfortably uniform temperature distribution.

Figure 9



Schematic duct-system for mechanical warm-air heating.

PLATE XX

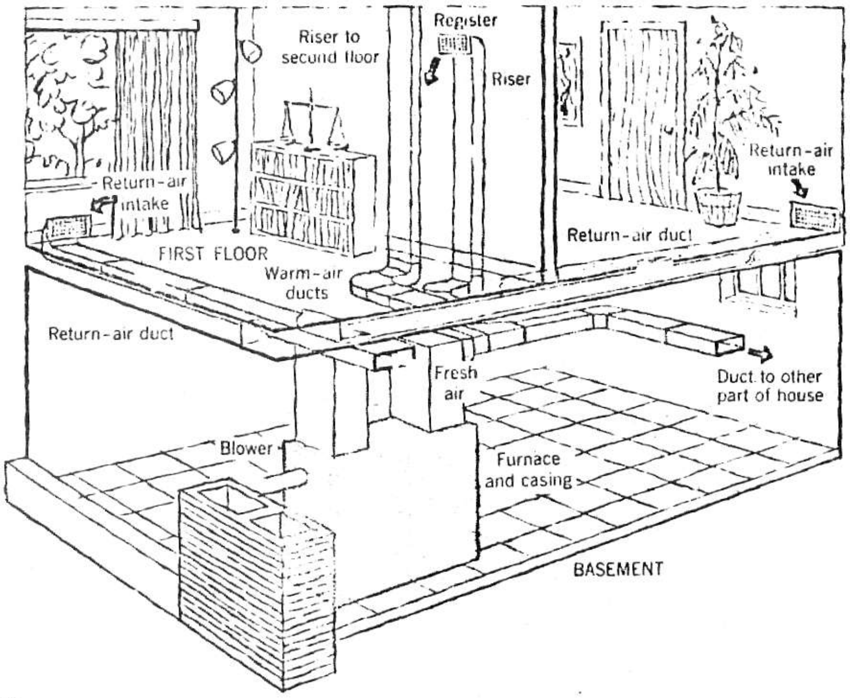


Fig. 10 Forced warm-air system. Reprinted by permission of the University of Illinois Small Homes Council from its copyrighted publication G 3.1 HEATING THE HOME.

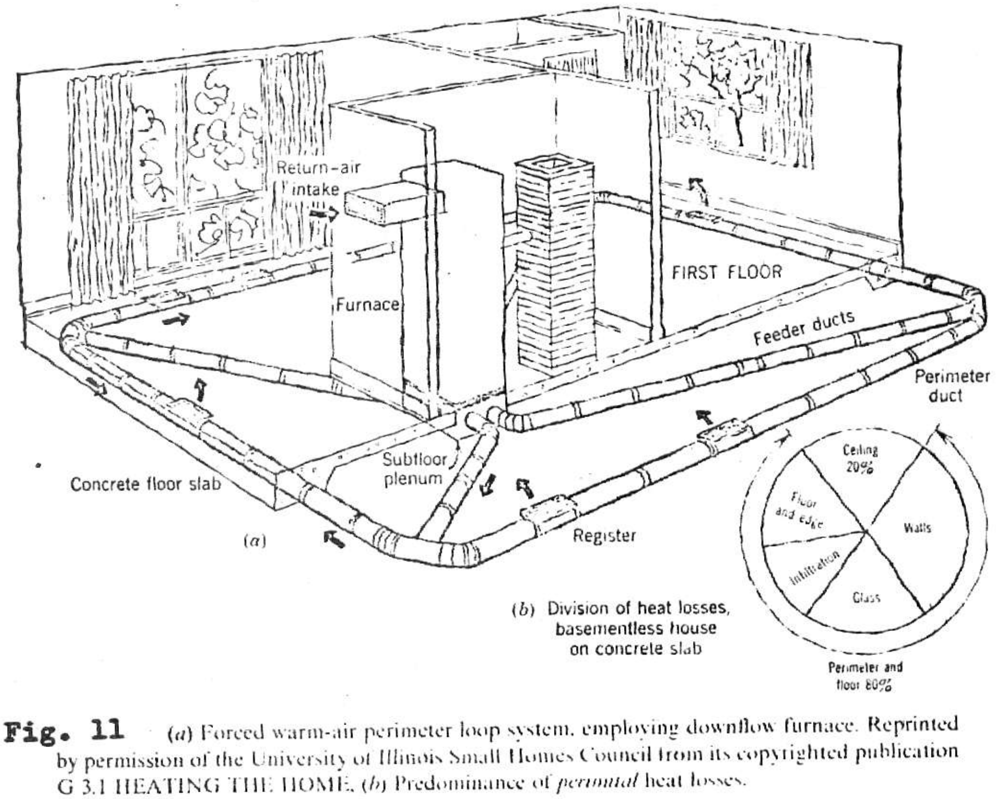
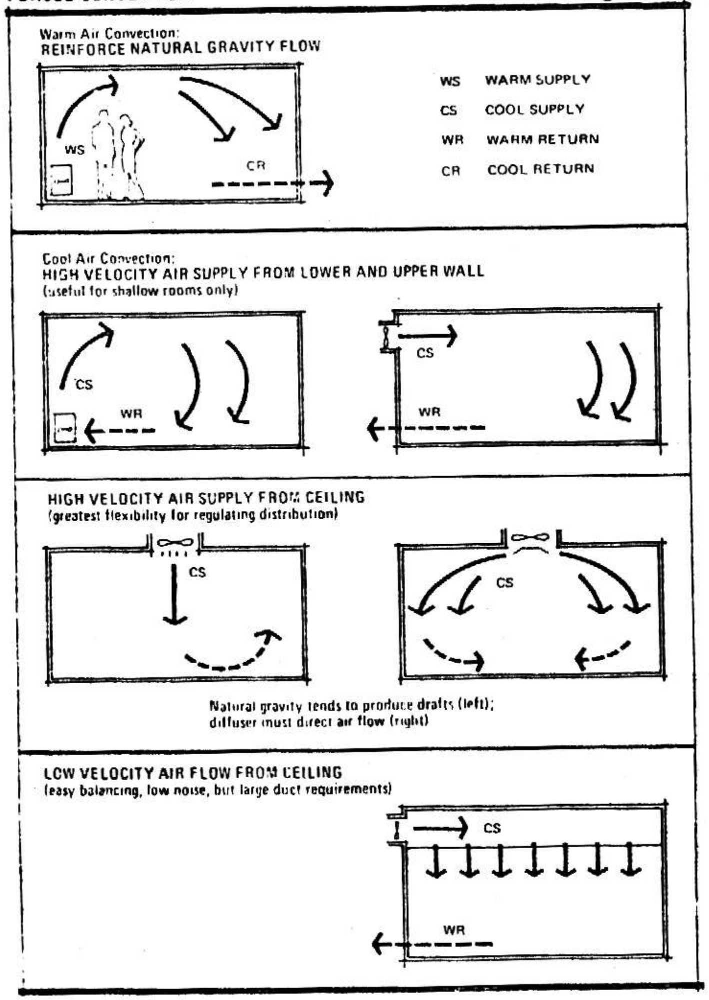


Fig. 11 (*a*) Forced warm-air perimeter loop system, employing downflow furnace. Reprinted by permission of the University of Illinois Small Homes Council from its copyrighted publication G 3.1 HEATING THE HOME. (*b*) Predominance of *perimetal* heat losses.

PLATE XXI

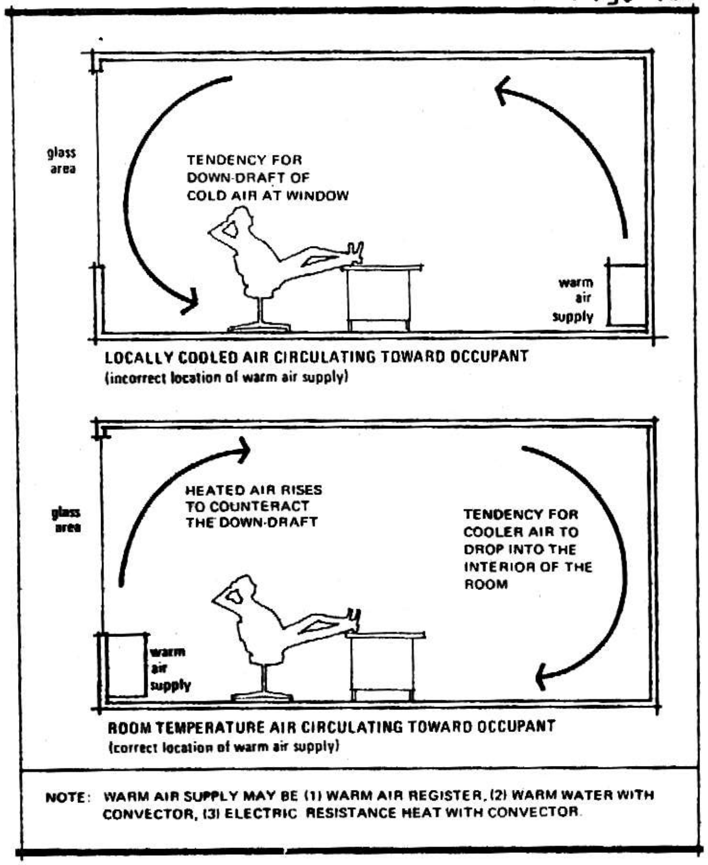
FORCED CONVECTION

Fig. 12



NATURAL GRAVITY CONVECTION

Fig. 13



Source: John E. Flynn and Arthur Segil, Architectural Interior Systems, (New York; Van Nostrand Reinhold Company, 1970) p. 238.

4. Humidity control is readily attained.
5. The air may be cleaned by filters or other means.
6. If properly designed or suitably adapted, the same air distribution system can be used for summer cooling, as well as winter heating.
7. The use of the fan permits flexibility in the location of supply and return grills, as required, to obtain proper distribution of air for comfort.
8. Controlled quantities of ventilation air may be drawn into the system and conditioned before being introduced into occupied portions of the structure. Recirculated air can be treated as necessary to obtain the desired quality.[32]

Forced air systems are equally adaptable for use in residential and non-residential structures.

4. Electric Heating

Electricity is energy in a refined form which is ideally suited to space heating because it is simple to distribute and control, according to ASHRAE. Complete electric heating systems are widely used in residences, schools, and in many commercial and industrial establishments. Electric space heating is often used where minimum initial cost is the dominating factor.[33] J.R. Kell and Oscar Faber, in the book

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[32] *Ibid.*, Chapter 9, "Forced Air Systems," p. 105.

[33] *Ibid.*, Chapter 18, "Electric Heating," p. 281.

Heating and Air-Conditioning of Buildings, give the advantages of heating by electricity:

1. absence of fumes or products of combustion;
2. avoidance of labor;
3. availability at any temperature at point of emission, hence, greater freedom in design of apparatus;
4. ease of thermostatic control;
5. transmissibility to any point, regardless of levels or limitations found with other media, i.e., portable appliances may be used; and
6. shortness of time lag.[34]

4. Cooling Systems

"The control of cold and damp is dwellings is comparatively simple and inexpensive in lands where fuels are readily available," says T.C. Angus, "But the mitigation of great heat, with or without excessive humidity, is a much more difficult problem. It may be said that really effective solutions have been found only in recent times."[35] This is true for many centuries. When the European people spent their lives in many parts of India and Africa, they suffered from extreme heat, which can set off a general deterioration in health and energy. Here, again, this presents a challenging problem for man. There are many different methods by which man can easily overcome the problem mechanically, however, there is, so far, no method which has been de-

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[34] J. E. Kell and Oscar Faber, op. cit., p. 297.

[35] T.C. Angus, op. cit., p. 75.

TABLE III

Principal Types of Electric Space Heating Systems

Decentralized Systems

- A. Natural Convection Units
  1. Floor drop-in heaters
  2. Wall insert and surface mounted heaters
  3. Baseboard convectors
  4. Hydronic baseboard convectors with immersion elements
- B. Forced Air Units
  1. Unit ventilator
  2. Unit heaters
  3. Wall insert heaters
  4. Baseboard heaters
  5. Floor drop-in heaters
- C. Radiant Units
  1. Radiant convector panel heaters
  2. Metal-sheathed element with focusing reflector
  3. Quartz lamp with focusing reflector
  4. Quartz tube element with focusing reflector
  5. Heat lamps
  6. Valance heaters
- D. Radiant Panel-type Systems
  1. Radiant ceiling with embedded conductors
  2. Pre-fabricated panels
  3. Radiant floor with embedded conductors

Centralized Systems

- A. Heated Water Systems
  1. Electric boiler
  2. Electric boiler, with hydronic off-beak storage
  3. Heat pumps
  4. Integrated heat recovery systems
- B. Steam Systems
  1. Electric boiler, immersion element or electrode type
- C. Heated Air Systems
  1. Duct heaters
  2. Electric furnaces
  3. Heat pumps
  4. Integrated heat recovery systems
  5. Unit ventilators
  6. Self-contained heating and cooling units

(Source: Chapter 18, "Electric Heating," ASHRAE Guide and Data Book 1970), p. 281.

vised for the cheap effective control of hot weather. Air conditioning, fans, and dehumidifiers are becoming more and more common as a feature of the houses of the well-to-do in the United States of America and Canada.

These modern cooling principles and equipment are a direct result of man's search for better ways to cool and preserve his foods. According to R.T. Andrews, this (air-conditioned) environment is worth the price.[36]

a) Principles of Cooling Systems

There are two main cooling systems, which can be subdivided to other sub-systems (see Plate XXII).

1. Evaporative Cooling System

Evaporative cooling was used in the Arabian desert long before the birth of Christ. F.T. Andrews explained that Nomads carrying goatskin water bags realized that water evaporating from the pores of the goatskin cooled the water inside. It was not until much later, however, that the principle of evaporative cooling was understood.[37]

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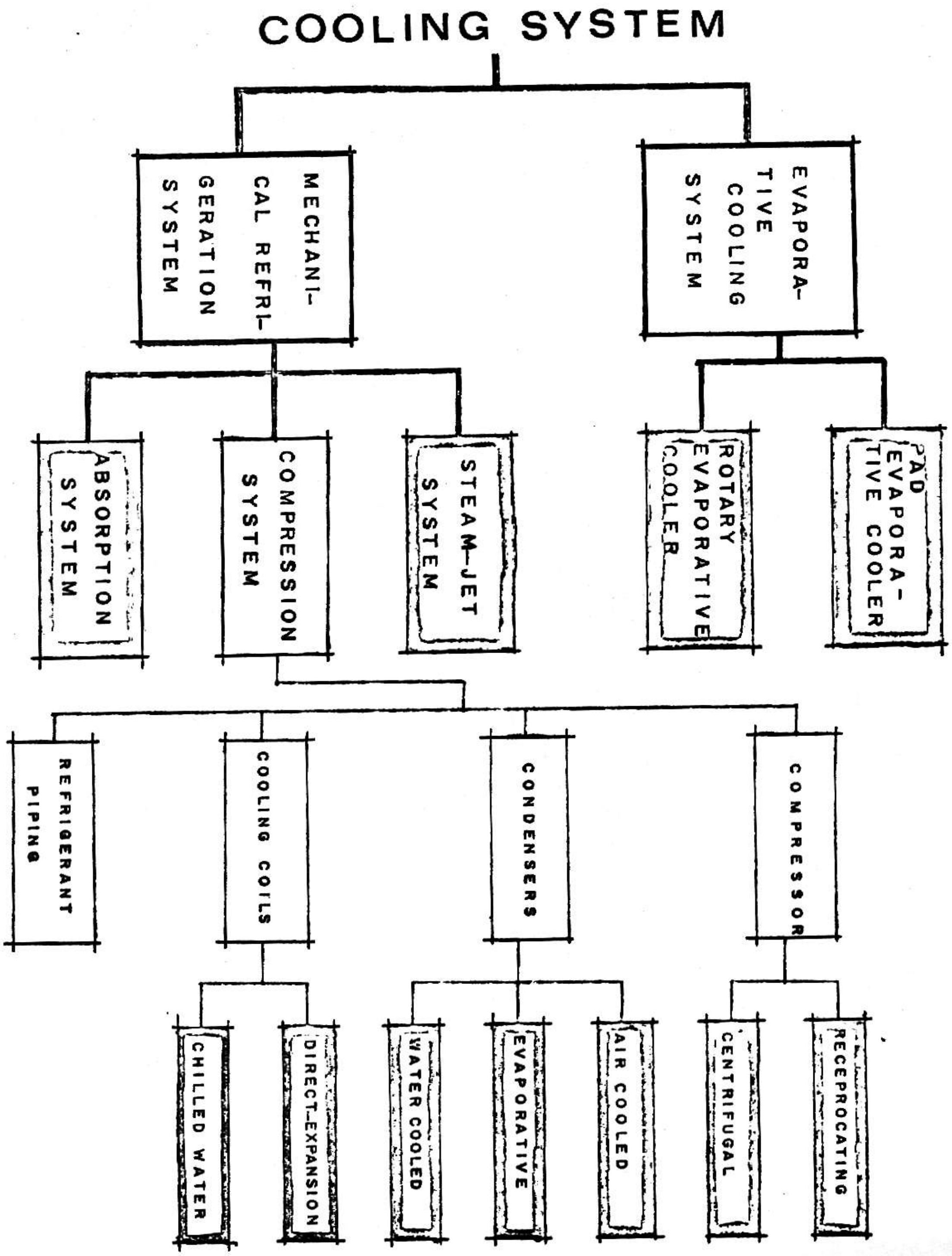
[36] F. T. Andrews, op. cit., p. 17.

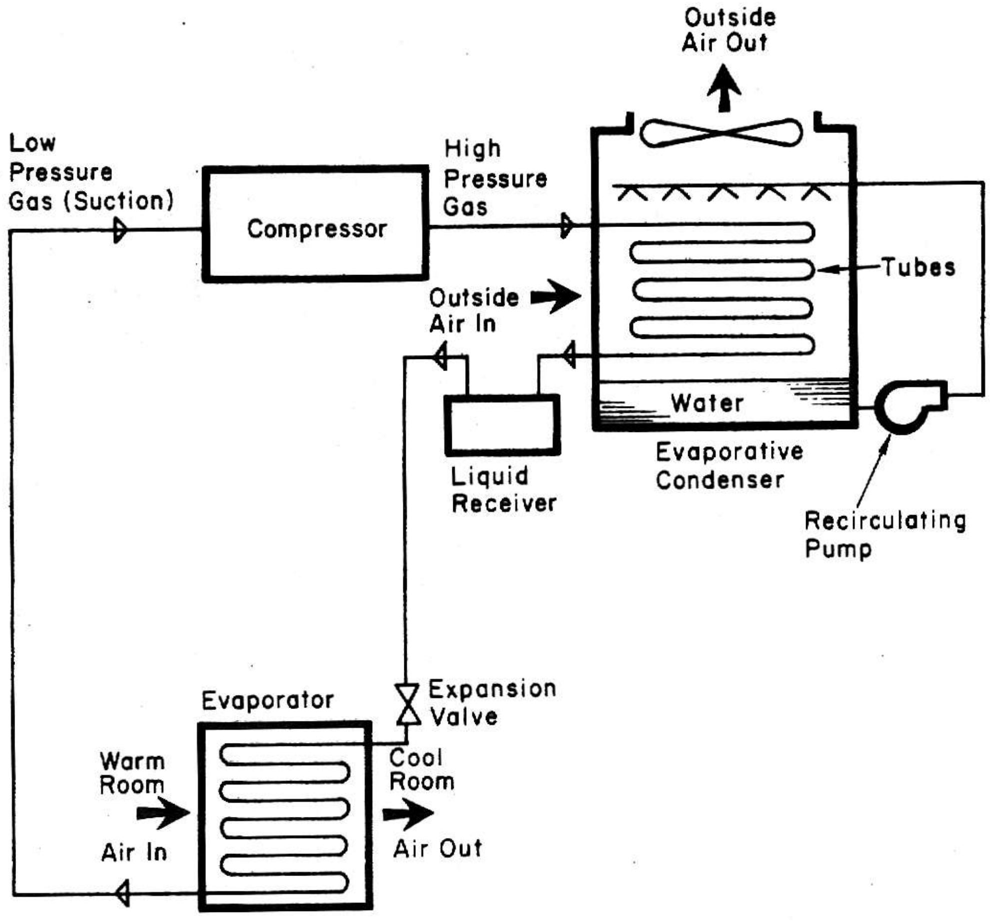
[37] Ibid., p. 17.

PLATE XXII


COOLING SYSTEM
MECHANICAL REFRIGERATION SYSTEM
EVAPORATIVE COOLING SYSTEM
ABSORPTION SYSTEM
COMPRESSION SYSTEM
STEAM-JET SYSTEM
ROTARY EVAPORATIVE COOLER
PAD EVAPORATIVE COOLER
REFRIGERANT PIPING
COOLING COILS
CONDENSERS
COMPRESSOR
CHILLED WATER
DIRECT-EXPANSION
WATER COOLED
EVAPORATIVE
AIR COOLED
CENTRIFUGAL
RECEPROCATING

Andrews continued, that heat energy is required to transform a liquid into its vapor state. The amount of heat required for this transformation is called the latent heat of vaporization. When a liquid evaporates, it takes heat from its surroundings and reduces the air temperature accordingly.[38]

Figure 14



Evaporative Condenser Cycle

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[38] Ibid.

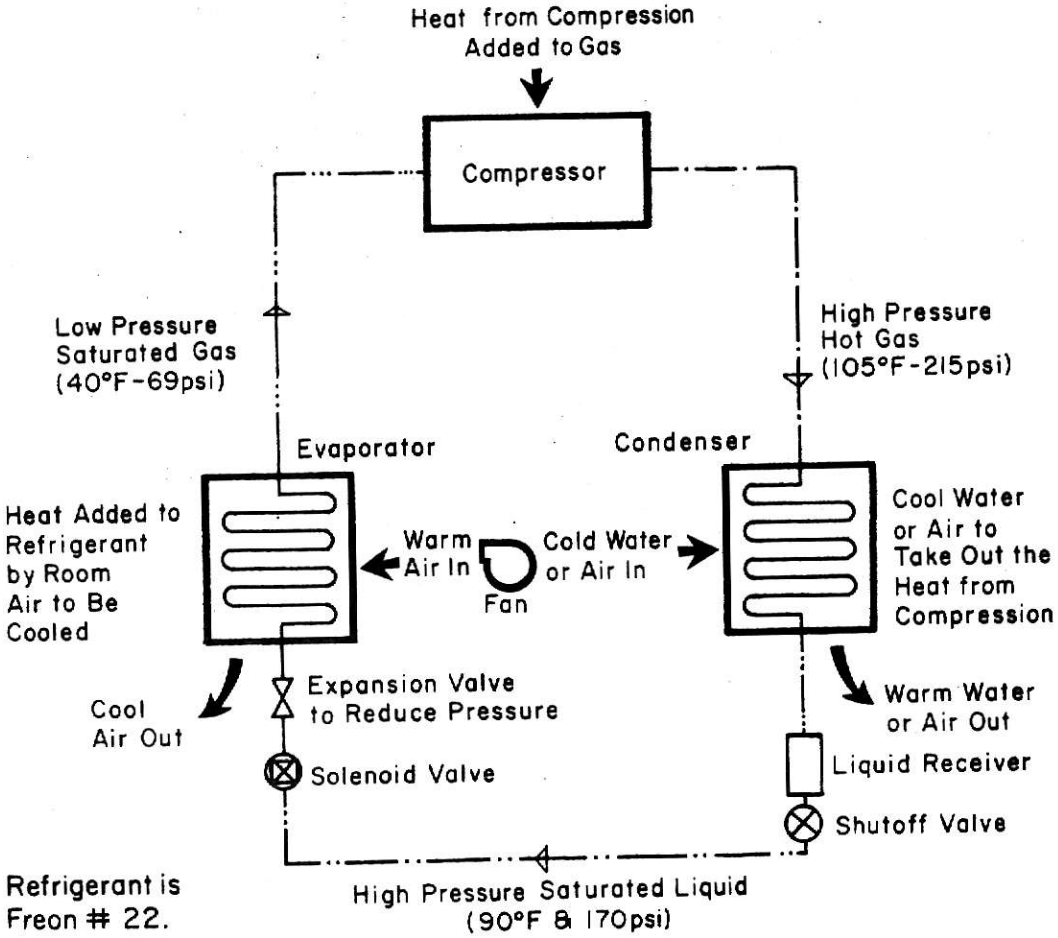
2. Mechanical Refrigeration

Three basic systems of mechanical refrigeration currently used in air conditioning are:

1. The steam-jet system. According to F.T. Andrews, this system is not extensively used because it is economical only for large tonnage systems and where surplus steam is available.[39]

Figure 15

Compression Refrigeration Cycle



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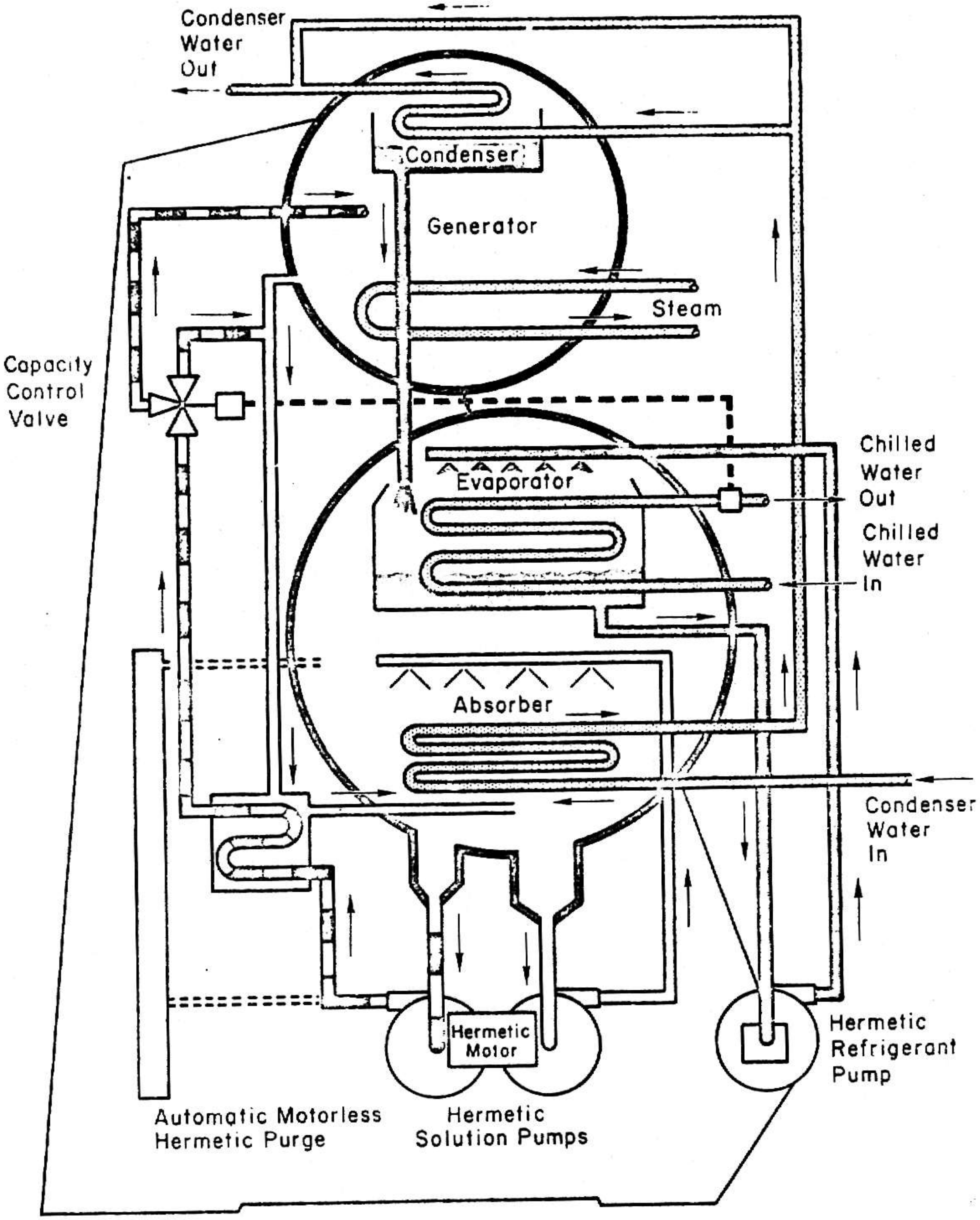
[39] Ibid., p. 20.

PLATE XXIII



Carrier Corporation

Absorption Machine Cycle

2. The compression refrigeration cycle. This is an important system to be studied because it takes advantage of a principle of physics, and it is more complicated than other systems.

In this system, heat must be supplied to any liquid to change it to the vapor state. Conversely, the same amount of heat must be removed from any gas to condense it from the vapor state to a liquid. The equipment most commonly used to create a refrigeration effect is a compressor, a condensor, and an evaporator.

F.R. Andrews clearly describes the system's work in this way (also see Fig. 15):

> The compressor's function in the cycle is to take low pressure gas -- like Refrigerant 22 (40 F and 69 psi) -- and to compress it to a high temperature pressure gas (10t F., 215 psi). The heat added by the compressor is called the heat of compression. The hot gas from the compressor discharges into a condensor, which removes the heat of compression and condenses it to a high pressure liquid (215 psi), which is usually stored in a received. Then, the liquid refrigerant is piped to an evaporator through an expansion valve. Under reduced pressure, the liquid refirgerant vaporizes and absorbs heat from the warm return air passing over the evaporation coils. This cooled air is supplied to the rooms by the air-conditioning system fan. The cole low pressure gas is redelivered to the suction side of the compressor to repeat the cycle.[40]

3. The absorption system. The absorption machine creates the same refrigeration effect as a compressor, but does it with a different kind of energy. Whereas compressors use mechanical energy, an

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[40] Ibid., p. 22.

absorption machine uses heat energy to evaporate and condense the refrigerant (see Plate XXIII). Lithium bromide in the absorber attracts the water vapor from the evaporator. As the water evaporates by being absorbed in the salt solution, it cools the remaining water in the evaporator. This refrigeration effect is captured by the water circulated in the air conditioning system. As the water vapor reduced the concentration of the lithium bromide, its solution loses its ability to attract more water vapor and must be reconcentrated. This is done in the generator, in which steam boils off the water vapor and discharges it to the condensor. The reconstituted lithium bromide is returned to the absorber where it begins the cycle all over again. The water vapor from the generator is condensed by cooling tower water and then returned to the evaporator.

When electric power is generated on site, waste heat from turbo gas-electric generators, gas engines, or diesel engines can be economically used to generate steam for space heating and in the generator, of the absorption machine.

Absorption machines are manufactured in sizes from 25 to 1000 tons. Normally, they are used on larger projects, especially those having large amounts of steam available, like hospitals or food processing plants. Absorption machines are free from vibration and noise, although they do require a great deal of floor space.[41] William Mc Guinness concludes: "The absorption machine has become very popular.

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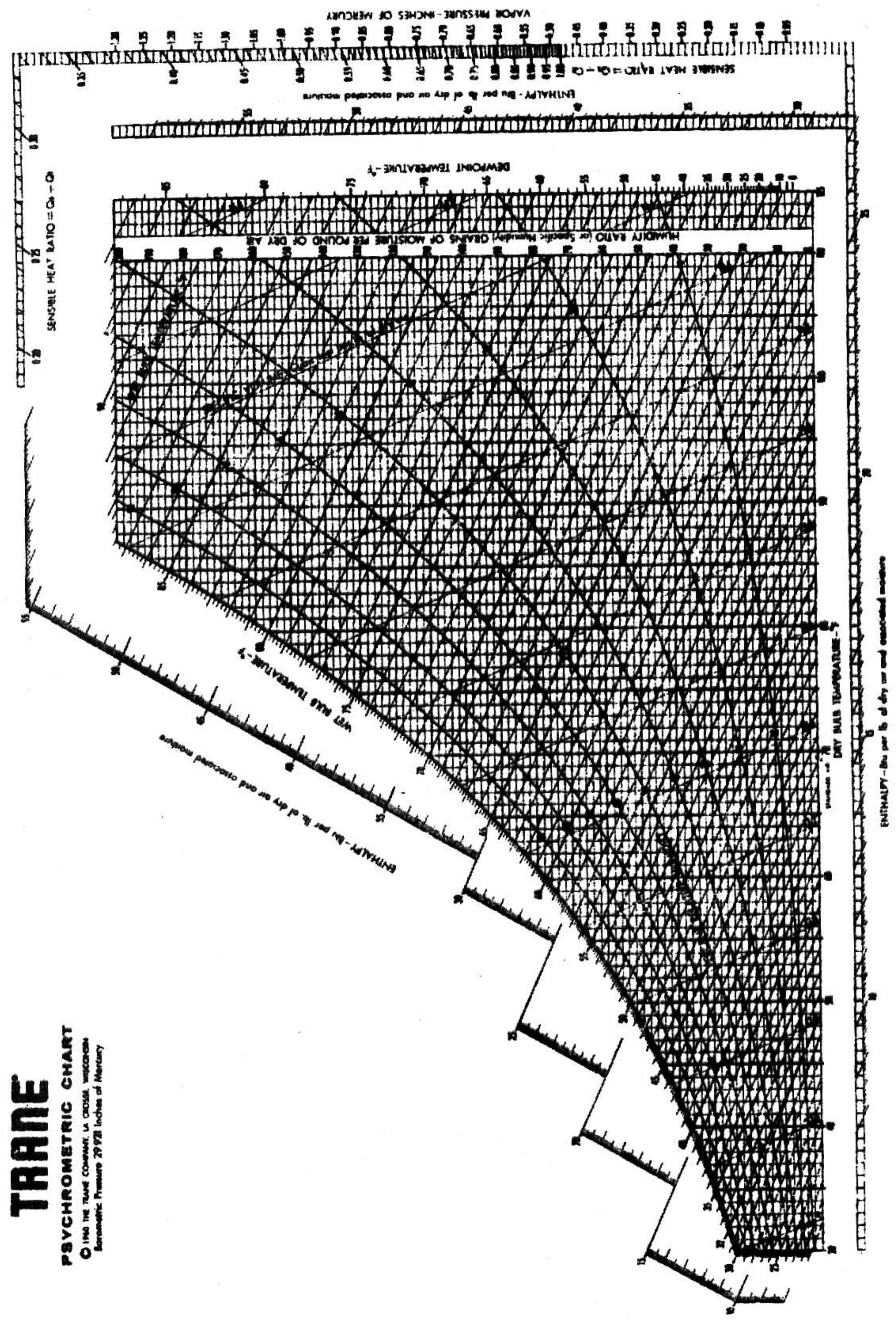
[41] *Ibid.*, p. 28.

PLATE XXIV


TRANE
PSYCHROMETRIC CHART
© 1960 THE TRANE COMPANY, LA CROSSE, WISCONSIN
Barometric Pressure 29.921 Inches of Mercury
VAPOR PRESSURE - INCHES OF MERCURY
SENSIBLE HEAT RATIO = Qs ÷ Qt
ENTHALPY - Btu per lb of dry air and associated moisture
DEWPOINT TEMPERATURE - °F
HUMIDITY RATIO (or Specific Humidity) GRAINS OF MOISTURE PER POUND OF DRY AIR
WET BULB TEMPERATURE - °F
DRY BULB TEMPERATURE - °F

It is often economically competitive with the compression machine, has fewer moving parts, is quieter and demands somewhat less attention."[42]

b) Psychrometric Chart Analysis

Figure 16

Dry-bulb Temperature — The temperature of air as registered by an ordinary thermometer.

Wet-bulb Temperature — The temperature registered by a thermometer whose bulb is covered by a wetted wick and exposed to a current of rapidly moving air.

Dewpoint Temperature — The temperature at which condensation of moisture begins when the air is cooled.

Relative Humidity — Ratio of the actual water vapor pressure of the air to the saturated water vapor pressure of the air at the same temperature.

Specific Humidity or Moisture Content — The weight of water vapor in grains or pounds of moisture per pound of dry air.

Enthalpy — A thermal property indicating the quantity of heat in the air above an arbitrary datum, in Btu per pound of dry air. The datum for dry air is 0°F and, for the moisture content, 32 F water.

Enthalpy Deviation — Enthalpy indicated above, for any given condition, is the enthalpy of saturation. It should be corrected by the enthalpy deviation due to the air not being in the saturated state. Enthalpy deviation is in Btu per pound of dry air. Enthalpy deviation is applied where extreme accuracy is required; however, on normal air conditioning estimates it is omitted.

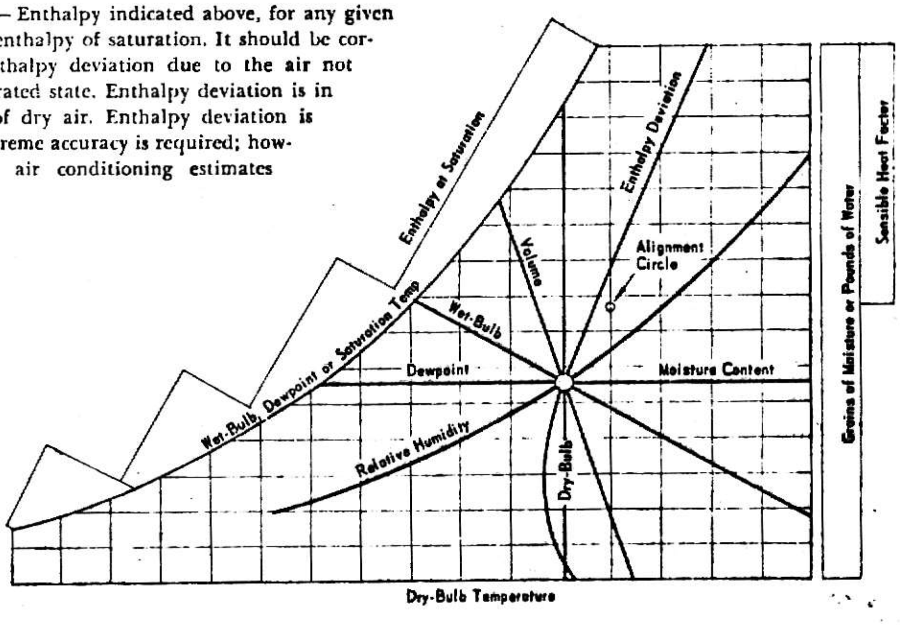
Specific Volume — The cubic feet of the mixture per pound of dry air.

Sensible Heat Factor — The ratio of sensible to total heat.

Alignment Circle — Located at 80 F db and 50% rh and used in conjunction with the sensible heat factor to plot the various air conditioning process lines.

Pounds of Dry Air — The basis for all psychrometric calculations. Remains constant during all psychrometric processes.

The dry-bulb, wet-bulb, and dewpoint temperatures and the relative humidity are so related that, if two properties are known, all other properties shown may then be determined. When air is saturated, dry-bulb, wet-bulb, and dewpoint temperatures are all equal.



SKELETON PSYCHROMETRIC CHART

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[42] William McGuinness, op. cit., p. 234.

"The psychrometric chart," according to Trane Air Conditioning Manual, "is one of the most serviceable tools available to the air conditioning engineer. The changes occuring in humid air, as it is subjected to various air conditioning processes, can be traced on the chart with a minimum of time and effort. There is no other way in which an air conditioning cycle can be illustrated as vividly and as quickly."[43] Melvin Ramsey, the consulting engineer says that the psychrometric chart can be used to design an air conditioning system to produce specific, required space condition. In most air conditioning systems, temperature is controlled and relative humidity is allowed to fluctuate within limits predetermined by apparatus sizing, on the basis of the other anticipated thermodynamic variables, i.e., outside air condition, internal heat and moisture gains, etc. According to him, such systems are usually successful when internal sensible heat gains are high, as in most offices, stores and restaurants, but not so successful in residences and hotel bedrooms, particularly in localities where the average daily temperature range is 10-12 F., or less. In general, those localities with the smaller daily temperature fluctuations have higher relative humidities.[44]

The definition and the analysis of the psychrometric chart are clearly explained by M. Ramsey in his book, Design Problems in Air Conditioning and Refrigeration, in which he writes:

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[43] The Trane Company, Trane Air Conditioning Manual, (Wisconsin: The Trane Company, 1958), p. 49.

[44] Melvin A. Ramsey, Tested Solution to: Design Problems in Air Conditioning and Refrigeration, (New York: Industrial Press Inc., 1966), p. 14.

> The psychrometric chart is merely a graphic representation of a broad range of air-water vapor mixtures. Every point on the chart represents a unique combination of air and water vapor, which combination we call a "condition." The chart, in its most useful form, is one on which all points representing mixtures, in any proportion, of air and water vapor at any two different conditions lie on a straight line connecting the points representing the two conditions. In other words, a straight line on this type of chart is the locus of all possible mixtures of its end points... its vertical coordinate is moisture ratio. The other orincipal coordinate, enthalpy, is roughly 30° from the vertical. Dry bulb lines are not perpendicular but fan out slightly toward the higher moisture ratios.
>
> Most lines and scales on the chart are clearly understood from data and the chart itself....
>
> It has been common practice to show line of <u>relative humidity</u> on psychrometric charts. A few charts have shown degree of <u>saturation or percentage humidity</u> (the definitions of these last two terms are identical)....
>
> It will be noted that this chart is based on standard sea-level pressure: 29.92 inches of mercury. For other altitudes, different charts must be used or corrections made. For atmospheric pressures about an inch of mercury (altitudes about 1,000 feet, below or above, sea level), sea-level data is correct within 3%.[45]

5. Air Conditioning Systems

In cooling and heating systems, the air-conditioning system is frequently mentioned. The definition of air-conditioning has been given in <u>Trane Air Conditioning Manual</u> as follows:

> Air conditioning is the science of maintaining the atmosphere of an enclosure at any required temperature and humidity. The condition to be maintained is determined solely by the use for which the conditioned space is intended.... Air conditioning can provide and maintain any atmospheric condition regardless of variations in outdoor weather.

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[45] <u>Ibid.</u>, pp. 2-3.

> In comfort cooling, the range of temperatures and humidities used narrows down to a comparatively small band. The location of this band on the psychrometric chart depends on the season of the year.
>
> In addition to the factors of temperature and humidity, there are the factors of cleanliness and air movement.... Air cleanliness is important from the standpoint of health ....
>
> Air should circulate freely in the room to which it is delivered, so that it can absorb heat and moisture uniformly throughout the entire room.... The best air conditioning systems are those able to maintain such conditions that the occupants of the room are not aware of inside atmospheric conditions.[46]

According to J.R. Kell, the application of air-conditioning may be considered under various headings:

1. Where crowds of people congregate, such as in restaurants, cinemas, and theatres.
2. Where the exclusion of air-borne dust is essential.
3. Where the process to be carried out can only be efficiently done within strictly controlled limits of temperature and humidity.
4. Where the type of buildings and usage thereof involves considerable heat gains, such as in multi-story office buildings with large glass areas subject to solar gain, and including heat-producing office machinery, computers, intensive electric lighting, etc.
5. In a great variety of conference rooms, lecture theatres,

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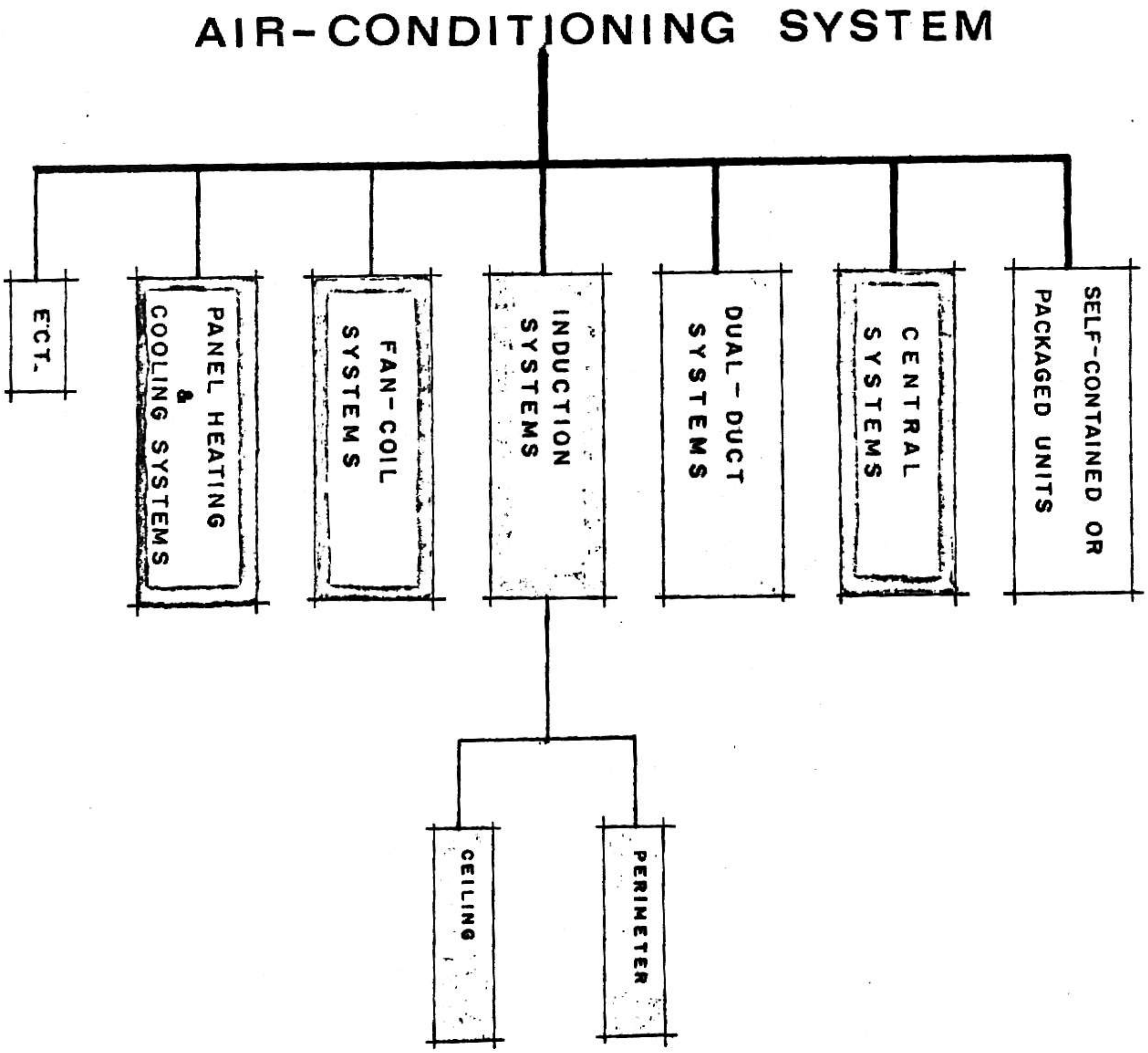
[46] Trane Air Conditioning Manual, op. cit., p. 10.

PLATE XXV


AIR-CONDITIONING SYSTEM
ECT.
PANEL HEATING & COOLING SYSTEMS
FAN-COIL SYSTEMS
INDUCTION SYSTEMS
DUAL-DUCT SYSTEMS
CENTRAL SYSTEMS
SELF-CONTAINED OR PACKAGED UNITS
CEILING
PERIMETER

laboratories, and animal houses.

6. The core areas of modern buildings planned in depth, where the accommodation in the core is remote from natural ventilation and windows and which is subject to internal heat gains from occupants, lighting, etc.[47]

All air conditioning systems involve the handling of air as the vehicle for cooling or warming, dehumidifying or humidifying. If the space to be air-conditioned has no occupancy, no supply of outside fresh air is needed. The air inside the room is being continually recirculated. In most practical cases, ventilation for occupancy has to be included, and in the design for maximum economy of heating ahd cooling, this quantity is usually kept to a minimum, depending on the number of people to be served (see more detail in Ventilation Section).[48]

The basic elements of air-conditioning systems of whatever form, according to J.R. Kell, are (see Plate XXVI):

1. Fans for moving air,
2. Filters for cleaning air, either fresh, recirculated, or both,
3. Refrigerating plant connected to heat exchange surface, such as finned coils and chilled water sprays.
4. Means for warming the air, such as hot water or steam heated coils or electrical elements.

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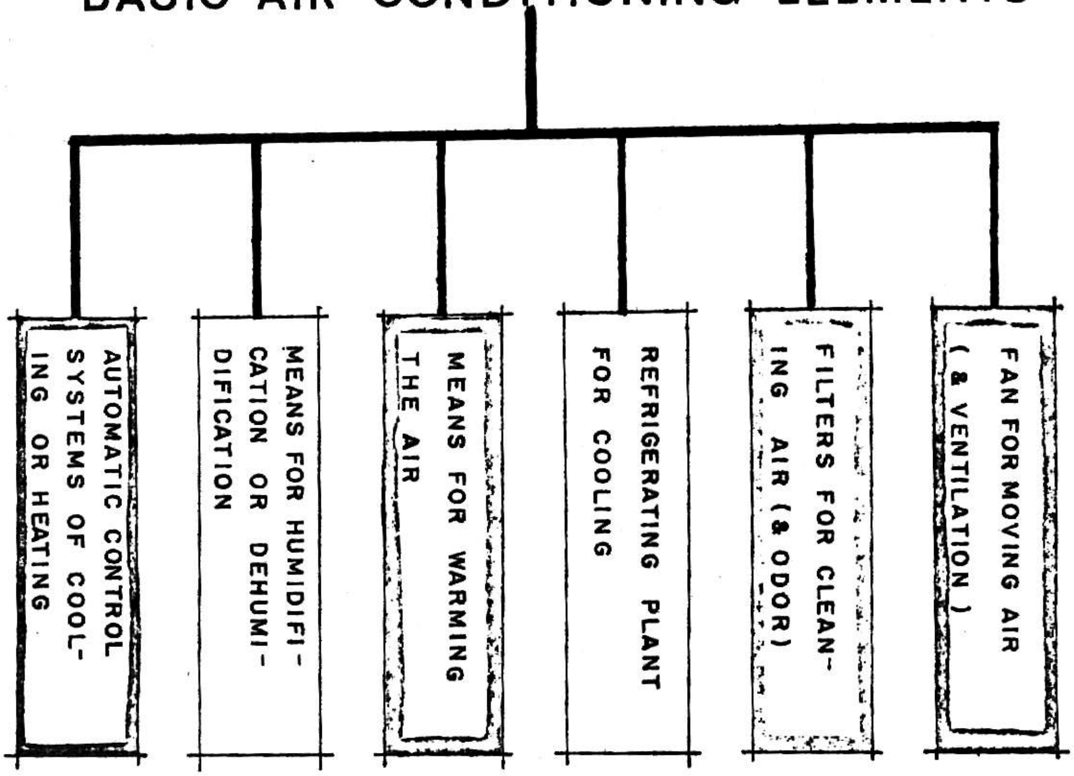
[47] J. R. Kell, <u>op. cit</u>., pp. 396-397.

[48] <u>Ibid</u>., p. 396.

PLATE XXVI



BASIC AIR-CONDITIONING ELEMENTS

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TABLE IV

Basic Systems for
Air-Conditioning Comfor
In Various Building Ty

SYSTEMS	HEATING										REFRIGERATION				CONDENSERS				COOLING							PIPING SYSTEMS			AIR SUPPLY & DISTRIBUTION													
	Gas fired furnace	Unit heater	Gas fired radiant heater	Hot water system	Electric strip heater	Electric ceiling radiant heater	Heat pump	Wall heater	Package gas fired absorpt	Direct fired absorption	Reciprocating Compressor-Ele	Reciprocating Compressor-Gas	Centrifugal Compressor	Absorption	Air cooled condenser	Evaporative Condenser	Evaporative water cooler	Cooling tower	Package direct expansion	Packaged Gas fired absorption	Direct fired absorption	Heat pump	Direct expansion (built-up)	Chilled water	Evaporative Cooler	Four pipe	Three pipe	Two pipe	Common system	Hot water multi-zone	Gas fire multi-zone	Double duct	High velocity	Packaged direct expansion	Packaged gas fired absorpt	Heat pump	Fan and coil	Induction unit	Underfloor perimeter	Evaporative cooler	Dual conduit	Gas fired furnace
AUDITORIUMS (1000+ Seats)	X				X					X	X	X	X		X	X	X	X				X		X	X		X	X	X	X	X	X	X						X			
BANKS																																										
a. Less than 5,000 sq. ft.	X				X				X		X				X	X		X	X	X	X			X	X		X		X	X	X	X	X	X	X							X
b. 5,000 - 10,000 sq. ft.	X				X					X	X	X		X	X	X		X				X		X	X		X	X	X	X	X	X	X									X
BOWLING ALLEYS (24+ Lanes)	X				X					X	X	X		X	X	X		X				X		X	X		X	X	X	X	X	X	X									X
CHURCHES																								X	X																	
a. 400-600 Seats	X								X		X				X	X		X	X	X	X			X	X		X		X		X			X	X				X			X
b. 600-1000 Seats	X									X	X	X		X	X	X		X				X		X	X		X	X	X	X	X								X			X
CONVALESCENT HOMES									X																																	
a. Adminstration	X				X			X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X			X		X		X
b. Kitchens	X				X					X	X	X	X	X	X	X	X	X								X		X						X	X			X			X	X
c. Patient Areas	X				X					X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X						X	X			X				X
COUNTRY CLUBS	X				X			X		X	X			X	X	X		X	X	X	X			X	X		X	X	X	X	X	X	X	X	X							X
EMERGENCY OPERATING CTRS. (C.D.)					X						X				X				X	X				X	X		X						X									
HONOR FARMS	X				X					X	X			X	X	X		X	X	X				X	X		X	X	X	X	X	X		X								X
HOTELS																																					X	X				
a. Low Rise (3 & 4 Story)					X	X	X	X		X	X			X	X	X	X	X				X		X	X	X	X	X									X	X				
b. High Rise (5+ Stories					X	X	X	X		X	X	X	X	X		X	X	X				X		X	X	X	X	X									X					
HOSPITALS					X						X	X	X	X			X	X																								
a. Administration																									X		X		X	X		X	X				X					
b. Delivery, Labor, Nurseries																									X		X		X	X			X				X					
c. Kitchens																										X		X												X		
d. Patient Areas																									X		X		X	X							X					
e. Surgeries																									X		X		X	X			X				X					
FACTORIES																																										
a. Office	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X							X
b. Shops	X	X	X		X				X		X	X	X	X	X	X	X	X	X	X	X			X	X	X	X		X	X	X			X						X		X
FIRE STATIONS	X	X			X				X		X			X	X	X		X		X	X			X	X		X	X			X	X		X	X							X
LIBRARIES	X				X					X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X		X	X		X					X
MARKETS (SUPER)	X	X			X					X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X			X	X		X					X
MEDICAL CENTERS	X										X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X			X	X		X					X
a. Low Rise (3-4 Story)	X				X					X	X	X	X	X	X	X	X	X				X		X				X			X	X	X				X					X
b. High Rise (8+ Story)					X						X	X	X	X	X	X	X	X						X	X		X	X		X	X	X	X				X					
MORTUARIES	X				X				X		X				X	X		X	X	X	X			X	X		X	X	X	X	X			X	X							X
MOTELS	X				X	X	X	X	X	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X						X	X	X	X			X		X
MUSEUMS	X				X				X	X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X		X					X
OFFICE BUILDINGS																																										
a. Single Story	X				X	X			X	X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X		X	X	X			X
b. Two Story	X				X				X	X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X		X	X			X	X
c. Low Rise (3-4 Story)					X					X	X	X		X	X	X	X	X				X		X	X		X	X	X	X	X	X	X				X	X			X	
d. High Rise (5+ Stories					X						X	X	X	X		X	X	X						X	X		X	X	X	X	X	X	X				X	X			X	
POLICE STATIONS		X			X				X	X	X	X	X	X	X	X		X	X	X	X	X			X		X	X		X	X		X	X	X							
RESIDENCES	X						X	X	X		X			X	X				X	X	X		X			X			X	X						X			X			
SAVINGS & LOAN BUILDINGS																																								X		X
a. Single Story	X				X	X			X	X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X		X		X	X		X
b. Two Story	X				X				X	X	X			X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X		X	X				X
c. Low Rise (3-4 Story)					X					X	X			X	X	X	X	X				X		X	X		X	X	X	X		X	X				X	X			X	
d. High Rise (5+ Stories)					X						X	X				X	X	X						X	X		X	X	X	X		X	X				X	X			X	
SCHOOLS											X	X	X	X			X	X					X																		X	
a. Adminstration	X				X				X					X	X	X			X	X	X			X	X		X	X		X	X	X		X	X							
b. Assembly	X				X										X	X								X	X		X	X	X	X	X	X							X			X
c. Classrooms	X				X				X					X	X				X	X	X			X	X		X	X	X	X	X	X		X	X		X					X
d. Dormitories	X																																									X
1. Single Story	X				X	X			X					X	X	X		X	X	X	X			X	X		X	X						X	X		X		X			X
2. Two Story	X				X				X	X				X	X	X		X	X	X	X	X		X	X		X	X						X	X		X					X
3. Low Rise (3-4 Story)					X					X				X		X		X				X		X	X		X	X									X	X				X
e. Gymnasiums	X				X				X					X	X					X	X			X	X		X	X	X	X	X			X	X							X
f. Kitchens	X				X																					X		X												X		X
g. Libraries	X				X				X					X	X				X	X	X			X	X		X	X	X	X	X			X	X		X					X
h. Multipurpose Bldgs.	X				X				X					X	X	X		X	X	X	X			X	X		X	X	X	X	X			X	X							X
i. Shops	X	X			X				X					X	X				X	X	X			X	X		X	X	X	X	X	X		X	X					X		X
STORES	X				X		X		X		X			X	X	X		X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X					X
THEATRES	X				X					X	X	X			X	X		X				X		X	X			X	X	X	X											X
WHITE OR CLEAN ROOMS										X	X			X	X	X		X										X	X	X	X			X	X							

5. Means for humidification, and/or dehumidification, and
6. A control system to regulate, automatically, the amount of cooling or warming.[49]

a) Type of Systems

For the simple understanding purpose, we divided air-conditioning systems into six types, according to their functions (see Plate XXV):

1. Self-contained air-conditioners,
2. Central system,
3. Dual-duct system,
4. Induction system,
5. Fan coil system, and
6. Panel cooling system.

6. Temperature Controls

One of the advantages for climate control by mechanical means is that men are able to control their environments as much as they desire, by the use of manually controlled or automatically controlled devices. However, in order to have full advantage from these devices, we must know, in the case of rooms for instance, how many thermalstats will be needed in each particular space and where they should be properly located.

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[49] *Ibid.*, p. 398.

PLATE XXVII

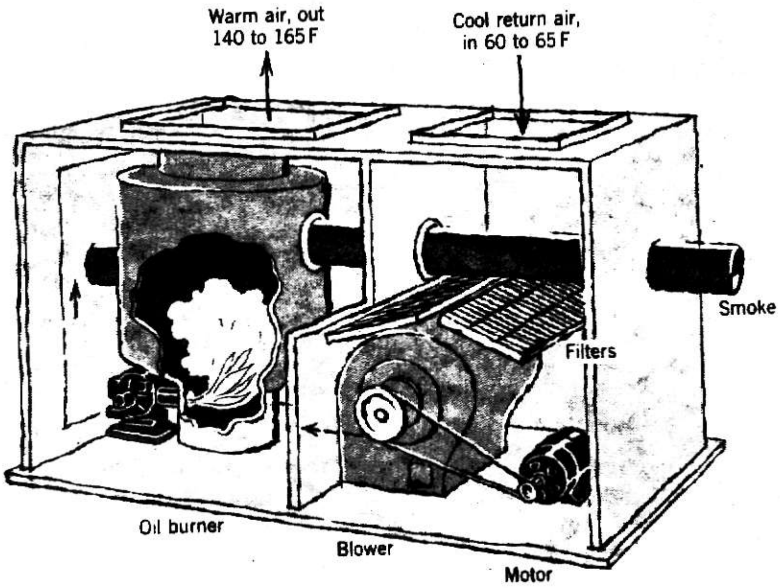
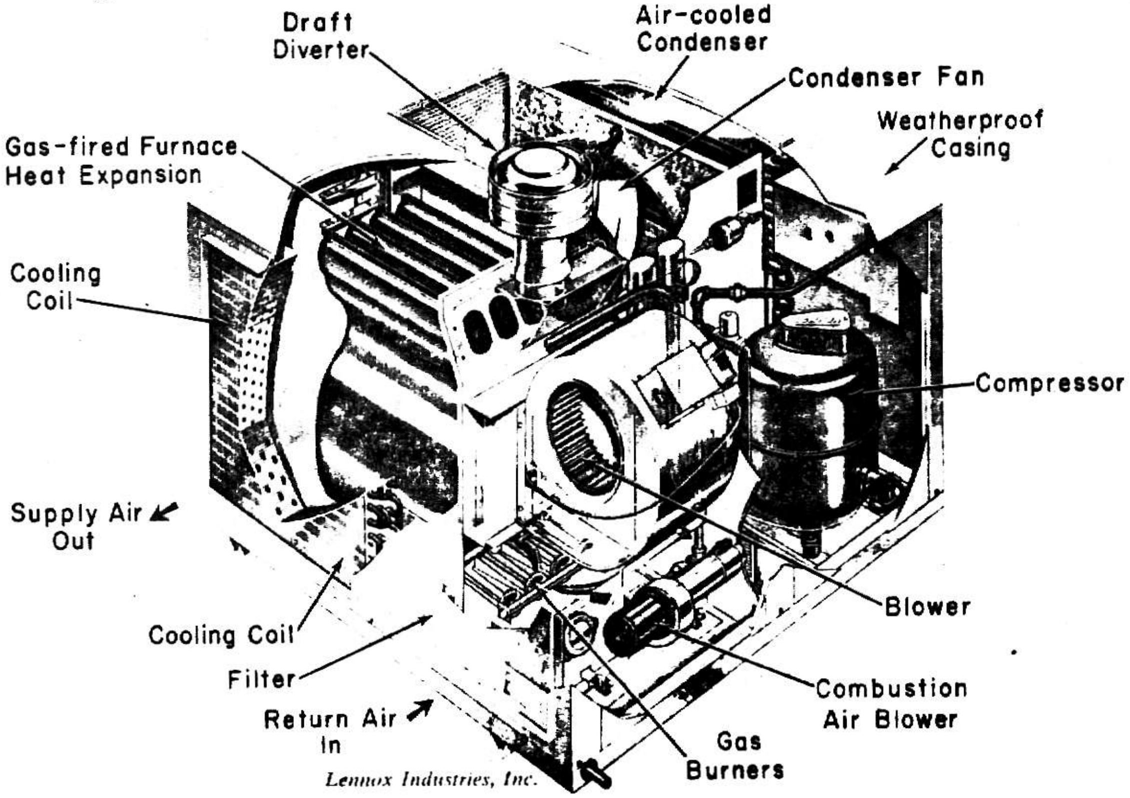


Fig. 17 Principle of the mechanical warm-air heating furnace. Other styles have the elements "in-line" and replace the U-path flow of air with straight line flow, vertically upward, horizontal or vertically downward (counterflow).

Fig. 18 **Combination Heating and Cooling Single-Zone Packaged Unit**



Lennox Industries, Inc.

a) Automatic Control

In the control systems, there are manually controlled and automatically controlled devices. The manually controlled is a simple on-off system which is used in a very small project. For example, some radiators are manually controlled, when we feel cold or hot we just open or close the radiator valves. However, today, most of our modern mechanical systems are controlled by automatic devices.

Automatic control systems are one of the most useful and important systems in our environmental comfort control. John E. Haines, ex-president of ASHRAE, wrote in his book, Automatic Control of Heating and Air-Conditioning:

> Most forms of automatic control are applied to heating, ventilating, or air-conditioning systems, or combinations thereof, to accomplish one or more of the following purposes:
>
> 1. To ensure certain desired or required conditions of temperature, pressure, or humidity.
> 2. To serve safety functions by keeping temperatures, pressure, or humidities within pre-determined limits or by preventing mechanical equipment from operating when its operation would be hazardous.
> 3. To ensure economical results by providing operating cycles, or a level of system performance that matches load conditions.
> 4. To eliminate human error.[50]

Present standards of comfort, combined with the rapid response of modern heating and cooling equipment, according to the ASHRAE Guide and

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[50] John E. Haines, Automatic Control of Heating and Air-Conditioning, (New York: McGraw-Hill Book Co., Inc., 1961), Second Edition, p. 1.

Data Book, mean that an air conditioning system must be considered as an integrated control where each component plays an important part in the overall performance. Control performance is usually evaluated in terms of:

1. system stability, the absence of excessive periodic control oscillations;
2. control offset, the minimum differences between the set point and the actual control point under stable conditions; and
3. system response, the ability to correct rapidly any system disturbances.[51]

Temperature control systems have three parts, according to Joseph Olivieri:

1. a sensing device,
2. a signal transmission system, and
3. the control device.[52]

When automatic controls are used, they send a signal electrically through wires to a motor-operated valve which opens or closes, as needed. Olivieri explained that the signal can also be a change in air pressure, which is transmitted through air piping to an air-operated valve. When ventilation is incorporated into a system, addi-

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[51] ASHRAE, Guide and Data Book System 1970, Chapter 32, "Automatic Control," p. 469.

[52] Joseph Olivieri, op. cit., pp. 283-284.

tional controls are required. He explained that, generally, a motorized damper is installed to operate the return-air and out-side-air dampers. These dampers can be controlled so that they open to a set position any time the fan runs. "Another system is to use a thermostat to sense mixed air temperature. This thermostat positions the damper motor, or motors, to maintain the desired temperature," he described.[53]

Control systems are divided into five main groups according to primary source of energy:

1. Electric control systems,
2. Electronic control systems,
3. Pneumatic control systems,
4. Hydraulic control systems, and
5. Conbimation electronic-pneumatic control systems.

The choice of the systems will be determined by preference, based on experience, size of job, cost, personnel in charge of plant, etc.

b) Zone Control

Zone control of the building becomes one of the most important parts in the temperature control. Only the carefully zoned layouts can help the mechanical comfort systems to work more satisfac-

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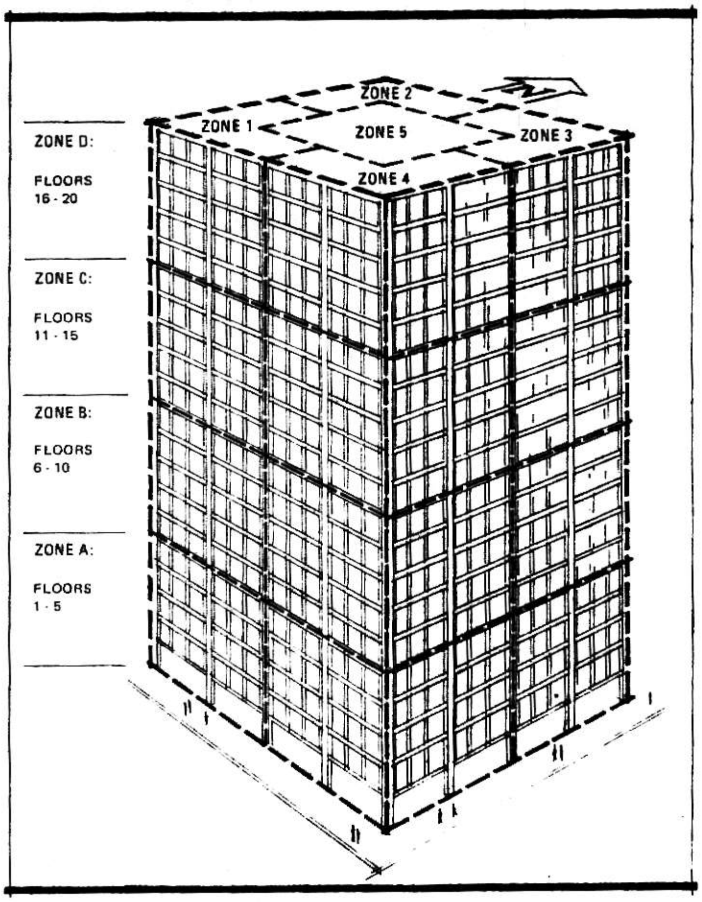
[53] *Ibid.*

torally and more economically. The ASHRAE clearly states:

> Zone control for any heating, ventilation, or air-conditioning system is employed where it is desired to control, by one set of controls, the heating or cooling effect in a number of rooms or areas having similar orientation or occupancy.

Figure 19

VERTICAL AND HORIZONTAL DEMAND ZONING



> Whether zoning a building for heating or cooling, the designer should consider the following factors in determining the number and arrangement of the zones:
>
> 1. Exposure. Solar effect, prevailing winds, and the shelter afforded by surrounding structures affect the heat gain or loss.
>
> 2. Occupancy. Indoor temperature requirements for the various activities carried on in different portions of the building and the hours of occupancy of the various spaces, impose definite control problems
>
> 3. Building Structure. The physical characteristics of the building will influence the subdivisions of the system into zones.... Other factors are the height of the building and its horizontal extent and form.
>
> 4. Floors. Even though several floors have the same wall exposure, it is advisable to have separate zones on the lowest and highest floors, due to variations of basement or ground floor requirements and the effect of roof exposure. It is also desirable to have a separate zone, or zones, for the intermediate floors.[54]

The number of zones for each space are also important when spaces are complex. The following are examples of some of the spaces which the ASHRAE suggested be zoned accordingly:

1. In larger buildings, accepted practice is to have at least one zone for each exposure.
2. For higher structures, each exposure may require subdivision, vertically into two or more zones.
3. The presence of two or more wings having the same general exposure may suggest the desirability of more restrictive zoning.

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[54] ASHRAE, Guide and Data Book System 1970, op. cit., pp. 483-484.

4. When the street floor, or any other portion of the building, is used for public occupancy or activities which differ from those carried on in the remainder of the building, it is desirable to provide separate thermostats and controls for each individual area.[55]

Zone controls alone may not provide satisfactory temperature conditions in all rooms or areas within the zone, according to the ASHRAE, because occupancy, lighting load, space arrangements, and similar factors cannot always be predicted with accuracy. A combination of zone controls and individual room controls in critical areas may be necessary for complete satisfaction. The advantage of individual room control is in fuel economy and comfort for the occupants. Each room should have a thermostat that controls valves or dampers on all the controlable sources of heating and cooling.[56]

c) Location of Room Thermostats

It is extremely important to know the proper place in which the room thermostat should be installed, and where it can measure the average temperature of the entire space. Therefore, in a residence, for example, the following precautions are given by John Haines in his book, Automatic Control of Heating and Air Conditioning:

> 1. The thermostat should always be located in a relatively open room in a representative part of the building.

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[55] *Ibid.*

[56] *Ibid.*

2. It should never be mounted on a wall where it will be exposed to cold drafts from an outside door or window.
3. It should never be mounted where it will be affected by heat from a nearby warm surface, such as pipes or ducts in a wall, or a radiator, or by direct currents from a warm-air register.
4. It should never be located where normal circulation of air in impeded by furniture or an opened door.
5. It should be located where it is safe from mechanical injury.
6. Room occupancy and usage should be considered. In a typical home, a satisfactory location for the thermostat can usually be found in the living room or dining room.[57]

7. Ventilation

"The idea of keeping indoor air healthful is most likely to be done by Northern people, who spend much of their time indoors," Henry Wright Jr. explained. "The Greeks and Romans normally gathered in the open, and in their largest enclosed building, the Pantheon, the Romans were able to solve the ventilation problem by simply providing an open oculus or eye in the top of the dome. It was not untill the twelfth century that fireplaces against the wall replaced the fire-in-mid-floor in most European castles, and long after that time smells, dampness, and drafts were normal elements of daily life in buildings of any size." He continued:

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[57] John E. Haines, op. cit., pp. 89-90.

[58] Henry Wright Jr., The Thermal Theory of Ventilation, an unpublished manuscript. Department of Architecture, Kansas State University, Fall 1971.

> The ventilation of mines and the holds of ships, necessary for very survival, was a primary field of early experiment. A rotary fan was observed at work in a mine by Agricola before 1553.... In the late seventeenth century Sir Christopher Wren used a crude fan in an attempt to improve the ventilation of the British House of Parliament, and in 1848 a steam driven fan was installed in the Boston Custom House. Until about 1870 fans were introduced and incorporated in ventilating systems for public buildings and schools.[58]

Ventilation is a very important matter for human environmental comfort. Lack of fresh air will finally result in unpleasant house odors and it can be a hazard to our health. McGuinness wrote, "If the house has very tight doors and windows, air is sometimes unexpectedly drawn through the flues of fireplaces and heating builers, disturbing their combustion processes and causing the introduction of dangerous carbon monoxide into the rooms."[59] Another serious problem which can occur when ventilation is missing is the moisture content of the room. Moisture that is given off by the occupants' bodies can reach very high levels. Joseph Olivieri stated: "Moisture levels in the room can get quite high. In fact, it is possible to reach nearly 100% relative humidity. It is even bad for building materials."[60]

John E. Flynn and Arthur W. Segil describe the rate at which the ventilation air must be introduced into the system that it depends on "the character of the process involved." They explain

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[59] William McGuinness, op. cit., Fifth Edition, p. 147.

[60] Joseph Olivieri, op. cit., p. 95.

In the general case of human occupancy, it depends:

1) on the volume of space per occupant;
2) on the intensity of the activity; and
3) on the general physical and sociological conditions involved.

Filters are generally not effective for odor control because filters will only intercept solid particles. However, activated carbon is effective, and this technique is generally used to eliminate odors in closed systems such as those used in submarines, mines, aircraft, etc.[61]

Table V

VENTILATION STANDARDS

APPLICATION	SMOKING	CFM PER PERSON		CFM PER SQ FT OF FLOOR Minimum*
		Recommended	Minimum*	
Apartment Average	Some	20	15	—
De Luxe	Some	30	25	.33
Banking Space	Occasional	10	7½	—
Barber Shops	Considerable	15	10	—
Beauty Parlors	Occasional	10	7½	—
Broker's Board Rooms	Very Heavy	50	30	—
Cocktail Bars	Heavy	30	25	—
Corridors (Supply or Exhaust)	—	—	—	.25
Department Stores	None	7½	5	.05
Directors Rooms	Extreme	50	30	—
Drug Stores †	Considerable	10	7½	—
Factories ‡§	None	10	7½	.10
Five and Ten Cent Stores	None	7½	5	—
Funeral Parlors	None	10	7½	—
Garage ‡	—	—	—	1.0
Hospitals Operating Rooms ‡**	None	—	—	2.0
Private Rooms	None	30	25	.33
Wards	None	20	15	—
Hotel Rooms	Heavy	30	25	.33
Kitchen Restaurant †	—	—	—	4.0
Residence	—	—	—	2.0
Laboratories †	Some	20	15	—
Meeting Rooms	Very Heavy	50	30	1.25
Office General	Some	15	10	—
Private	None	25	15	.25
Private	Considerable	30	25	.25
Restaurant Cafeteria †	Considerable	12	10	—
Dining Room †	Considerable	15	12	—
School Rooms ‡	None	—	—	—
Shop Retail	None	10	7½	—
Theater ‡	None	7½	5	—
Theater	Some	15	10	—
Toilets ‡ (Exhaust)	—	—	—	2.0

*When minimum is used, use the larger.
‡See local codes which may govern.
†May be governed by exhaust.
§Use these values unless governed by other sources of contamination or by local codes.
** All outdoor air is recommended to overcome explosion hazard of anesthetics.

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[61] John E. Flynn and Arthur Segil, *op. cit.*, p. 88.

Ventilation, according to the ASHRAE, is the process of supplying or removing air, by natural or mechanical means, to or from any space. The basic purpose of ventilation is the removal of odors. This is accomplished by the introduction of fresh air. For most people, ventilation is summed up in the act of opening a window.

There are two methods of ventilation; the natural ventilation, and the mechanical ventilation. The most basic method of ventilation is natural ventilation, consisting of forces which move air into, through, and out of the building. These forces are wind forces and the difference in temperature between the air inside and outside of a building.

a) Natural Ventilation

There are formulas for calculating the amount of ventilation which can be obtained by a controlled means, using both the wind and temperature difference. According to Charles Burton, when wind is used, the following items must be considered:

1. average wind velocity,
2. prevailing wind direction,
3. seasonal and daily variations in velocity and direction, and
4. local wind interferences.

Inlets should be placed to face directly into the prevailing wind, while outlets should be placed in one of the following five places:

1. on the side of the building, directly opposite the direction of the prevailing wind;
2. on the roof in the low pressure area caused by the jump of the wind;
3. on the sides adjacent to the windward face where low pressures occur;
4. in a monitor on the side opposite from the wind; and
5. in roof ventilators or stacks.[62]

According to Charles Gay, the inlets and outlets should be approximately of the same size and nearly opposite each other, to give an unobstructed passage for the air currents or cross draught.[63]

In the winter, wind action results in too much ventilation and in reduced indoor temperatures. During this season, ventilation may be produced through the difference in temperature, rather than by the wind action, and, consequently in weight, between indoor and outdoor air, and is largely vertical. For the most part, the inlets are near the ground on the windward side and the outlets near the top of the building on the leeward side to induce a chimney action. Roof ventilators offer the most satisfactory type of outlet.[64] Their function is to provide a storm-proof and weather-proof air outlet or inlet. The capacity of these units depends on:

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[62] Charles Burton, Lecture materials in Thermal Systems Course, Department of Construction Science, College of Architecture and Design, Kansas State University, Spring 1972.

[63] Charles Gay, op. cit., p. 201.

[64] *Ibid.*

1. location on roof;
2. resistance that the unit and duct offer to air flow;
3. height of draft; and
4. efficiency of the unit in utilizing wind force in operation.[65]

Roof ventilators may be stationary, pivotlet or rotating types, and are designed to give egress for the air, regardless of the direction of wind. Motor fans are sometimes used to increase the flow of air. Stacks are often employed in buildings designed for occupancy, rather than industry, to carry the exhaust air from the rooms to the ventilators, the inflow coming through the windows.[66]

b) Mechanical Ventilation

Mechanical ventilation methods can be divided into:

1. localized exhaust (power and gravity), and
2. dilution by out-door air.

According to Charles Burton, localized exhaust is merely putting a mechanical exhaust over a piece of equipment which has fumes or vapors which need to be removed.

Dilution by out-door air, simply means introducing fresh air in-

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[65] Charles Burton, lecture materials, op. cit.

[66] Charles Gay, op. cit., p. 202.

to space in such quantities that odors and stagnant air is not evident.

When outside air is drawn into spaces for ventilation, an equal quantity must be exhausted. Various means of permitting removal of air to the outisde can be used for an exhaust system. Joseph Olivieri explains:

> Too often forgotten is the fact that to exhaust air you must have air. If you do not supply tempered make-up air to the space, exhausted air will be pulled into the building through every crack or crevice, creating a most uncomfortable situation. Not only are objectionable drafts created, but, unless the heating system has the capacity to handle 100 times the planned infiltration, cold rooms will result....
>
> A very important reason for exhaust ventilation is to remove the heat from a process. The process can be an industrial one where you also remove harmful contaminants. Other examples of heat producing processes are cooking, laundering, or the mysterious rituals in beauty parlors. In the case of kitchen hoods, 100 cfm. per sq. ft. of hood should be exhausted. .... if the occupancy rate is one person per 150 cu. ft., we require 20 cfm. per person to remove objectionable body odors.... As the space per person increases, the ventilation required decreases, as follows:[67]

air space cu. ft. per person	cfm per person sedentary	cfm per person moderate activity
200	16	24
300	12	18
400	9	13
500	7	12
750	5	7

In the case of natural ventilation, the architect has a full responsibility to place the openings so that they may be effective in-

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[67] Joseph Olivieri, op. cit., p. 95.

lets and outlets for air movement through buildings to ventilate them. The use of natural ventilation can and cannot be an economical solution depending on the type of the buildings and the surrounding. First, it eliminates the cost of operating expense, and the cost of mechanical systems. Second, filtration of air moved naturally is not possible. Therefore, it can create a building maintenance problem which has an economic significance. When we open the windows for natural ventilation, we may not only bring a large amount of dust and dirt, but also, noise and sometimes unpleasant odors into the room. In such cases, mechancial ventilation may be the best economic solution.

Mechanical ventilation, according to Kinzey, permits extensive use of ducts and a freedom of layout of inlets and outlets which is not possible with natural ventilation. He describes:

> Maximum recirculation of air and minimum use of outside air is the economic solution to air conditioning. Both the equipment cost and operating cost are higher where large qualities of unconditioned air are drawn from outdoors than when partially conditioned return air is recirculated. Air that can be easily cleaned, humidified, and heated for recirculation should be used to a greater extent than outside air.[68]

8. Thermal Insulation and Moisture Control

There are factors which are important to both climate control, with and without mechanical systems. Thermal insulation, and moist-

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[68] Bertram Kinzey, op. cit., p. 242.

ure control are two factors which become necessary in our home or building. Insulation cannot stop the flow of heat, in or out, of the building, but it can slow down the flow. This means that when we heat or cool the well-insulated building or home, we will save a large amount of heating or cooling energy from leaking out of the building. In the long run, it means saving money also. Moisture control is also equally important. Moisture causes the condensation on windows, doors, or walls which can endanger building materials. There is a special type of insulation material for moisture control. It is called a water vapor barrier, and is widely used in building construction today.

a) Thermal Insulation

The verb "insulate" is derived from the Latin word "insula" meaning island, according to Paul Close, and means to isolate or place in a detached state. An insulation, therefore, is a material or substance which isolates some force, or source, of energy such as electricity, heat or sound.[69]

A thermal insulating material, therefore, is a material having a high degree of heat resistance per unit of thickness. Paul Close, former technical secretary and editor of ASHRAE, explained in his book, Sound Control and Thermal Insulation of Buildings, that from a practical standpoint, two requirements are necessary in order for a material

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[69] Paul D. Close, Sound Control and Thermal Insulation of Buildings, (New York: Reinhold Publishing Corporation, 1966), p. 5.

to qualify as an insulation, namely,

1. it must have a low heat conductivity, that is, a high degree of heat resistance per unit of thickness, and
2. it must be installed in an adequate thickness.

He explained that the purpose of a thermal insulation is to retard the passage of heat in one direction or the other. While theoretically, the purpose of a thermal insulating material is to keep the "cold out," as well as the "heat in," the transfer of heat through the enclosure is always from the warm to the cold side.[70]

By retarding the flow of heat, according to the ASHRAE, thermal insulation may serve one or more of the following functions:

> 1. to reduce heat gain or heat loss of a pipe, duct, vessel, or structure;
> 2. to facilitate control of the temperatures of a process;
> 3. to control the surface temperature for personal protection and comfort;
> 4. to prevent water vapor condensation or icing on cold surfaces; and
> 5. to reduce temperature fluctuations within an enclosure when heating or cooling is not needed or available.
>
> Additional functions of thermal insulation and necessary materials may include:
>
> 1. to add structural strength to a wall, ceiling, or floor section;
> 2. to provide a support for surface finish;
> 3. to add resistance to water vapor transmission;

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[70] *Ibid.*, pp. 6-7.

4. to prevent or retard spread of fire or flame;
5. to reduce noise.

Thermal insulations consist of the following basic materials:

1. fibrous or cellular mineral matter, such as asbestos, glass silica, rock, or slag;
2. fibrous or cellular organic matter occurring in nature, such as cane, cotton, animal hair, rubber, wood bark, including cork;
3. cellular organic plastics, such as polystyrene or polyurethane; and
4. heat reflecting metals (which must face air or evacuated spaces).[71]

Many natural insulation materials attract vermin, insect or other pests, and some are also hazardous to fire; therefore, commercial and manufactured insulation materials have been developed to overcome these problems. The physical forms of these products are:

1. loose-fill and cement;
2. blanket insulations;
3. batts insulations;
4. insulation board;
5. slab or block insulators;
6. reflective insulations;
7. plastic foams; and
8. miscellaneous types.[72]

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[71] ASHRAE, Handbook of Fundamentals, op. cit., Chapter 18, "Thermal Insulation and Water Vapor Barriers," p. 241.

[72] Paul Close, op. cit., p. 221.

Some products combine the properties of two or more types of insulation, such as reflective mineral wool blanket insulations. However, it is necessary, before using any commercial insulator, to read their instructions and recommendations for the material first, because each manufactured insulator has its own property for a certain application.

The use of an insulating material for retarding the heat flow through a wall or other construction unit may be accomplished by one or more of three methods which Paul Close described in this manner:

> 1. By replacing materials of high conductivity with materials of low conductivity.
> 2. By adding insulating materials to the construction, such as by partially or completely filling the air space with an insulating material. Blanket insulations, fills, batts and other types are used for this purpose.
> 3. By replacing one or both of the confining surfaces of an air space with a material of low emissivity, that is, with a reflective insulation such as aluminum foil.[73]

According to Paul Close, building construction has been divided into three major components, namely: 1) floors, 2) walls, and 3) roofs and ceilings. Insulating the building, or the residence, may also be classified in this way. He states:

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[73] *Ibid.*, p. 327.

1. Walls: Outside walls and walls adjacent to unheated spaces, such as enclosed porches and unheated garages, should be insulated.
2. Ceilings and roofs: Either the ceiling or the roof, or both, should be insulated.
3. Floors: should be insulated as follows:
    - a) Floor over unheated crawl spaces should be insulated.
    - b) In houses without basements having concrete slabs on the ground, insulation should be applied around the perimeter of the concrete slab, that is, between the slab and the footings.
    - c) Concrete slabs of ground floors containing pipe coils for radiant heating should be insulated.[74]

The costs involved in insulating either heated or refrigerated equipment, air-conditioned rooms, pipes, ducts, tanks, and vessels, are of a magnitude to warrant careful consideration of the type and quantity of insulation to be used. The ASHRAE explained that economic thickness is defined as the minimum annual value of the sum of the cost of heat loss, plus the cost of insulation, or, in more general terms, as the thickness of a given insulation that will save the greatest cost of energy while paying for itself within an assigned period of time. At low values of thickness, the amortized annual cost of insulation is low, but the annual cost of heat energy is high.[75]

b) Moisture in the Building

Most moisture problems in residences occur in winter and be-

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[74] Ibid., p. 260.

[75] ASHRAE, Handbook of Fundamentals, op. cit., p. 249.

come increasingly important as homes are built smaller and tighter. According to the ASHRAE, water vapor originates from such necessary living requirements as cooking, laundry, bathing, breathing, and perspiration of people. Another large source of water vapor is sometimes the bare earth in a crawl space or basement. Also, in new construction, moisture is added by poured concrete slabs, masonry construction and new plaster. All this water vapor must escape from the dwelling.[76]

Condensation on windows can be seen very easily in the winter and visible condensation may also occur in summer. It is often seen on basement concrete walls or floors that are cooled by the earth, and on exposed cold water pipes. The ASHRAE explained the action in this manner:

> Being massive, they tend to hold a constant temperature from day to day while the weather dew-point temperature rises. When no water vapor is released in the space the dew-point tends to equal that of the outdoors (though it is likely to lag when there is slight ventilation). At times the dew-point temperature rises above the temperature of walls, floors, and pipes with resulting condensation.[77]

An excessive accumulation of moisture in a wall (or roof, can be prevented by one or more of the following measures, according to the ASHRAE:

1. providing a vapor and air barrier to limit vapor entrance into the wall,

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[76] Ibid., Chapter 19, "Moisture in Building Construction," p. 269.

[77] Ibid., p. 269 and p. 276.

2. ventilating the building to reduce vapor pressure therein, or
3. ventilating the wall cavity to remove vapor that has entered.[78]

The ASHRAE also suggested that some positive ventilating or dehumidification must be designed in the building with capacity to remove moisture in the amount that represents the difference between that generated by the occupancy and the amounts lost through such natural and installed ventilation, as kitchen exhaust fans and from opening outside doors to enter and leave the premises.[79] (See further details in the "Ventilation" section.)

Water vapor barriers are the insulation materials which especially provide a resistance to the transmission of water vapor under specified conditions. Like other insulation materials, they do not necessarily stop the flow of vapor, but serve as a medium of control to reduce the rate and volume of flow. In refrigeration and air conditioning applications, and in buildings, water vapor barriers are applied to thermal insulation on cold pipes, ducts, refrigerated enclosures, and structures. Their function is to prevent accumulation of water within the insulation or construction.[80] But for the con-

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[78] Ibid., p. 278.

[79] Ibid., p. 280.

[80] Ibid., p. 246.

the condensation of the window, double-glazing glass, or heating surfaces at the bottom of the glass, will help in getting rid of water vapor. By retarding water vapor transmission, according to ASHRAE, water vapor barriers help to:

1. keep the insulation dry, and reduce the heat load requirements for the cooling system;
2. prevent structural damage by rust, corrosion, or the expansion effect of freezing water; and
3. reduce paint problems or exterior wall construction.

About the effectiveness of a barrier system, the ASHRAE explained that any vapor barrier reducing water accumulation depends on its permanance, and also on its location within the insulated section. It is to be emphasized that the vapor barrier must be applied to the surface exposed to the higher water vapor pressure. For most applications, this will be the warm side. The effectiveness may be greatly reduced if openings, even though very small, exist in the barrier.[81]

There are many types of water vapor. The selection depends upon its application and the properties of water barrier.

9. Conclusion

Mechanical systems have become more and more important in controlling the indoor comfort environment. These systems have successfully provided internal comfort to residences in the extreme climatic

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[81] Ibid.

conditions, and maintain suitable temperatures and humidity as the occupants' desire. The systems have various advantages over non-mechanical ones. For example, they can be controlled to suit certain persons' comfort requirements. They are independent from the changeable outdoor climatic conditions. Heating and cooling can be provided at any time of the year, and mechanical ventilation can provide clean and fresh air, while getting rid of odor, heat and moisture in the building.

However, the use of non-mechanical systems in conjunction with mechanical ones, is very desirable. They may help in reducing the cost of heating and cooling. Sun control devices such as overhangs, louvers, and other natural elements such as trees, can be utilized to serve this purpose. In some restricted areas such as cities, these natural elements may not be too appropriate. In this case, there are other optional elements which the architect may use such as double glazing, or heat-absorbed glass, etc.

Therefore, it is advisable for architects to follow the news about the new developments of such mechanical systems, and of new materials. In designing a building, the architect should study the basic mechanical systems, and choose the suitable one appropriate to his particular project, with the help from the engineer. This should be done as early as possible, while his design is in progress.

V. CLIMATE CONTROLS BY NON-MECHANICAL MEANS

The internal comfort control in the building can be controlled by various elements. These include mechanical heating, cooling and air conditioning systems, as well as the building materials themselves; proper design of roofs, overhangs, etc., and the use of natural windbreakers and weather barriers such as trees, shrubs, etc. The orientation of the building also contribute considerably to comfort. However, the relative importance of each element is governed by the climatic zones in which the building is located (see Plate XXVIII).

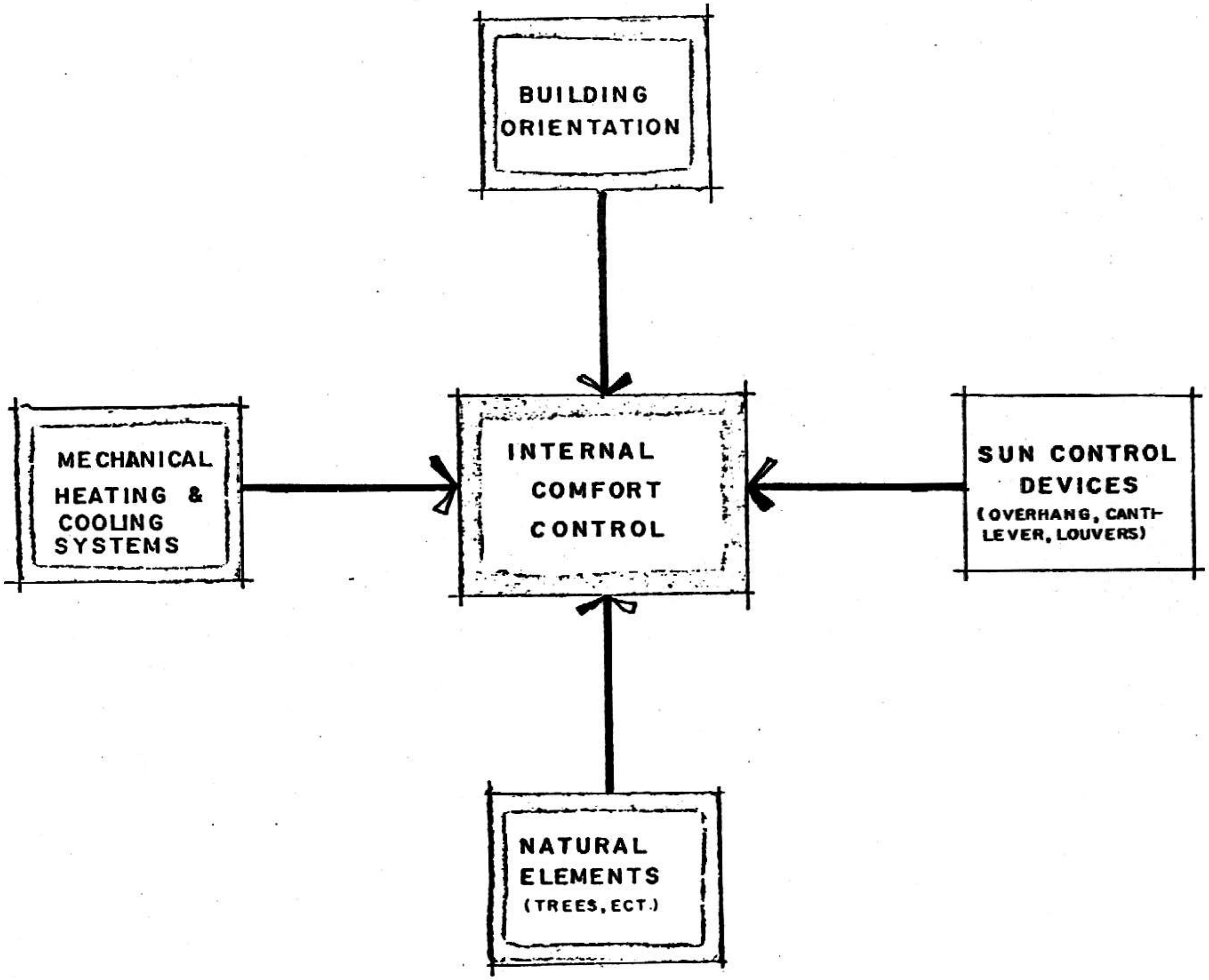
In hot-dry zones, for example, natural elements such as trees may not exist. Mechanical air-conditioning systems are economically prohibitive in many hot-dry and hot-humid countries of the world, therefore, in order to maintain internal comfort in these areas, non-mechanical and natural elements must be employed. Previous civilizations have experimented with various elementary "systems" to maintain some degree of comfort using "natural" means.

1. History and the Development of Climate Control

Comfort control without mechanical systems can be traced back as early as the beginning of the evolution of man. The cavemen protected his body by clothing it with animal's skin. He lived in the cave because it provided him with some degree of comfort. It furnished protection from rain, snow, and summer heat. In the summer, the area inside the cave is much cooler than the outside areas. The massive earth surrounding the cave absorbed the sun's heat, and ra-

PLATE XXVIII

INTEGRATION OF COMFORT CONTROL ELEMENTS



diated some of this energy into the cave at night when it was cold outside. If possible, the cave entrance faced the north, to prevent entrance of the sun during the day and, by the use of a fire (built at the entrance) the cavedweller was kept reasonably warm. The earth acted as insulation.

In hot-humid zones, thatch is an easily obtainable material and is used for roof covering. If the roof is properly pitched, this covering provides good protection from both rain and solar radiation. The small air spaces in the thatch provides considerable insulation during the hot days. The loosely patched thatch allows the moving air to ventilate the surface layers and, thereby, add to the cooling effect. The material is so inexpensive that it could easily be replaced when it becomes infested. Thatch, therefore, has been used by primitive people in the hot-humid areas for centuries. In spite of modern technology and the introduction of new building materials, such as aluminum sheets, thatch is still widely used by the peasants in the Southeast Asian countries and in some South Pacific islands, as an efficient roof covering (see Part V, Table X, Building Materials Used in Various Climates).

In hot-dry countries such as Egypt, Iran, and the Southwestern United States, natives employed materials such as adobe (mud, and earth) to construct their shelters. This readily available material provided a substantial wall of considerable bulk. The small air spaces and bulk of this type of construction delays the entry of heat, so that it took most of the day to reach the interior. The wall cooled at night, when the temperature dropped. The number and size of openings were reduced and placed high to reduce ground radiation and to minimize sun penetration during the heat of the day. The light color of these primitive dwelling surfaces also assisted in reflecting some of the solar heat. Underground shelters were often found in many hot-dry areas, including the whole underground villages in Israel and Egypt.

The construction of massive walls and roofing materials, the use of light color or reflective material for surfaces, and the construction of small openings are still being used in many of these hot-dry areas where the economy does not permit more sophisticated construction and equipment. Our contemporary insulations and construction methods employ these principles in a more efficient manner. High labor cost and inefficient use of space make massive walls and roofs' construction appears to be impractical in an industrialized society.

During winter months, or in cold areas, man had to develop a heat source within his dwelling and inhibit the passage of heat to the outside. Before the invention of the stove, large fire places were often built in the center of the house as the primary heat source. Basement area, in that time, was used as the food storage area in the summer and also was used for placing heating units which were a gravity warm-air and one-pipe steam system, in later times. The snow covering on the roof acted as an insulator to help retain heat within the structure.

In industrialized societies, modern building technology and new materials have affected considerable changes in heat distribution and residential design (see section on Climate Controls by Mechanical Means). Massive walls and cumbersome heating systems (depending on gravity) have disappeared. Fireplaces and other large heating units located in the center of the house no longer function as the main sources of heating. They have been replaced by the "modern" mechanical heating (and cooling) systems which no longer are no longer dependent on "natural" air flow.

Because of the lack of technology, and the limited materials available, the primitive builder could not ignore climate in the design of man's shelter. The primitive people built their own shelter for survival, as well as comfort, with a wide range of climatic conditions. They utilized natural elements to help in providing protection from a variety of climatic conditions.

Therefore, the study of the history of the primitive dwelling is very useful to not only reinforce the fundamental principles of comfort, but also, for the newly developing nations which cannot afford mechanical systems to provide internal comfort.

With the advent of efficient heating and cooling systems, in Europe and the United States, in the past decade, architects and builders have tended to ignore climate in the design of residences. As a result, many buildings are not only expensive to maintain, but do not provide adequate comfort as far as temperature is concerned.

2. Climate Control Factors

a) Site Selection in Respect to Climate

To select the most favorable building site for our house, we should know about the microclimatic condition of the site we are going to select. This is because the different characteristics of sites have different microclimates. An even flat site, for example, has temperatures which increase or decrease, depending on adjacent slopes or mountains, buildings, pavements, and many other factors. Temperature, for instance, drops about three degrees for each thousand feet of elevation, enough to make a noticeable difference between the climates of suburbs at different elevations in mountainous cities,[82] (see Plate XXIX and Plate XXX).

b) Location of the Site

If it is possible, the site should be located where we can get the prevailing wind, a good view, and winter sun. It should be far away from industrial areas, the city dumping ground, or the air fields. In the case where the location must be in the city, the utilization of various natural elements including water, rocks, sand, grass, trees and shrubs will help create a feeling of "oasis" in the city.

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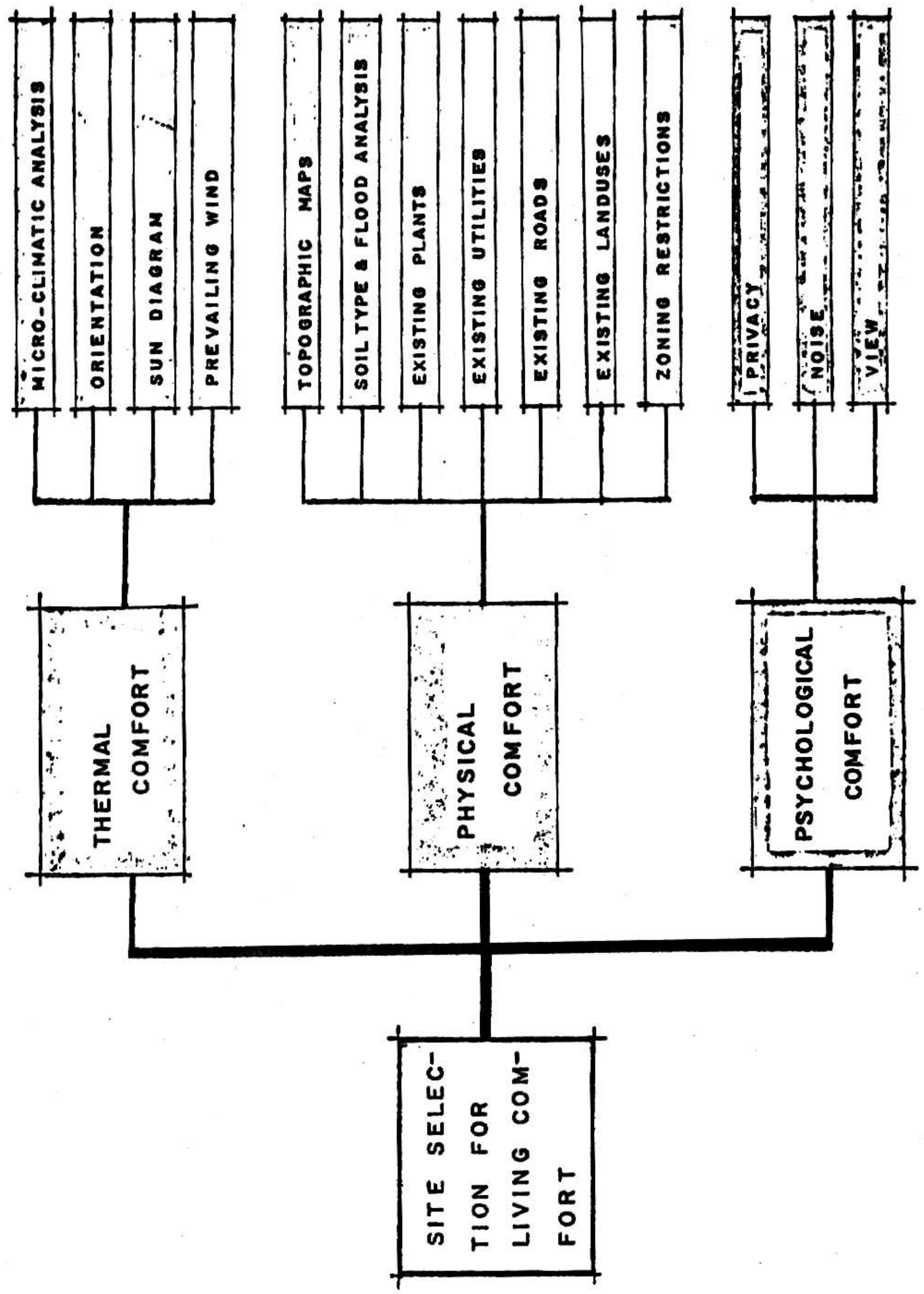
[82] Leavitt, Dudley, "Microclimate," House Beautiful, May 1954, pp. 180-183.

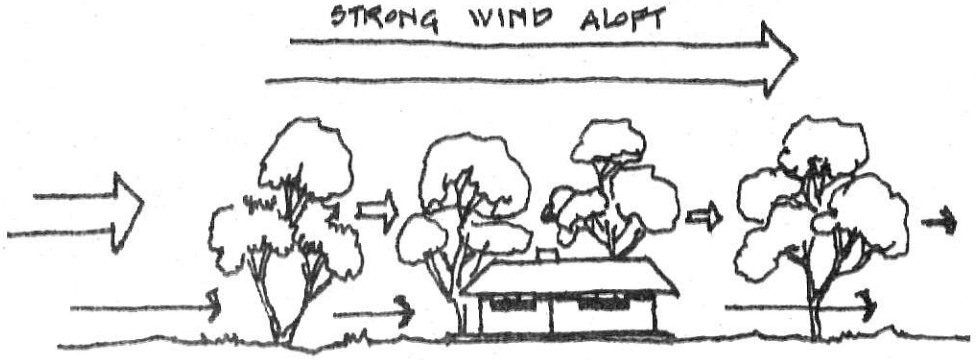
PLATE XXIX



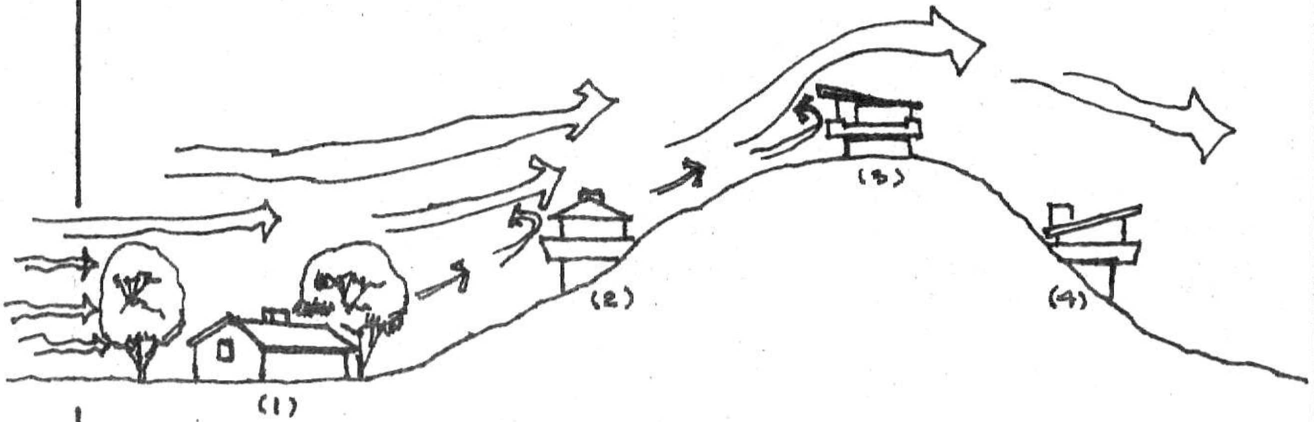
Site Selection Analysis

PLATE XXX

SITE SELECTION WITH RESPECT TO CLIMATE



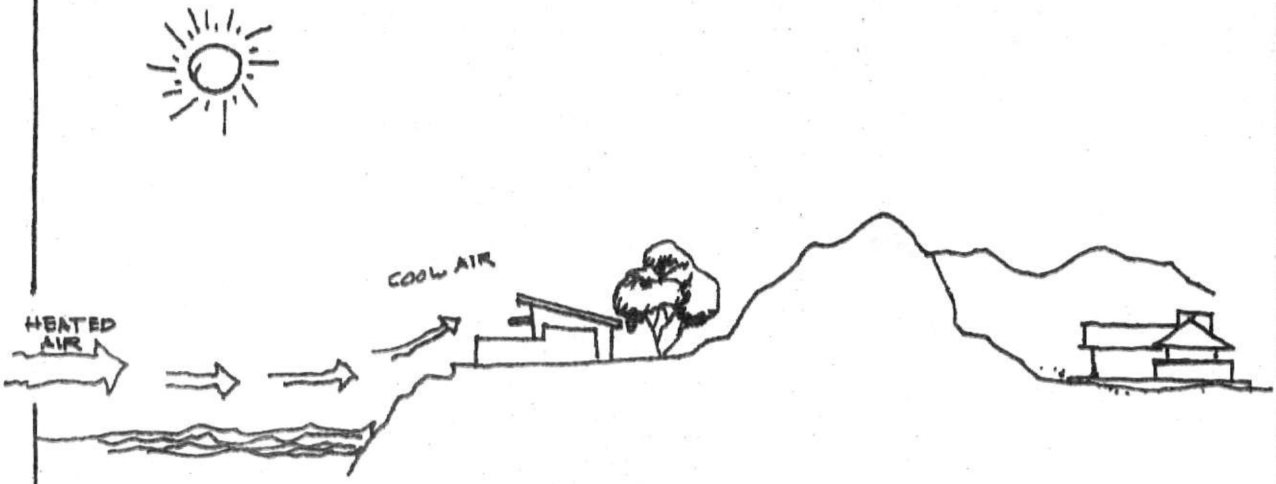
Trees and buildings slow the wind over flat ground.



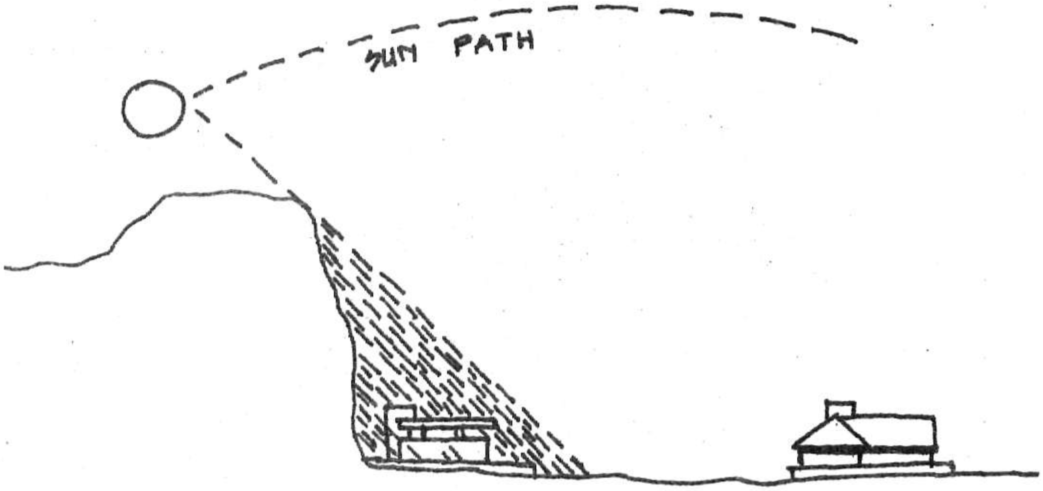
Terrain Regulates Intensity of the Wind Received by a Site:

Comfort under climatic conditions may require protection from prevailing winds or exposure to them. The force of the wind at house No.1 is reduced because of the natural ground friction and the obstacles acting as baffles. House No.2, high enough on the slope to clear the obstacles, receives the breeze at its normal force. House No.3 has the windiest location. Direct air movements are intensified by the currents deflected up the slope from below, all concentrated at this point as they pass over the peak. Air around house No.4 on the protective slope is relatively calm. Knowledge of prevailing winds at different seasons should be a design factor.

PLATE XXX (CONTINUED)



Bodies of the water may add to the moisture content of the air, but have a definite cooling effect by lowering temperature of air passing over them.



A hill, or other obstruction may cut the total time the sun falls upon the site. Less sun means less heat absorption by the ground, less stored heat to radiate, and an earlier start to evening radiation.

(Adapted from Leavitt Dudley's "Microclimate," House Beautiful, May 1954, pp. 180-183).

c) Orientation of the House

Orientation with respect to climate can be important to the house which depends on natural ventilation. It, therefore, should be oriented to allow the prevailing wind to ventilate through the structure. The orientation, with respect to solar radiation, also becomes important. The undesirable sunlight coming into the living space may cause overheating, and an uncomfortable feeling. Therefore, the orientation of the large opening away from the west side of the structure is desirable (see Plate XXXI and Plate XXXII).

3. Solar Control Study

Solar radiation is one of the most important climatic factors, as we have previously mentioned. Sun is the largest source of providing us with sunlight, as well as heat radiation. The heat from the sun can be used as the main source of heating the dwelling. In

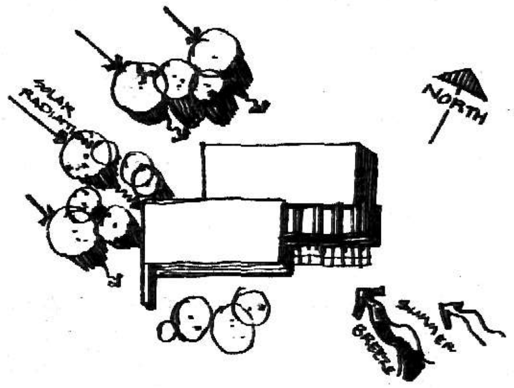
Figure 20

Recommended Solar Orientation for Various Rooms

	Orientation							
	N	*NE*	*E*	*SE*	*S*	*SW*	*W*	*NW*
Work space with exterior exposure	X	X						X
Recreational and lounge areas with exterior exposure				X	X	X	(X)	
Courtyards and terraces			(X)	X	X	X	(X)	

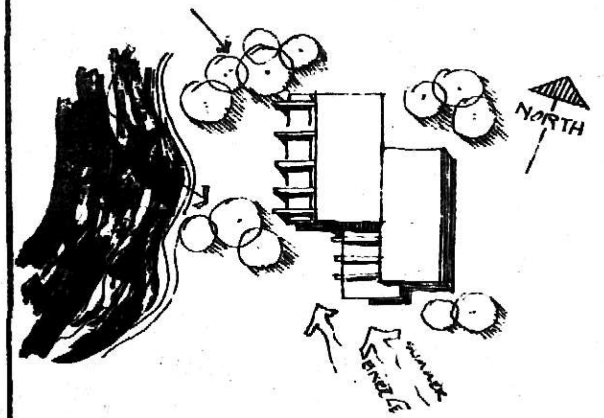
NOTE: The American Public Health Association committee on the hygiene of housing has recommended: "at the winter solstice, at least one-half of the habitable rooms of a dwelling should have a penetration of direct sunlight of one-half hour's duration during the noon hours when the sun is at its maximum intensity."
(This recommendation refers primarily to the germicidal action of solar radiation.)

House Orientation



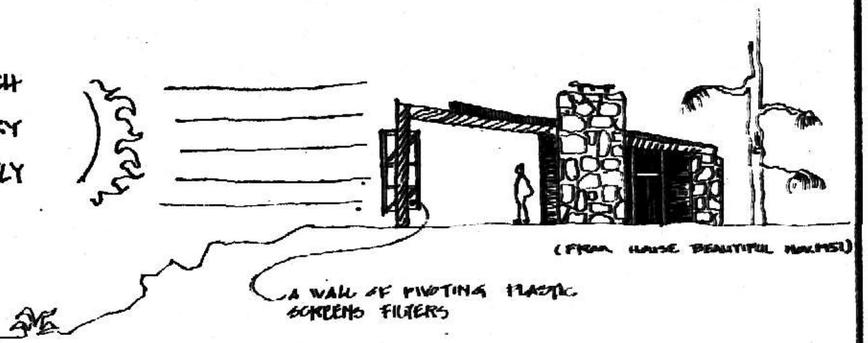
ORIENTATION OF THE HOUSE SHOULD BE CONSIDERED IN TWO RESPECTS, ONE IS WITH THE RESPECT TO WIND, AND OTHER WITH THE RESPECT TO SOLAR RADIATION.

ORIENTATE THE HOUSE IN SUCH A WAY THAT THE SUMMER BREEZE IS INVITED THROUGH THE HOUSE WHILE THE COLD WINTER WIND IS BLOCKED BY THE ROWS OF TREES, OR HIGH WALLS. WEST WALL SHOULD BE PROTECTED FROM SOLAR HEAT.



HOWEVER, ORIENTATION IS NOT NECESSARILY THE MOST IMPORTANT CONDITION FOR CLIMATIC CONTROL PURPOSES. VIEW MAY MEAN MORE THAN OTHER CONSIDERATIONS IN A HOUSE AND THE AXIS IS TURNED TO GIVE AN UNOBSTRUCTED VIEW OF RIVER OR VALLEY.

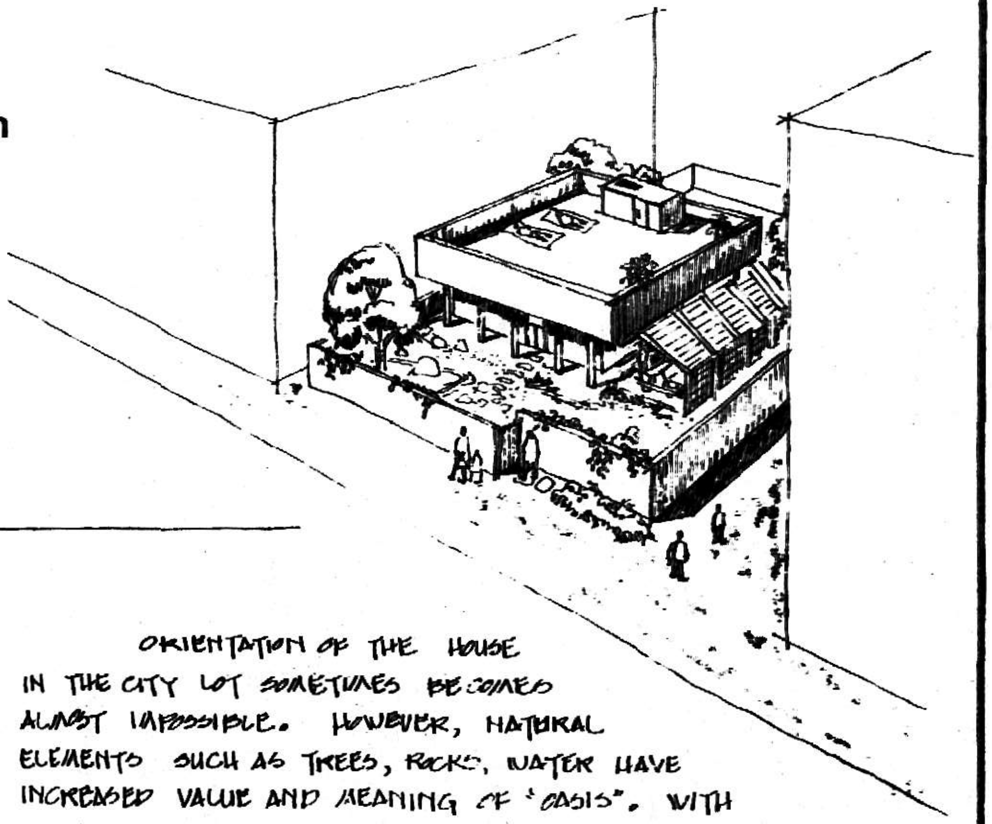
IN THIS CASE, SUN CONTROL DEVICES, SUCH AS LOUVERS, CANOPY, ETC., HELP PROVIDE NECESSARY CONTROL. ON THE OTHER HAND, WITH ADEQUATELY INSULATED WALLS OF LIGHT EXTERNAL COLOR, AND EFFECTIVELY SHADED WINDOWS, ORIENTATION WITH RESPECT TO SOLAR RADIATION MAY BE NEGLIGIBLE.



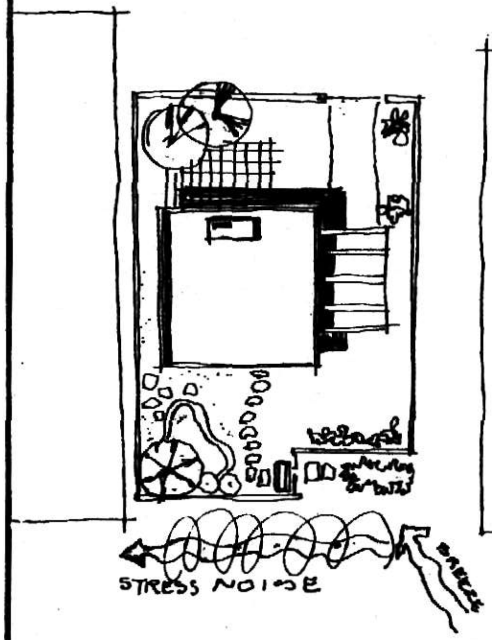
(FROM HOUSE BEAUTIFUL MAR.1951)

PLATE XXXII

House Orientation in The City



ORIENTATION OF THE HOUSE IN THE CITY LOT SOMETIMES BECOMES ALMOST IMPOSSIBLE. HOWEVER, NATURAL ELEMENTS SUCH AS TREES, ROCKS, WATER HAVE INCREASED VALUE AND MEANING OF 'OASIS". WITH CAREFULLY DESIGN AND UTILIZATION OF THESE ELEMENTS, AND WITH THE HELP OF SUN CONTROL DEVICES AND MECHANICAL SYSTEMS, THE HOUSE IN THE CITY CAN BE AS PLEASANT AS ONE IN A RURAL AREA.



In some areas, efforts to use solar energy for cooking purposes and heating water for domestic uses, are progressively underway. (For more detail about solar energy, read Farrington Daniels' <u>Direct Use of the Sun's Energy</u>.) The advantages of sunlight were listed by Jeffrey Aronin in <u>Climate and Architecture</u>, as follows:

- Sunlight is a powerful bactericidal agent.
- Sunlight exerts a specific curative effect too on tuberculosis, and is a powerful stimulant to a person's ability to resist it.
- Sunlight is essential for the growth of children as well as all sorts of plant and animal life.
- Sunlight can be used as a source of heat.
- Sunlight has a psychological effect on well-being.
- Sunlight facilitates ventilation by warming the air and causing gentle convection currents.
- Sunlight helps to keep the areas around buildings clean.[83]

In certain architectural projects, the admittance of sunlight and heat may be desireable, or it may be a nuisance. This is a problem for the architect to study and solve. However, there are numerous tools which the architect can use to control the sun and its direction. The two methods which are widely known are by artificial means, and include overhangs, louvers, shading screens, etc., and natural means such as trees, shrubs, vines, etc. The basic principle of these devices is to intercept solar radiation before it enters into the building in the first place (see Plate XLVI through Plate XLIX).

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[83] Jeffrey Aronin, <u>Climate and Architecture</u>, Progressive Architecture Book, (New York: Reinhold Publishing Corporation, 1953), p. 61.

Overhangs can be designed to exclude the sun at any time of the day or year. Sun shading screens can be in the form of a screen attached to a building or of screens placed away from a building. Bamboo curtains can cut down the sun light and glare, while admitting are to be ventilated through. Jalousie blinds, venetian blinds, shutters, and awnings are the common devices which are widely used.

In modern buildings, large areas of glass are being used without any sun shading devices. Sunlight can cause overheating in such buildings. Therefore, the orientation of these large glass areas are very important. However, the orientation problem in the city is sometimes restricted. In this case, one technical solution of the problem is the use of double glazing. E.F. Ball gave some advantages of double glazing over single glazing in reducing heat loss or heat gain, as follows:

> 1. By using double glazing, the inside surface temperature of the glass is increased and the energy available for inducing convective down-draught is accordingly reduced.
> 2. Where a large window is fitted in a room it may well be justifiable to double-glaze if for reasons of comfort alone, even if the reduction in heat loss is not sufficient to justify this course on economic grounds.
> 3. Double glazing is often installed as much with the object of minimizing window condensation as for thermal insulation for reducing heat losses.[84]

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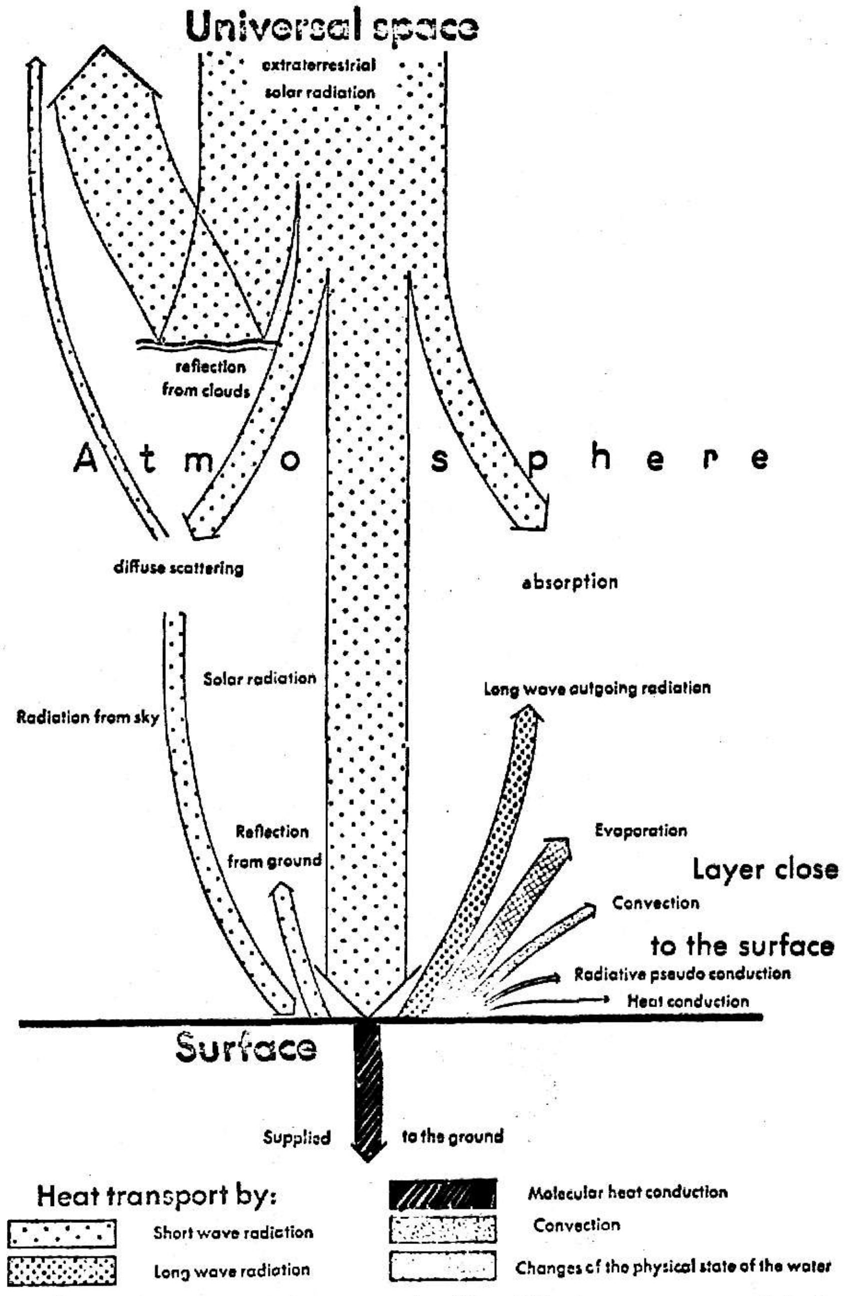
[84] E.F. Ball, <u>Some Factors in Window Design</u>, "Heat Insulation," (London: Building Research Station, Ministry of Technology, March 1966), p. 9.

PLATE XXXIII



Heat exchange at noon for summer day. (The width of arrows corresponds to the transferred heat amounts.)

Trees, shrubs, vines, etc., are used as the natural means to help shading the building and its surroundings, and it may, in some degree, provide visual and psychological comfort to people. The placement of trees, however, should be in such positions that will provide the desired shade at various times of the day and year. Sun angles and azimuths are useful and necessary for determining the locations exactly (see Appendix I). Planting should not be so dense as to interfere with the circulation of air around the building.

In general, the best way to control the sun is a combination of these two methods. However, in some architectural projects one method may be better than the other. Fortunately, most of the sun control devices, both artificial and natural means, can also be used to control prevailing wind, rain, and perhaps, the air temperature.

4. Climate and Building Materials

As soon as men felt the need for a better shelter than living in a cave, and when he was able to construct some shelters and had invented some tools, he built his new place *our* of materials at hand. With limited means, his early shelter was also very much influenced by the climatic conditions which dictated form. Blache explained that the conditions of soil and climate have determined whether the use of wood, earth, or stone should predominate.[85] In the hot-humid areas, they

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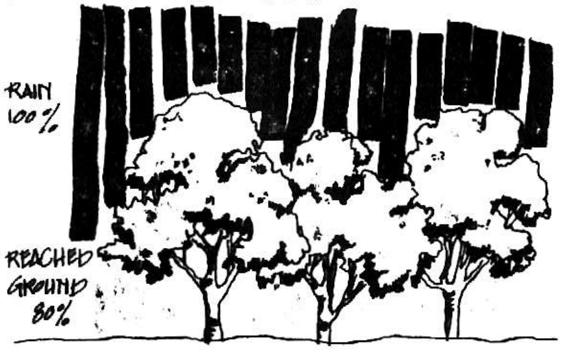
[85] Vidal de la Blache, Principles of Human Geography, (London: Constable Publishers London, 1952), p. 238.

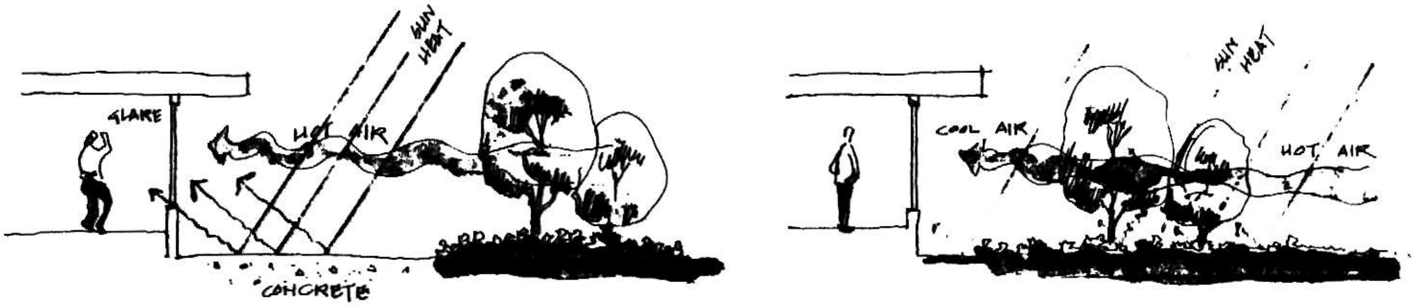
PLATE XXXIV

PLANTS AS CLIMATIC CONTROL ELEMENTS

TREES SLOW AIR MOVEMENT CONSIDERABLY ALLOWING HEAVIER DUST PARTICLES AND POLLUTANTS TO SETTLE DOWN. DENSE PLANTINGS CAN REDUCE AIR VELOCITY 75 TO 85 PER CENT.



PLANTS INTERCEPT PRECIPITATION IN THE FORMS OF RAINS, SNOW OR FOG, FOR EXAMPLE, CONDENSES ON THE LEAVES OF PLANTS AND FALLS TO THE GROUND.



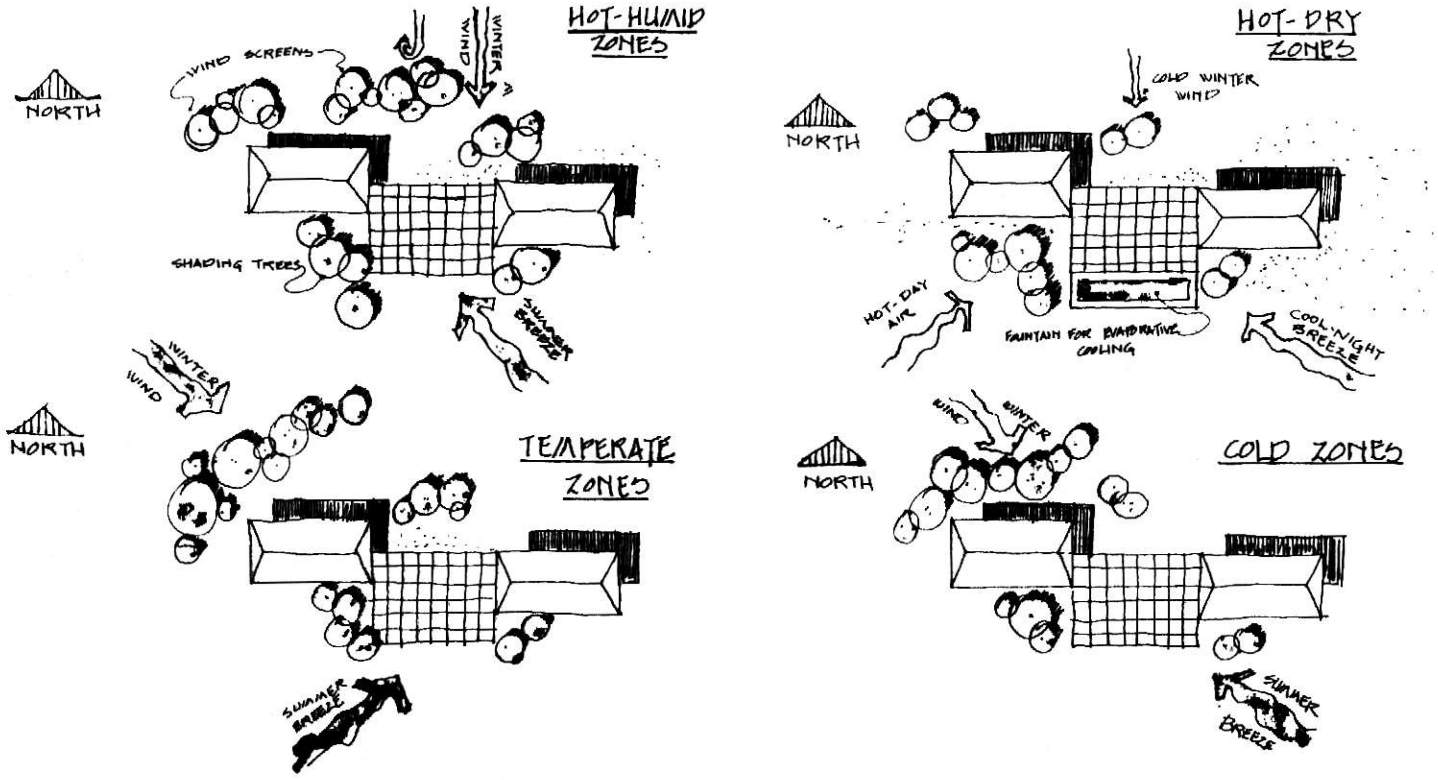
TREES, SHRUBS, AND OTHER NATURAL ELEMENTS MAY BE USED TO BLOCK THE COLD WINTER WIND, PROVIDE NECESSARY SHADE, AND COOL THE HOT INCOMING AIR.

PLATE XXXV

Plant Arrangement in Various Climatic Zones

HOWEVER, IN PLACING TREES, SOME PRECAUTIONS SHOULD BE TAKEN INTO ACCOUNT. TREES SHOULD NOT BE PLANTED TOO CLOSED TO THE HOUSE. THEY CAN BE THE SOURCE OF WEAKENING THE FOUNDATION (BY THEIR ROOTS), HOUSING OF INSECTS AND PESTS.

THE SUN SHADE EFFECT OF TREES DEPENDS ON THE WIDTH AND HEIGHT OF THEIR CROWNS, AND ON THE SIZE OF THE TREES. THERE IS SOME SUGGESTIONS THAT DISTANCE FROM THE TREE TO THE HOUSE SHOULD BE EQUAL TO THE HEIGHT OF THE TREE.



built their shelter with thatch, grass, cane, straw, leaves, and even organic waste products. In the hot-dry areas, they built their houses with earth, mud, sun-dried brick, and clay. Wood was used widely in the temperate and cold areas. Stone was used for shelter near rivers, or the sea.

Today, many new industrial materials are replacing some of the local materials. The thatched roof, for example, was replaced by Aluminum sheets in many of the hot-humid areas, although many thatched roofs are still being constructed. Massive walls and roofs in the hot-dry areas of the United States have been replaced by well insulated materials, and so forth. It is the architect's responsibility to study and find out the most suitable materials to be used in particular areas of each particular climatic condition, because the type of building materials chosen have a great deal of impact on the thermal comfort control in buildings.

VI. CLIMATE IN THE CITY

1. Introduction

In the city, climate control factors such as site selection, location and orientation are less effective. The land is so expensive that we cannot afford to waste any open space. For example, a square foot of central city in Houston costs up to $110.00; in Atlanta, $100.00; in Chicago, $500.00; in San Francisco, $200.00; and on Wall Street in New York City, $600.00.[86] Sunlight, wind, views,

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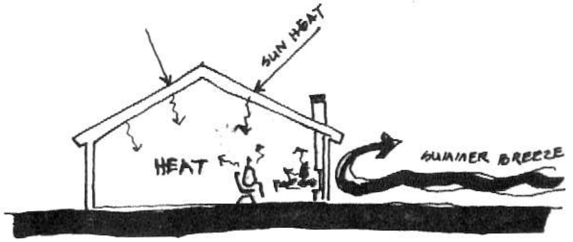
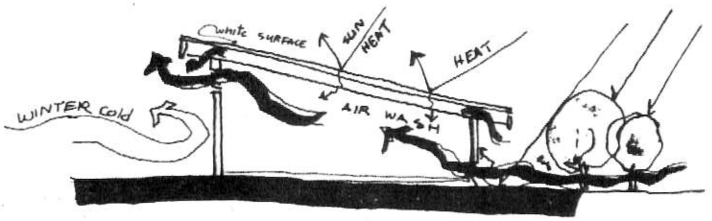
[86] Editors of Forture, <u>The Environment</u>, (New York: Harper and Row, Publishers, 1970), p. 149.

PLATE XXXVI

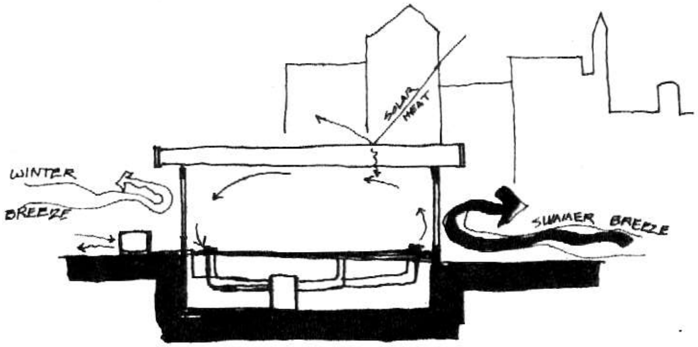
Economical Aspect in Housing



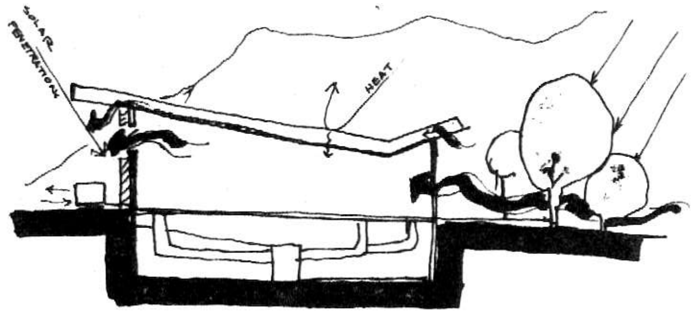
THE HOUSE THAT IS BUILT WITHOUT TAKING INTO ACCOUNT BOTH NATURAL ELEMENTS, AND CLIMATIC DESIGN FACTORS, OR THE USE OF MECHANICAL CONTROL SYSTEMS SUCH AS AIR-CONDITIONING WILL BE THE LOWEST IN UTILITY COST, BUT PERSONAL COMFORT WILL SUFFER IN SOME EXTENTS.



THE HOUSE THAT USES ADVANTAGE OF NATURAL ELEMENTS, SUCH AS VEGETATIONS, ETC., AND CLIMATIC DESIGN FACTORS, SUCH AS, ORIENTATION, LOCATION ACCORDING TO THE SUN AND PREVAILING WIND, INTO THE DESIGN CONSIDERATION WILL PROVIDE THE PERIODLY COMFORT WITH A SMALL AMOUNT ON UTILITY COST. (IF WITHOUT ANY HEPE OF MECHANICAL COMFORT CONTROL)



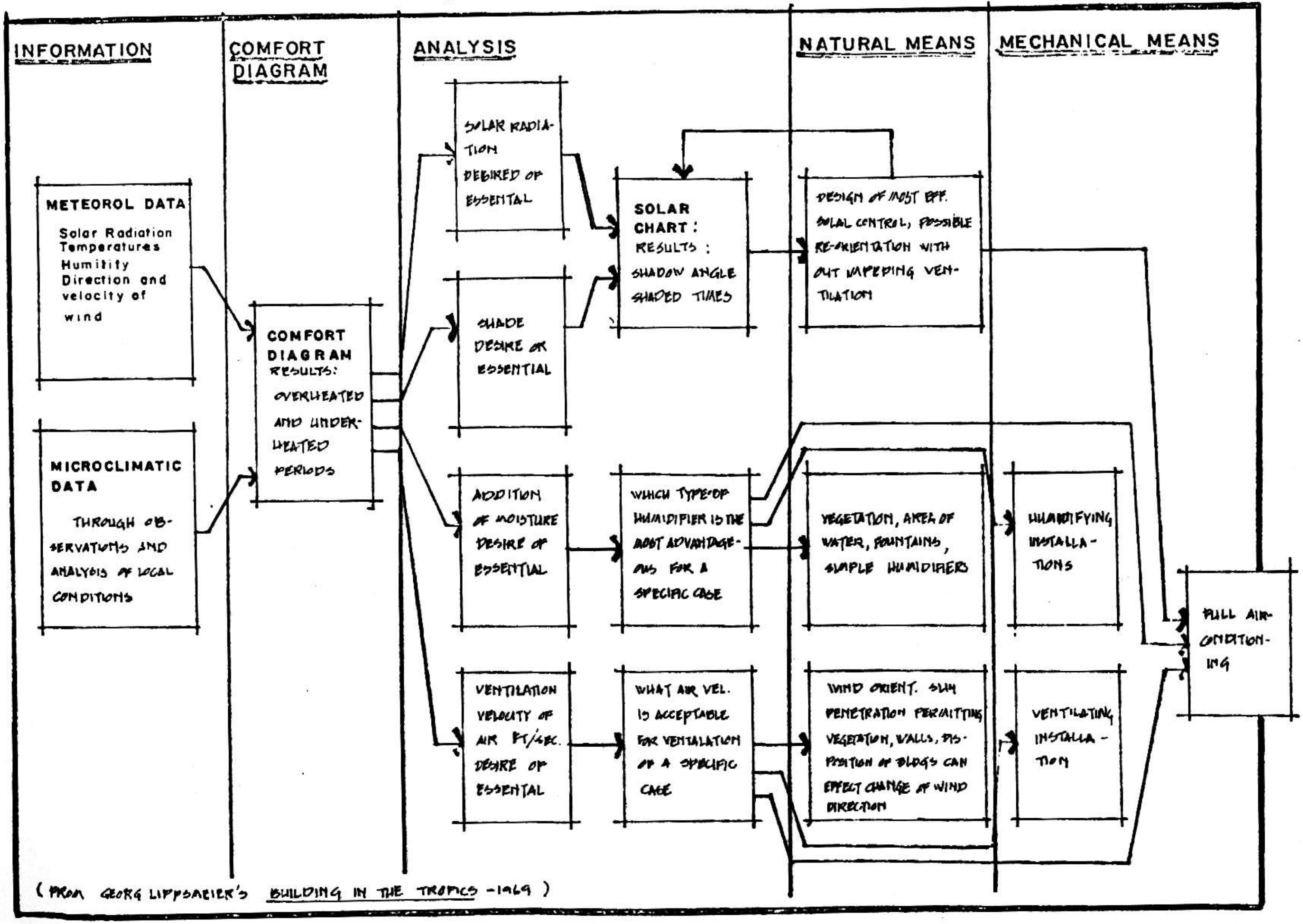
THE HOUSE THAT IS ENTIRELY CONTROLED BY MECHANICAL CONTROL SYSTEMS TO PROVIDE COMFORT WILL BE VERY HIGH IN THE UTILITY COST, BUT MAY BE THE BEST SYSTEM IN LOCATIONS SUCH AS CITIES, URBAN AREAS, OR WHERE THERE ARE RESTRICTIONS IN PROVIDING NATURAL ELEMENTS OR EVEN ORIENTATION OF THE STRUCTURE.



THE HOUSE THAT IS ABLE TO COMBINE BOTH MECHANICAL MEANS AND NATURAL MEANS OF CONTROLING THE COMFORT WILL CUT DOWN ON SOME OF THE UTILITY COSTS. IT MAY BE THE BEST SYSTEM IN LOCATIONS WHERE THE LAND AREA IS PLENTIFUL, AND THERE ARE MORE FREEDOM TO UTILIZE NATURE ELEMENTS IN CONTROLLING EXTREME CLIMATE

PLATE XXXVII

Order of Necessary Investigations



(FROM GEORG LIPPSMEIER'S BUILDING IN THE TROPICS -1969) and so on, are no longer necessary, either because it is difficult to obtain, or it is not available. Pollution in the sky is one of the main factors which destroys our natural climate in the city, and forces people to stay inside. Jose Luis Sert and the C.I.A.M. (Contres Internationaux d' Architecture Moderne), warned us thirty years ago about air and water pollution in the city, the lack of open space, and so on. At one point, he said:

> Architecture, that learned interplay of volumes, light, shadows, and color, is absent from these grey and dismal streets, which lose themselves in the distance. But by this system it has been possible to subdivide and build urban land to a maximum degree. Space is expensive, and houses build on the street line do not waste space. Sewer pipes are closer to the house -- another economy. No longer are garden fences necessary, nor the care of trees and plants.[87]

Rudolf Geiger explains it to us in this way: "The total transformation of natural landscape into houses, streets, squares, great public buildings, skyscrapers, and industrial installations has brought about changes of climate in the region of large cities.... "[88] In the city, we have less natural cover of the land such as trees and grass, which tend to stabilize temperatures and to decrease extremes. Not only that, plants also provide moisture in the air in the hot summer. Phsyically and psychologically, it makes us feel cooler (see Climate Affects Plants and Animals, in Part III). In order to illustrate this

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[87] J.L. Sert and C.I.A.A., Can Our Cities Survive?, (Cambridge: The Harvard University Press, 1942), p. 46.

[88] Rudolf Geiger, The Climate Near the Ground, op. cit., p. 487.

point, we shall look into a study which was published in the Architectural Forum in the March, 1947 issue:

> On a very hot day, when the air temperature in a meteorological shelter read 98° F., asphalt pavement nearby reached a temperature of 124° F. The air layer between one and four feet above the asphalt -- i.e., the zone in which human beings would walk -- had a temperature of 108° F. In the same instance, a concrete surface was 14° F. cooler than the asphalt.... It is generally found that air temperatures about one foot above the soil on sunny summer days are about eight to ten degrees lower than the soil surface itslef. The difference between exposed soil (depending somewhat on its color) and grass surfaces is between ten to fourteen degrees F. -- the grass, of course, being the cooler curface. Between grass and paved surfaces, the temperature differential may be much greater....
>
> On a bright day, the amount of light reflected from concrete or similar light surfaces will range from 25 to 35 per cent of the incident light, while grass surfaces reflect only about 10 to 15 per cent of the light .... At midday, one to six feet above the ground, the air under a tree is around 5° F. lower than that in an unshaded environment....[89] (See Plate XXXVIII)

2. City Pollution

There are many kinds of pollution gathering in the city such as air pollution, water pollution, and now we also classify noise as pollution.

Air pollution is the major problem in the city. It is caused by automobiles, industrial plants, and so on. It is harmful to our health because we have to breath the air mixed with chemical wastes.

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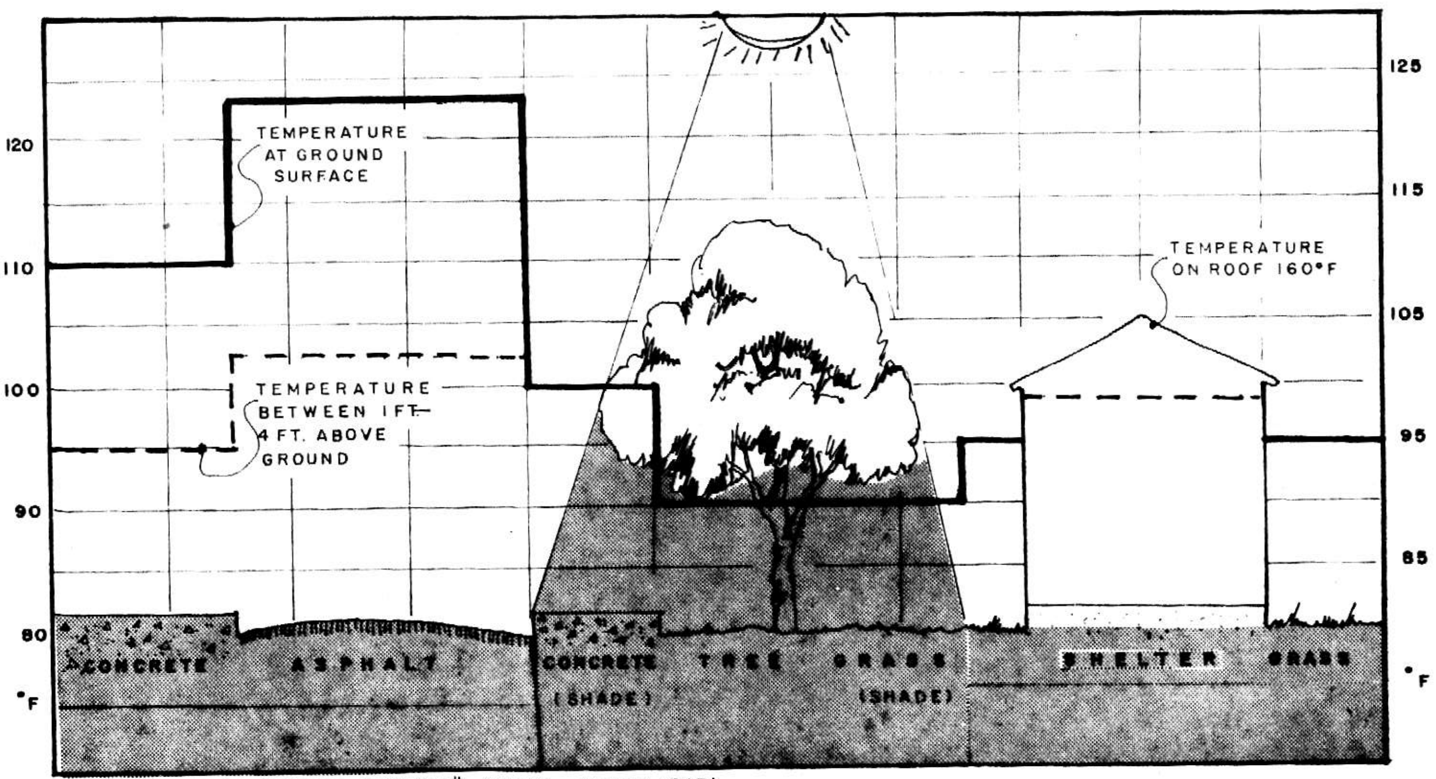
[89] ______. "Micro-climate," Architectural Form, March 1947, Vol. 86, pp. 114-122.

PLATE XXXVIII

Various Temperatures – Surfaces



(REDRAWN FROM "MICRO-CLIMATE" FORUM, MARCH 1947)

When these unpleasant gases and particles mix with fog, it becomes smog. As Professor Louis J. Battan of Meteorology and Associate Director of the Institute of Atmospheric Physics at the University of Arizona describes: "The smog bathed the city in its own debris, attacking all living things. People felt it in their eyes. Tears streaked down faces. Every breath meant a lungful of polluted air."[90]

Air pollution is killing our plants, birds, animals, people and it also damages property. It damages the internal structure of leaves, and discolors stone, and paints. The unclean sky cuts down, not only visibility, but also the most valuable sunrays. Smog just acts as a filter in the sky, according to J.L. Sert, it prevents the sun's ultraviolet rays, which amount to less than two percent of the total solar radiation, from penetrating to the earth. These rays are necessary to the health of human beings. J.L. Sert States:

> For these ultraviolet rays are largely absorbed by the dust, the humidity, and the gases with which this layer of vitiated air is filled. The significance of this fact becomes more pertinent if it be considered that factory smoke is produced in its largest quantities during the daytime, precisely during the hours when the city would benefit most by the sun's rays.[91]

Climate in the city really hits hard in the slum area, where there is a lack of sunlight and fresh air. Here, tuberculosis can

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[90] Louis J. Batton, The Unclean Sky, (New York: Doubleday and Company, Inc., 1966), p. 3.

[91] J.L. Sert and C.I.A.M., op. cit., p. 116.

always be found, along with many other kinds of diseases.[92]

Water pollution also does a great deal of damage to our environment. Nature itself pollutes water in the lakes and rivers, but both lakes and rivers have the ability to purify themselves. Sunlight bleaches out some pollutants such as leaves, animal wastes, and solutions of minerals. Others settle to the bottom and stay there.[93]

The most dangerous pollutants are caused by man. In polluted streams and lakes, hundreds of different contaminants can be found: bacteria and viruses; pesticides and weed killers; phosphorus from fertilizers, detergents, and municipal sewage; trace amounts of metals, acid from mine drainage, organic and inorganic chemicals; many of these are known for their long term ill effects on human health -- according to Bylinsky. Unfortunately, sunlight cannot bleach out these types of pollutants.[94]

Noise pollution is another critical situation, even though it has little connection with the climate. In the city, noise, or unwanted sound, can cause deafness if it is in a very high decibel level. The effect of noise upon humans is psychological and intensely personnal. It relates, not only to a lifetime of experience, but also to mood.

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[92] _Ibid._, p. 26.

[93] Gene Bylinsky, Editor of Forturn, _The Environment_, op. cit., p. 21.

[94] _Ibid._

3. Solution of the Problems

a) Zoning Requirements

With the knowledge of climatology, we can find some ways to improve our conditions in the city. The study of wind flow patterns gives us the plan to zone the residential district away from the industrial district. Sert wrote that zoning them according to their nature and situating them so that prevailing winds may dissipate their smoke and gases, thereby reducing air pollution in residential districts, is necessary.[95]

b) Plant Materials as a Barrier

Nature provides plants to reinforce the livable environment of man, but man himself destroys them endlessly. Man can make use of plants to control his environment from a small scale, as in a house design, to a large scale, as in cities. The effect of plants on climate and environment has already been mentioned (see Part III, the section on Climate Affects on Plants and Animals).

With the use of plants, architects and planners can now plan the city by separating industrial districts from residential districts by means of green bands. The object of such zones would be that of serving as isolating elements, thus protecting the residential districts and other zones of the city from the nuisances and hazards caused by smoke, gases, and factory noises.

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[95] J. L. Sert, op. cit., p. 116.

c) Limitation on Height of Buildings

Sunlight is necessary to human health, and it is lacking in cities because of smog, dust and also skyscrapers. The laws of New York City, for instance, require a set-back from the street for all tall buildings with respect to the heights of these buildings, in order to invite the sunlight to penetrate to the streets. The height of buildings and their spacing, according to Sert, is one of the most important factors physically and psychologically effective to people in the city. He suggested that: "If a city is to be designed that will take into consideration the elementary requirements of good living, a relationship must be established between the height of buildings (dwellings or others) and their spacing. The higher the buildings, the greater the space required between them."[96]

4. Conclusion

To combat the man-made climate, we need a great deal of will power. It is very expensive, and yet, it is extremely necessary. Unless man can adapt to this new environment by breathing dirty air; drinking dirty water, and by equipping the new born baby with a special lung to purify dirty air, then we do not have to spend any more time and money on fighting pollution.

About man adapting to the environment, René Dubos insisted that "Life in the modern city has become a symbol of the fact that man can

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[96] Ibid.

become adapted to starless skies, treeless avenues, shapeless buildings, tasteless bread, joyless celebrations, spiritless pleasures -- to a life without reverence for the past, love for the present, or hope for the future."[97] Pollution, the climate which man creates, clearly endangers our plants, animals, and our health. The era of technology and scientific progress should now be slowed down, and the era of cleaning up pollution should seriously begin. Until we can definitely stop pollution with our superior technology, and until our industrial plants produce no harmful smoke or waste, then the progress of mankind has come up against an obstacle of frightening proportion, which will continue to increase until halted.

Meanwhile, architects and planners have to plan the city with the knowledge of topography and climatology in order to deal with pollution. They must learn how to use whatever they can find from plant materials to building technology, to deal with our pollution in order to give the people in the city a better place to live, better air to breathe and a better view to see.

> The breadth and variety and beauty of our land, the richness of our mines and soil and forests and water, the favorable nature of our climate -- all of these natural factors have provided a setting in which the optimum, the ingenuity and drive of the American people thrive and grow and are rewarded....
>
> The combination of natural and human resources,

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[97] Rene Dubos, Man Adapting, op. cit., p. 279.

> in turn, has given substance to the promise of equality and opportunity for all. A generous land has produced a generous and confident people, a people who have dreamed great dreams of personal, national, and human destiny and who have seen many of these dreams come true.... Many Americans have taken our resources for granted and have relied, without reflection, on their continued plenty. Many have failed to imagine a time when the air and water would lose their sparkling quality, when each man's living space would itself begin to shrink under the pressure of growing population, when the beauty of life on our continent would be marred by offensive sights and sounds and odors.... Man has applied a great deal of his energy in the past to exploiting his planet. Now we must make a similar committment of effort to restoring that planet. Our scientific capacity has grown so much that we are able to leave the earth; yet our glimpse of its beauty from the barren moon has only reminded us of how much we must love earth's qualities. The unexpected consequences of our technology have often worked to damage our environment; now we must turn that same technology to the work of its restoration and preservation....
>
> -- Statement from President Nixon.

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[98] Richard Nixon, statement from <u>The Environment</u>, <u>op. cit.</u>, pp. 11-13.

PART V

CLIMATE AND DESIGN APPROACHES

PART V

CLIMATE AND DESIGN APPROACHES

VII. ARCHITECTURAL APPROACHES TO DESIGN FOR DIFFERENT CLIMATES

1. Introduction to Schematic Designs for Various Climatic Zones

Due to a variety of internal and external conditions, this report will consider, schematically, the top (roof), sides (walls), and bottom (foundation or basement) of enclosures for habitation.

a) Roof

The roof is the building surface usually most exposed to the direct rays of the sun and rain. Its main objective is to protect the living spaces from solar radiation, and from precipitation. The roof materials, color of the external surface of the roof, and heat transmission characteristic of the roof construction, have a great influence on the temperature and comfort in the interios living spaces. For instance, a white or light color roof reflects an appreciable amount of the solar radiation.

Design characteristics of roofs, throughout history, reflect consideration of materials that shed moisture, rain, and show -- rather than heat. With the exception of hot-dry regions, ventilation of the underside of the roof is an important consideration in preventing

PLATE XXXIX

SYMBOLS FOR SCHEMATIC DESIGN

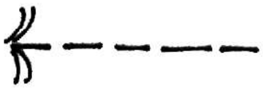
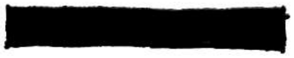
	SOLAR RADIATION, REFLECTIVE HEAT WAVE AND HEAT WAVE FROM INTERNAL SOURCES
	HEAT RADIATION THROUGH MATERIALS
	HOT AIR (INTERIOR)
	COOL AIR (INTERIOR)
	SUNLIGHT
	COOL SUMMER BREEZE, AND AIR WASH IN THE ATTIC OR CRAWL SPACE
	UNDESIRABLE BREEZE, EITHER COLD WINTER BREEZE, OR HOT-DRY AIR BREEZE (ESP. HOT-DRY AREAS)
	RAIN FALL
	MASSIVE WALL OR VERY WELL INSULATED MATERIALS OF WALLS OR ROOF
	LIGHT MATERIAL
	INSULATION

PLATE XL

ROOFS

EXTERNAL HEAT SOURCE

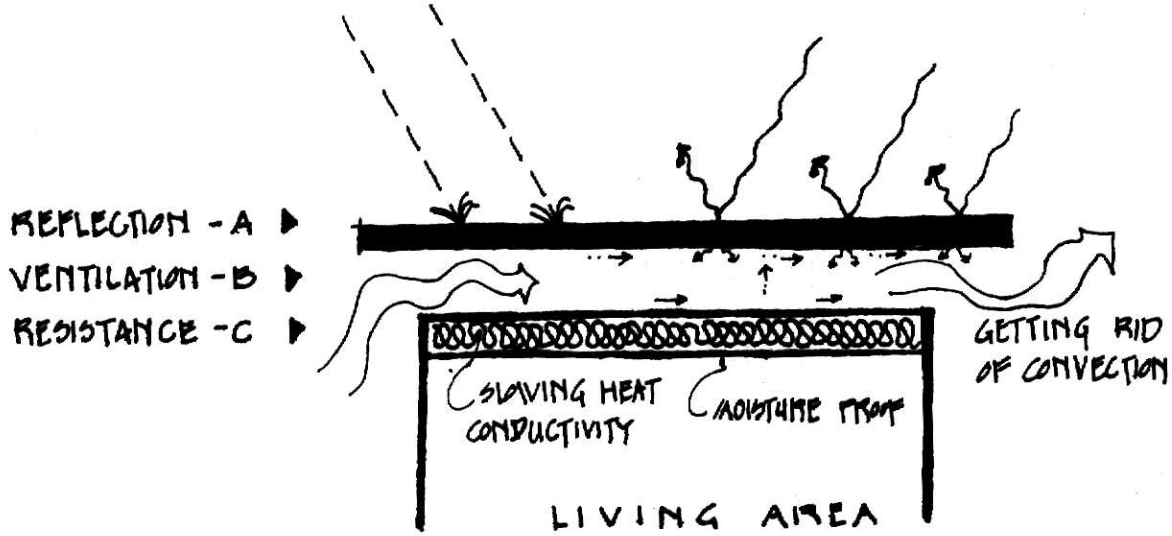


DIAGRAM I INTEGRATION OF MATERIAL AND DESIGN TO RECOGNIZE THE PRINCIPLES OF REFLECTION, VENTILATION, AND CONDUCTIVITY IN FLAT ROOF CONSTRUCTION

A- LIGHT COLORED SURFACE TO REFLECT HEAT

B- VENTILATED AREA BETWEEN TOP AND UNDERSIDE OF ROOF TO DISSIPATE CONVECTED HEAT

C- INSULATED AREA TO ABSORB HIGH PER CENT OF REMAINING HEAT BEFORE IT REACHED LIVING SPACE

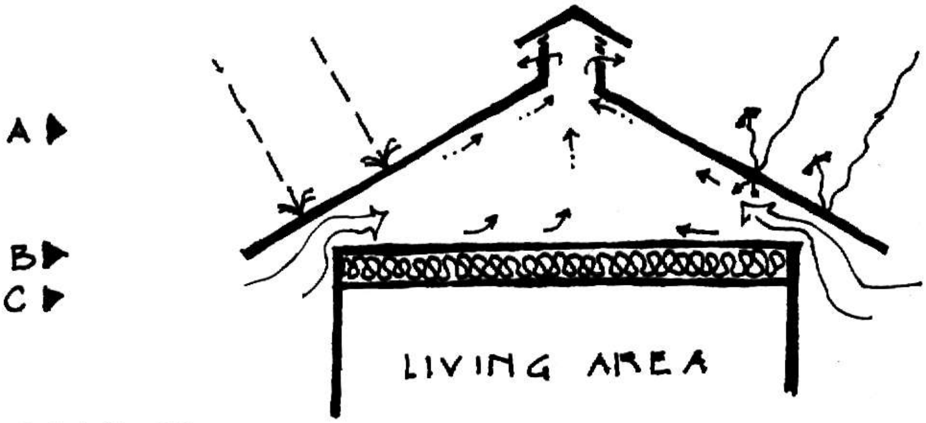


DIAGRAM II

ALTERNATE DESIGN – PITCHED ROOF SURFACE

PLATE XL (CONTINUED)

ROOFS

INTERNAL HEAT SOURCE

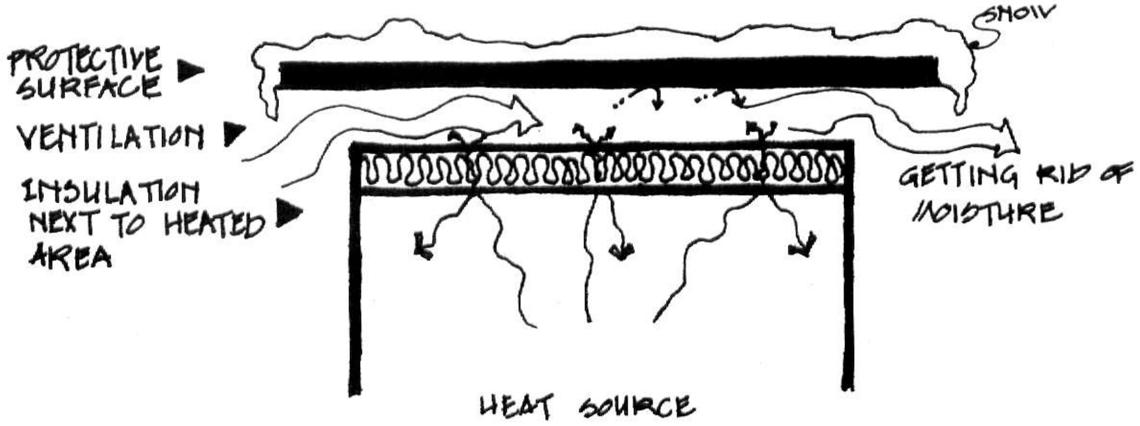


DIAGRAM III

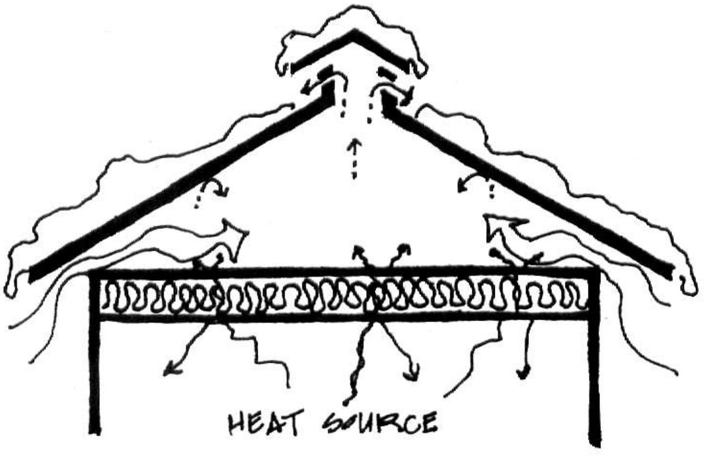
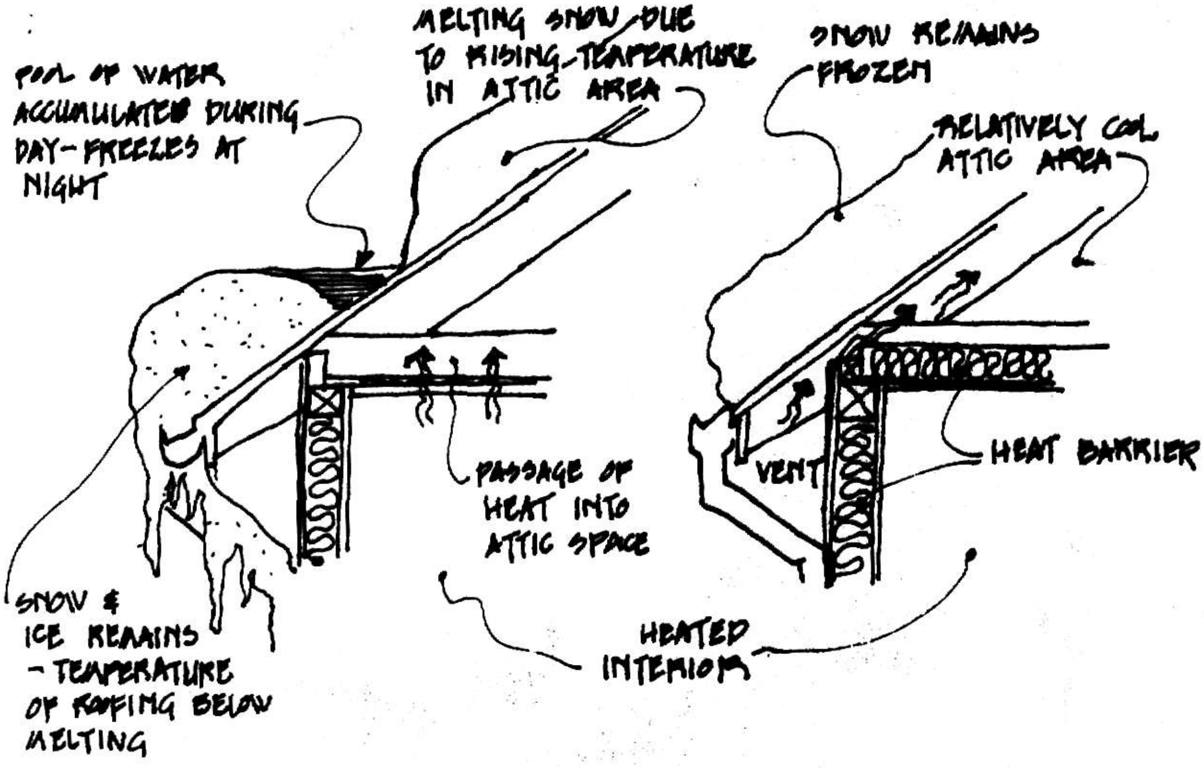


DIAGRAM IV

accumulation of moisture and condensation on the underside of the roof, due to temperature variations. Proper ventilation will also prevent heat build-up between the ceiling and the roof. Most of the heat generated from external sources gains access through the roof, according to Wolfgang Langewesche. He explained that the heat penetrates the materials of the attic floor -- the floor boards, the insulation and the plaster which forms the ceiling of the rooms below, and then radiates down to the room.[1]

During the cold season, in temperate and cold regions, snow may melt on the roof surface covering an attic area. The unprotected overhang allows the snow to remain, thus forming an ice barrier behind which a pond of liquid water may accumulate (see Figure 21 below). Water may

Figure 21



SUFFICIENTLY (RIGHT) AND INSUFFICIENTLY (LEFT) INSULAED AND VENTILATED ROOF

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[1] Wolfgang Langewesche, "Summer Heat is Man-Made," House Beautiful, June 1955, p. 112.

easily find its way into the building through cracks in shingle and tile roofing, causing damage to the insulation of the roof or decay of wooden parts of the structure. In order to prevent the formation of ice dams, the temperature of the roof surface should, as far as possible, be equal to the air temperature. To achieve this, according to Roger Taesler, a good heat insulation is necessary. However, a certain amount of heat transfer will always take place from the interior, causing the air temperature in the attic space to rise. This heating can also be caused by solar energy penetrating the roofing. In order to keep the roof surface cold and also prevent condensation in the attic space, louvers or vents must be placed at strategic places.[2]

When the total living area of a residence is distributed on a single level, the roof area is a relatively large proportion of the total exposed surface. Proper design of roofs assumes greater relative importance, therefore, in a single story design than in a multistory design. It is difficult to predict the total percentage of heat loss or gain through the roof surface unless the type of wall material, amount of glass and orientation are known.

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[2] Roger Taesler, "Problems Caused by Snow Relating to Building Techniques," Building Climatology, Secretarial of the World Meteorological Organization, Geneva, Switzerland, 1970, pp. 146-147.

b) Exterior Walls

The general functions of a wall are clearly illustrated in James Fitch's wall diagram (see Plate XLI). Exterior walls are usually designed to support the structure. They may be transparent or opaque to permit, or enclose, a view of the exterior. They must exclude rain, snow, and wind and also have proper thermal qualities.

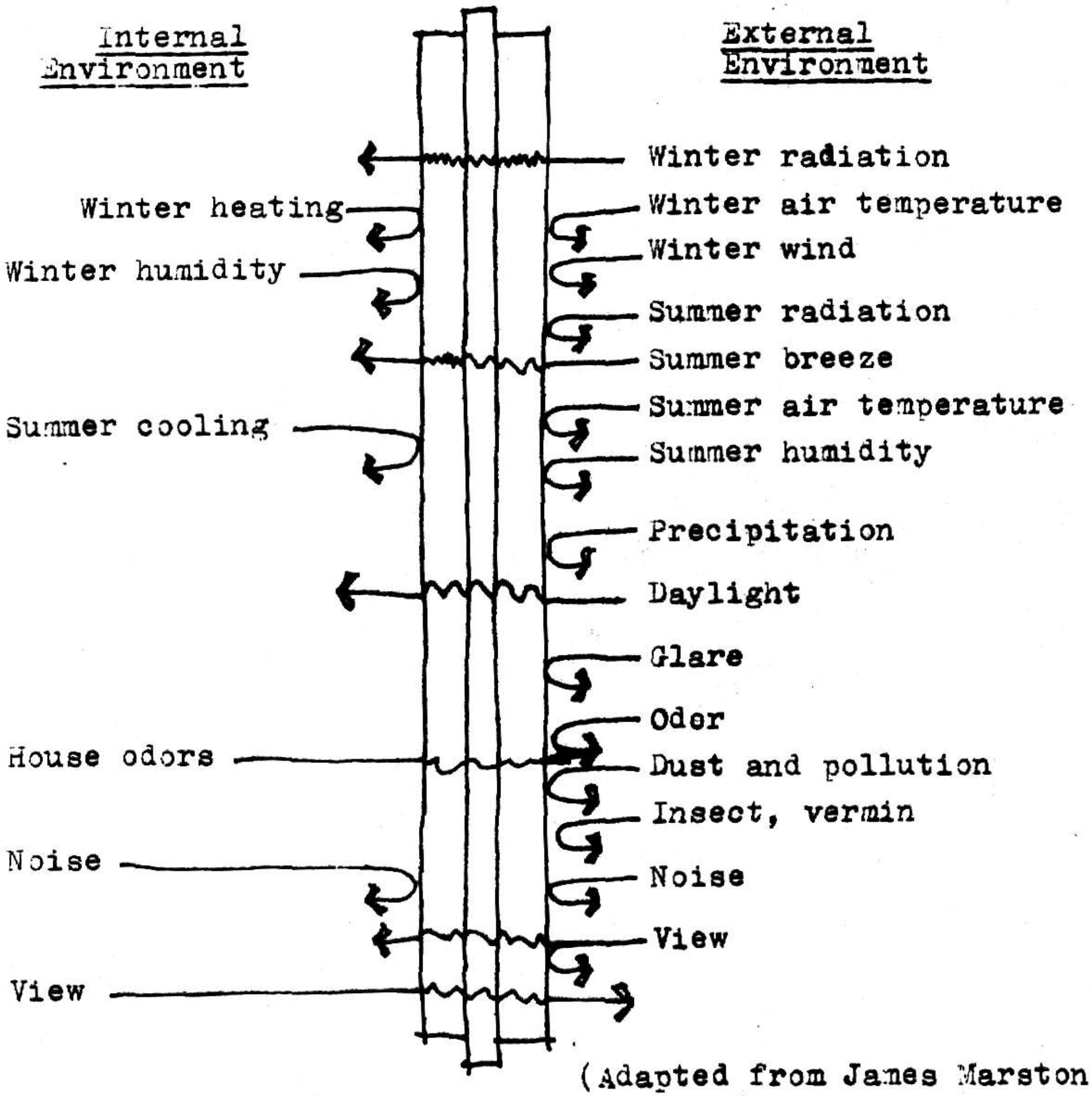
In the past, man had to rely on thick walls in hot-dry climates to prevent excessive heat penetration. Today, it is no longer necessary to rely on mass and thick walls may not always be desirable in these hot-dry areas. More efficient materials of high insulating value are often built into the walls to serve the same purpose. Although heat flow is reversed during a large portion of the year in some temperate and cold climates, these same wall characteristics apply.

In most hot, humid climates, thick walls or high heat capacity materials have little advantage, unless an artificially controlled interior temperature is maintained, due to the fact that there is a small temperature variation day by day throughout the year. Controlled ventilation in the wall and around it is a very important factor, not only in hot, humid areas, but also in temperate and cold climatic zones, in order to prevent condensation of moisture which can ceteriorate materials and considerably reduce the efficiency of the insulation (see Plate XLIII).

PLATE XLI

WALL

FITCH'S WALL DIAGRAM



(Adapted from James Marston Fitch's "Experiential Bases for Aesthetic Decision," in Environmental Psychology, 1970.)

PLATE XLII

WALLS

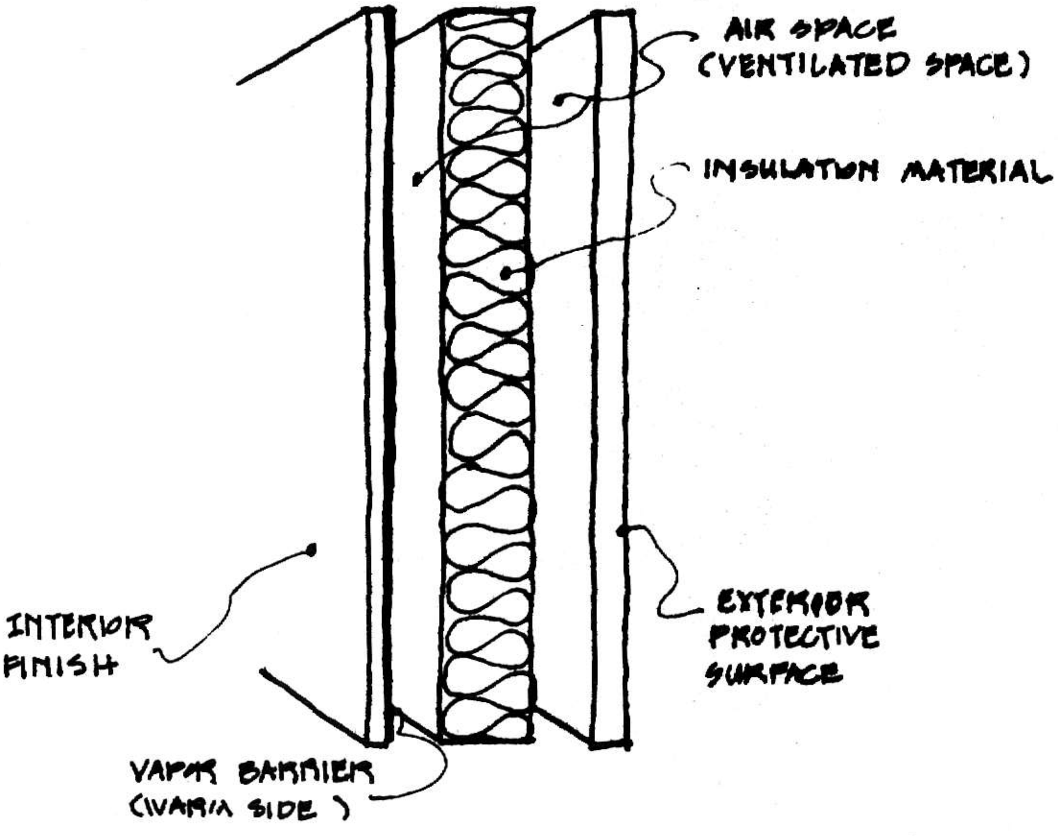
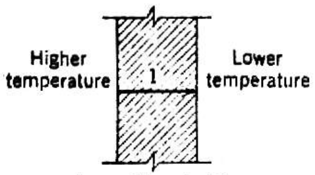
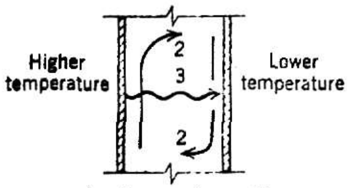


PLATE XLIII



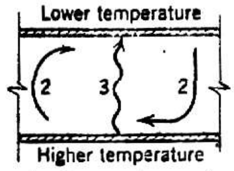
Any solid material, wall, floor or roof

A single solid material illustrates the transfer of heat from the warmer to the cooler particles by conduction (1).



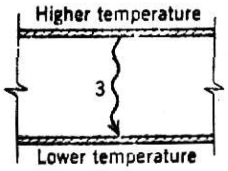
An air space in a wall

As air is warmed by the warmer side of the air space it rises. As it falls down along the cooler side it transfers heat to this surface (2). Radiant energy (3) is transferred from the warmer to the cooler surface. The rate depends upon the relative temperature of the surfaces and upon their emissive and absorptive qualities. Direction is always from the warmer to the cooler surface.



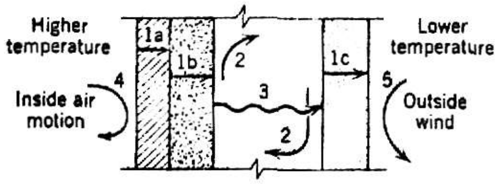
An air space in a roof

The convective action (2) in the air space of a roof is similar to that in a wall although the height through which the air rises and falls is usually less. The radiant transfer is up in this case because its direction is always to the cooler surface.



An air space in a floor

When the higher temperature is at the top of a horizontal air space the warm air is trapped at the top and, being less dense than the cooler air at the bottom, will not flow down to transfer its heat to the cooler surface. This results in little flow by convection. The radiant transfer in this case is down because that is the direction from the warmer surface to the cooler.



A composite assembly of building materials in place at the site

This example of a wall in place illustrates the several methods by which heat is lost through a composite assembly of materials. Conduction at varying rates in different materials is accounted for in 1a, 1b, 1c. Convection currents (2) and radiation (3) carry the heat across the air space.

Heat is conducted from the room air by warm air currents that strike the inside wall. Heat is conducted away *from the exterior surface of the wall by the action of the wind.*

Nature of heat flow through materials, air spaces and assembled structures.

Conduction	1	Inside surface conductance	4
Convection	2	Outside surface conductance	5
Radiation	3		

Source:

William McGuinness, Mechanical and Electrical Equipment for Buildings, (New York; John Wiley & Sons, Inc., 1967)

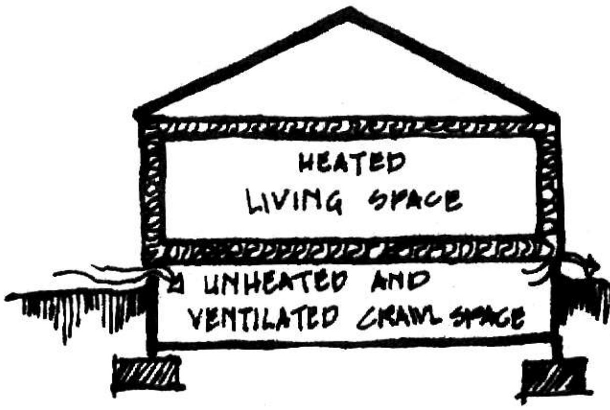
c) Floor

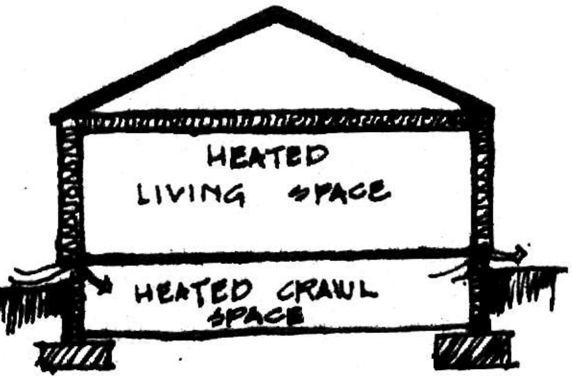
The floor is the component of the building which has somewhat less exposure to climatic conditions, as compared to the roof and walls. However, internal comfort is also dependent on the treatment of the floor with respect to temperature. In the past, many houses were built with basements. In the summer, for instance, a basement is cooler than other parts of the building which are above ground. People began storing food in the basement to keep it cool. In addition, in cold climates, it was necessary to locate the heating systems below the lowest register or radiator. Due to a lack of insulation materials, the basement area also prevented excessive heat loss through the first floor. Today, with insulation materials, modern heating systems, and refrigerators for storing foods, a basement is no longer necessary, unless the owner wishes to provide extra storage space of a storm shelter.

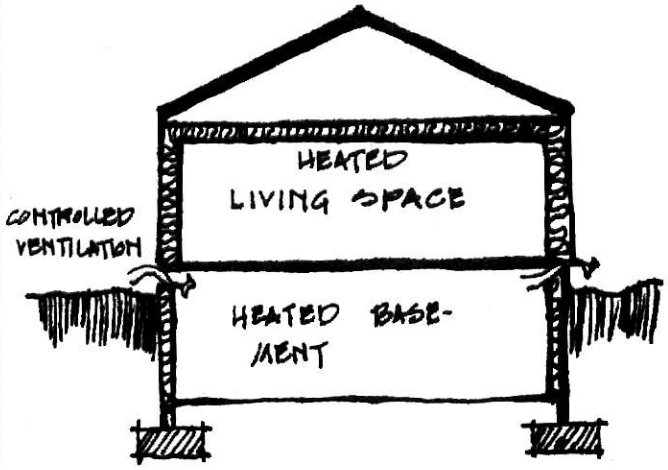
In hot-dry areas, where the earth is relatively cool, history has illustrated that many houses are built below grade to take advantage of this cooling effect. In contrast, houses in hot humid areas were often raised above the ground level because of the damp ground which supports favorable conditions for insects, pests, and fungi. This raised location also provided better exposure to breezes and flood protection, if needed. However, these design characteristics are equally appropriate for our contemporary designs.

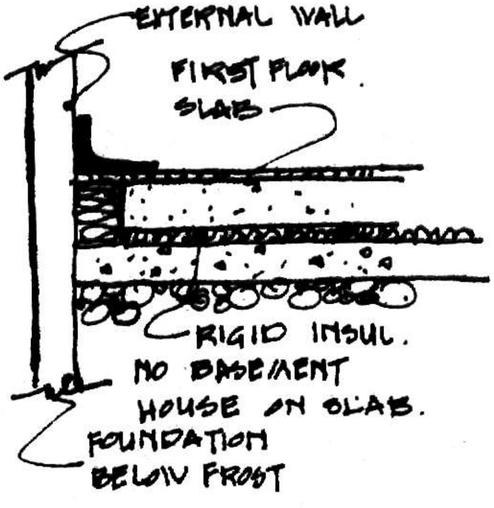
PLATE XLIV

FLOOR









d) Openings

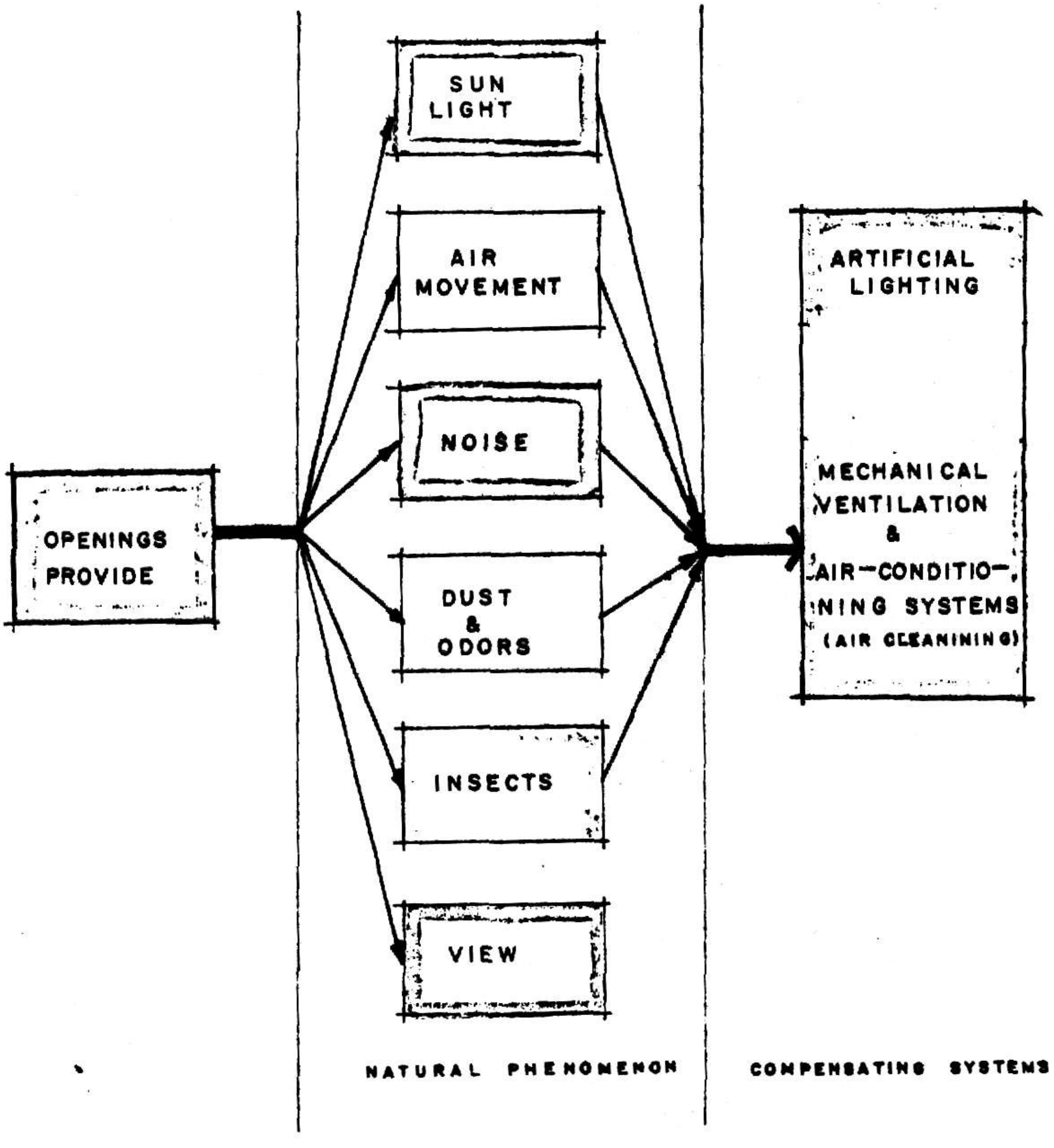
Openings may be a window, clerestory, door or a glass wall. The functions of an opening are varied: for circulation and natural ventilation, to admit sunlight, or to provide a view. Windows and other devices that provide natural ventilation also admit dust, odor, insects, and noise into the interior space of a dwelling. Mechanical air-conditioning systems have overcome these problems by permitting the designer to "seal" the house. Artificial lighting systems also compensate for natural daylight. Therefore, doors and windows need no longer be designed to provide ventilation and light, but for circulation and to provide visual contact with the exterior (see Plate XLV).

An opening must adequately protect the interior from rain, snow, and heat gain or loss. In the orientation of the building, sun control devices and weather barriers may be employed in order to protect the opening. The judicial use of natural elements such as shrubs, trees, and vines can help to interrupt the wind, sunlight, dust, and so forth.

In hot-dry areas, openings should be minimized, if possible, to prevent the heat penetration and heat radiation from the ground. However, since the cool evening breeze usually blows from the south, if the opening is shaded on the south side, a moveable covering over these openings will receive this cool night breeze. In hot, humid areas, openings are extremely necessary for ventilation purposes in buildings

PLATE XLV

Function of Wall Openings



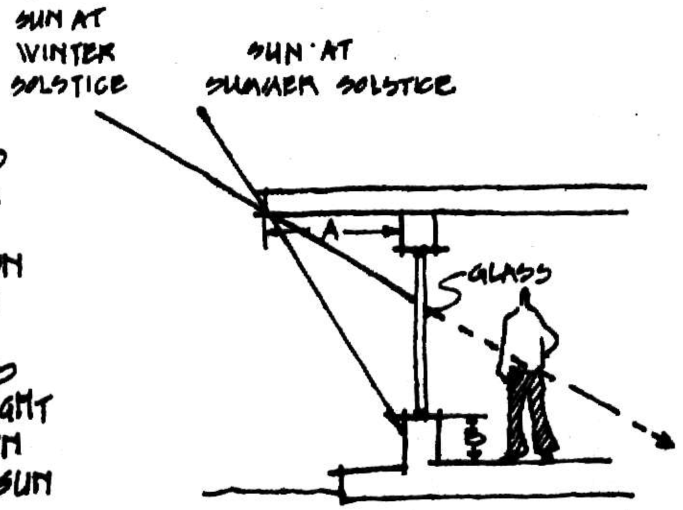
THEREFORE, OPENINGS ACT MAINLY AS VISUAL FUNCTIONS & CIRCULATION (DOORS)

PLATE XLVI

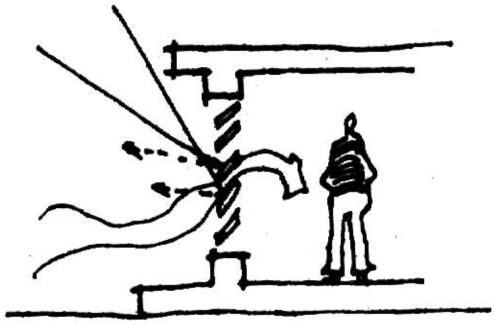
OPENINGS (SOUTH EXPOSURE)

OVERHANG MAY PROTECT THE OPENING FROM SOLAR RADIATION BUT ALLOWS SUN PENETRATION FOR WINTER WARMTH IN COLD AREAS.

DISTANCE "A" SHOULD BE RELATED TO THE HEIGHT OF SILL "B" DEPENDING ON LATITUDE & DEGREE OF SUN CONTROL DESIRED



LOUVER PROTECTS BOTH SUMMER AND WINTER SOLAR RADIATION, AND ALSO PROVIDES VISUAL PRIVACY IN HOT AREAS.



LOUVERED OVERHANGS MAY BE USED TO PREVENT ENTRY OF DIRECT SUNLIGHT BUT PROVIDE INDIRECT REFLECTED LIGHT

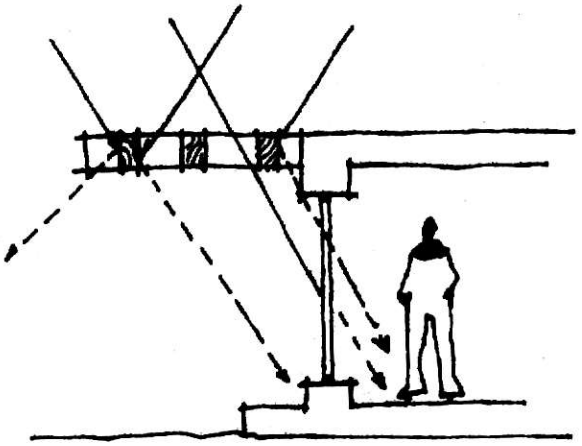
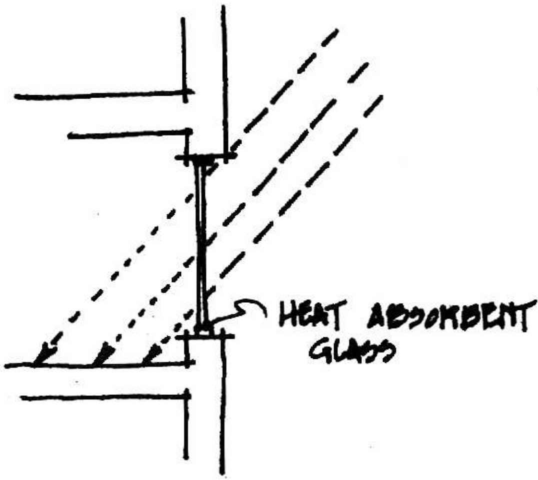
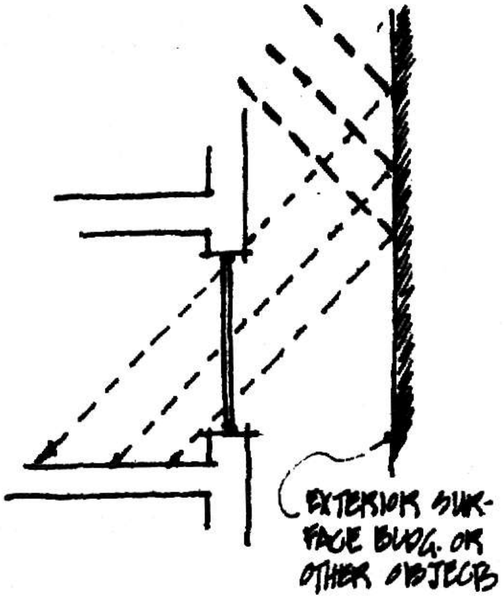


PLATE XLVII

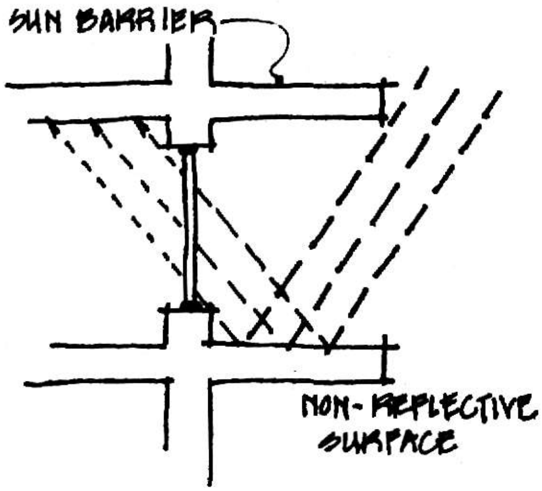
CONTROL OF EXTERNAL HEAT SOURCE THRU TRANSPARENT SURFACES



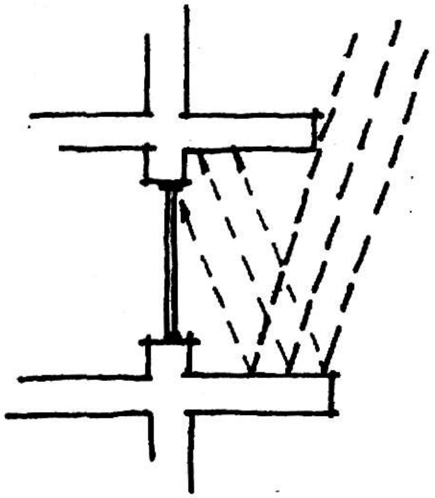
DIRECT TRANSMISSION



DIFFUSE RADIATION



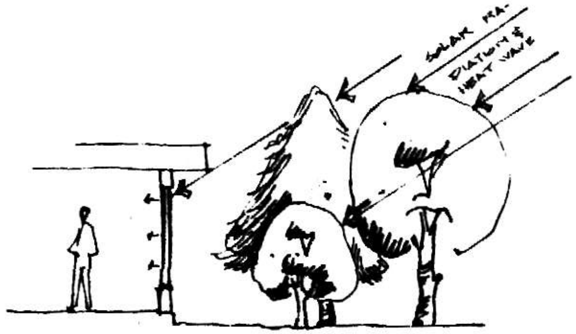
REFLECTIVITY



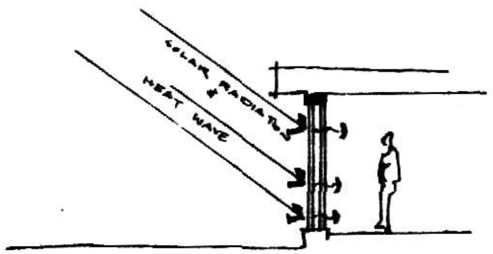
IF SOUTH EXPOSURE, PROJECTION OF OVERHANGS PREVENTS REFLECTIVE RAYS OF SUN FROM PENETRATION (IN SUMMER)

PLATE XLVIII

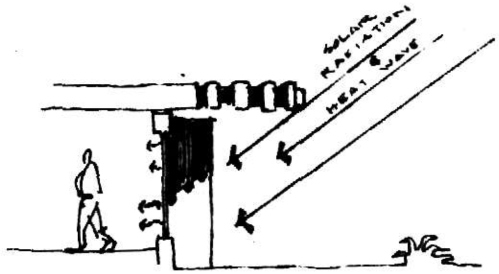
SUN CONTROL DEVICES ON TRANSPARENT AREAS OF BUILDINGS



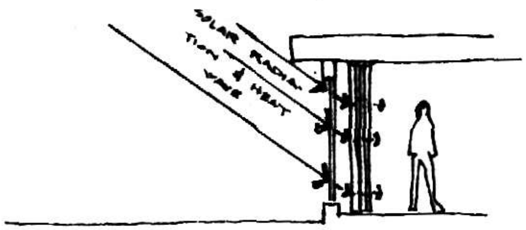
NATURAL DEVICES: BUILDING ORIENTATION, TREES, AND SHRUBBERY, SHADE OF OTHER ELEMENTS SUCH AS, BUILDINGS, OR HILLS ETC.



OPENING ITSELF: HEAT-ABSORBING GLASS DOUBLE GLAZING, GLASS JALOUSIES AND AWNINGS, ETC.

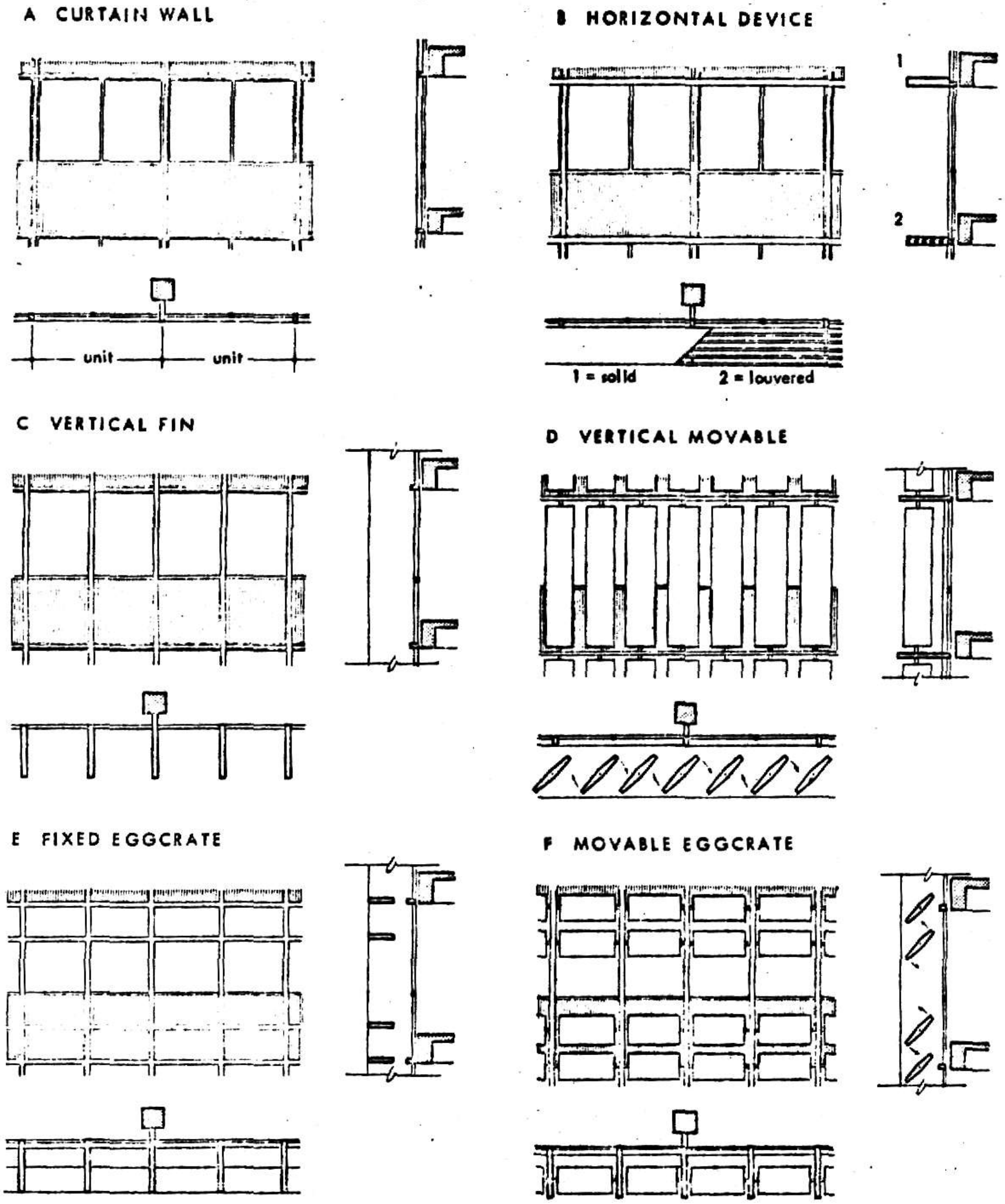


DEVICES OUTSIDE THE OPENING: SHUTTERS, FIXED OR MOVABLE LOUVERS, FIXED EXTERIOR VENETIAN BLINDS, CANOPIES, OVERHANGS, BALCONIES, ETC.



DEVICE INSIDE THE OPENING: SLATTED BAMBOO SHADES, DRAPERIES, VENETIAN BLINDS, SINGLE OR DOUBLE CLOTH ROLLER, ECT.

PLATE XLIX



Standard types of shading devices.

Source: Victor Olgyay, Design with Climate, (Princeton: Princeton University Press, 1963) which are not airconditioned. All of the structures in this area must be protected by adequate insect screens. It is quite general to find that interior openings are also protected by screens in many hot, humid countries where insect protection is one of the main design considerations.

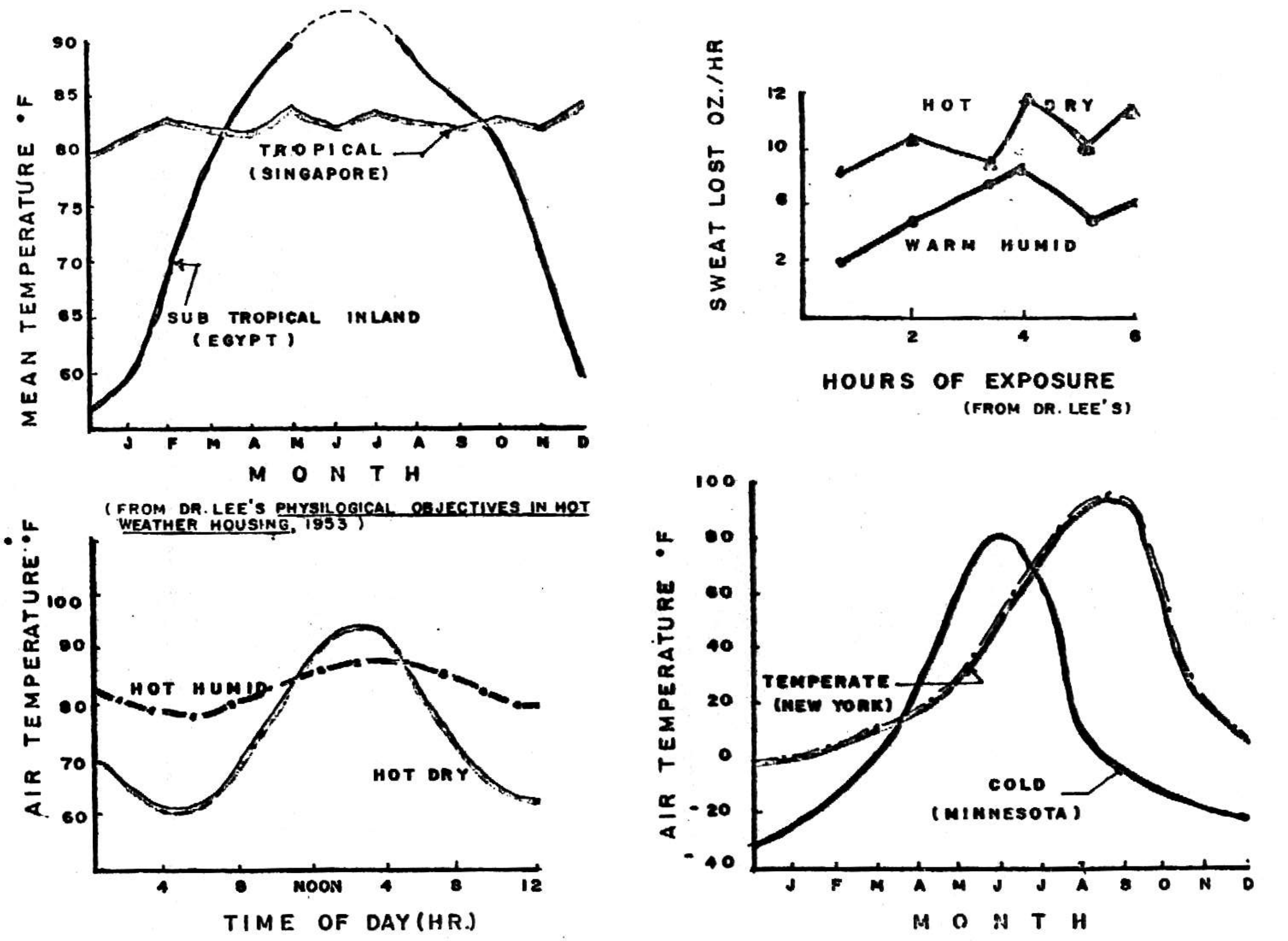
2. Characteristics of Various Types of Climate

In the early part of this study, we classified the various climates in the world into six different zones, namely: Hot, Monsoon, Mediterranean, Desert, Temperate and Cold (see Part II, Climate in General). But for the convenience of our study, we divided climate into four different types: Hot-humid, Hot-dry, Temperate and Cold. Each individual type has its own characteristics and has a great influence on the design of shelter in that region. Therefore, it is necessary to study these characteristics in order to build a better environment for people in differing climates.

This section contains useful and important information on the characteristics of each climatic zone in the form of plates and tables. The information is mainly generalized within each zone and not necessarily applicable in a particular area in that zone, unless it is noted. Also included in this section, is a description of the types of building materials normally used in differing areas. These plates and tables will help the architect to grasp a quick understanding of climates and give a general idea of the building materials which are suitable for different areas of the world (see Plates L - LII and Tables VI - X).

PLATE L

Graphs of Temperature Difference



(FROM DR. LEE'S PHYSILOGICAL OBJECTIVES IN HOT WEATHER HOUSING, 1953)

(FROM DR. LEE'S)

(FROM SAINI'S ARCHITECTURE IN TROPICAL AUSTRIALIA)

(FIGURES FROM OLGYAY'S DESIGN WITH CLIMATE, 1963)

PLATE LI

CHARACTERISTICS OF VARIOUS TYPES OF CLIMATE

HOT HUMID

- Tropical rain forest
- Monsoon lands
- Temperature and high humidity remaining the same throughout the year
- Annual mean of maximum degree temperatures in shade 96° F., at night, temperatures 77° F.
- Annual precipitation over 787.4 inches
- Relative humidity about 55 - 100 percent
- Ground condition -- green landscape
- High heat storage of ground
- Cloudy sky and hazy
- Moderate reflection of solar radiation from clouds
- Moderate to high direct solar radiation
- Constant heating and cooling patterns of land and sea creating regular land and sea breezes

HOT DRY

- Desert, semi-desert
- Low precipitation
- Annual precipitation less than 9.8 inches
- Annual mean of maximum day temperatures in shade 100.5° F., at night 68° F.
- Relative humidity about 10 - 55 percent
- Violent and strong winds
- Dry ground conditions
- Very few plants
- Clear blue sky
- Uncomfortable glare due to the exceptionally high amount of light reflected

PLATE LI (cont'd)

TEMPERATE

- Changeability
- Hot in the summer and cold in the winter
- Sufficient rainfall at all seasons
- Temperatures ranging between 102° down to -14° F.
- Annual precipitation over 48 inches
- Annual average relative humidity between 56 - 76 percent
- Amount of snowfall up to 36 inches
- Sun distribution fairly uniform throughout the year
- Average wind velocities between 10 miles per hour to 15 miles per hour throughout the year

COLD

- Temperatures ranging from -35°F. to 95° F.
- Cold, long winter
- Cold winter wind throughout the season
- Very pleasant sunshine in winter and also in the short summer
- Higher outdoors relative humidity in the summer than in the winter
- Average rainfall about 27 to 30 inches

(Sources: see Tables IV - IX)

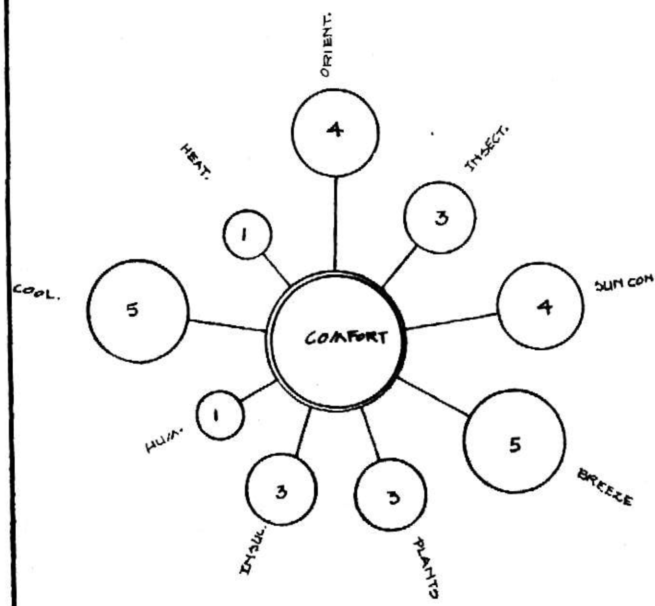
EXPLANATION OF PLATE LII

Relative Importance of Design Factors in Hot humid, Hot dry, Temperate, and Cold areas.

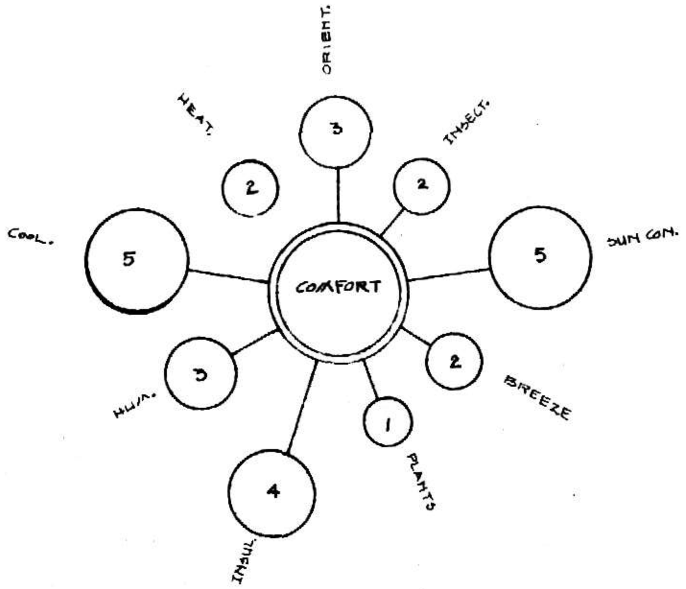
This plate shows the size of circles which indicates the importance factors based on five points scale. In hot humid areas, for example, cooling and air movement are the most important design factors, while in the hot dry areas, cooling and shading devices are the most important design factors. In cold areas, for instance, heating and insulation of the dwelling are important while in temperate areas, heating and cooling are equally important in design factors for providing internal comfort environment.

PLATE LII

HOT HUMID



HOT DRY

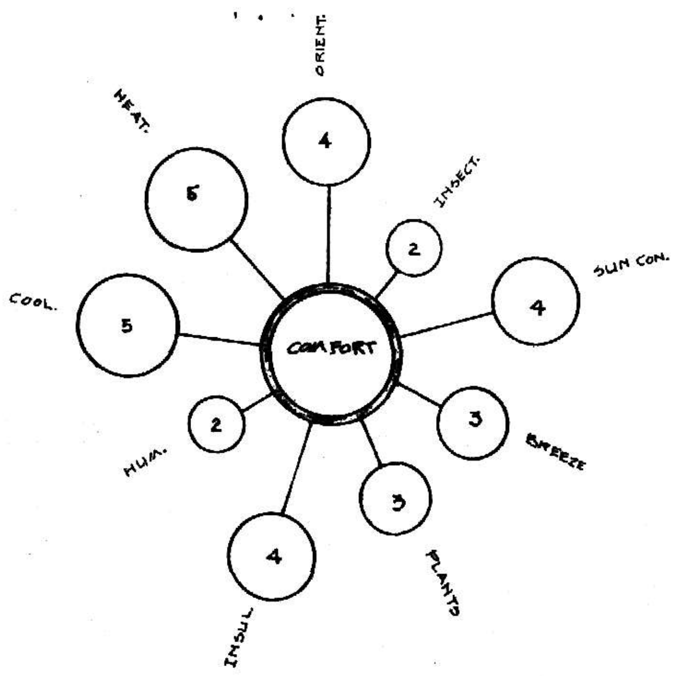


SIZE OF CIRCLE INDICATES IMPORTANCE
BASED ON FIVE POINTS SCALE

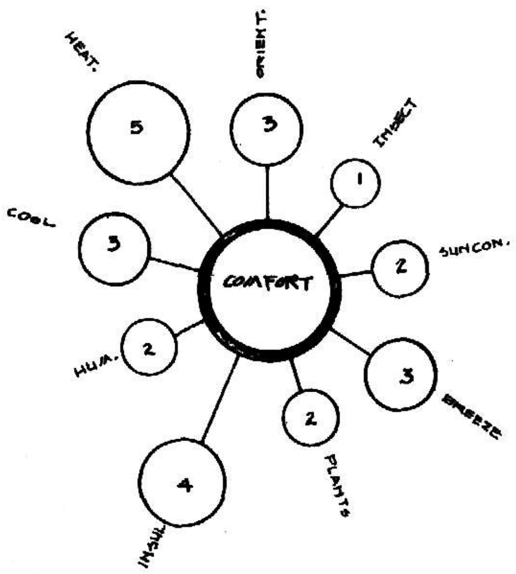
COOLING	5	PLANTS	3	COOLING	5	HUMIDIFY	3
SUMMER BREEZE	5	INSECTS SCREEN	3	SUN CONTROL DEVICES	5	SUMMER BREEZE	2
ORIENTATION	4	HUMIDIFY	1	INSULATION	4	INSECT SCREEN	2
SUN CONTROL DEVICES	4	HEATING	1	ORIENTATION	3	PLANTS	1
INSULATION	3			HEATING	2		

PLATE LII (CONTINUED)

TEMPERATE



COLD



SIZE OF CIRCLE INDICATES IMPORTANCE

BASE ON FIVE POINTS SCALE

HEATING	5	SUMMER BREEZE	3
COOLING	5	PLANTS	3
ORIENTATION	4	HUMIDIFY	2
INSULATION	4	INSECT SCREEN	2
SUN CONTROL DEVICES	4		

HEATING	5	HUMIDIFY	2
INSULATION	4	SUN CONTROL DEVICES	2
ORIENTATION	3	PLANTS	2
COOLING	3	INSECTS SCREEN	1
SUMMER BREEZE	3		

EXPLANATION OF TABLE VI-IX

These four tables show the effects of climates on people, and the suggested approach to design for hot humid, hot dry, temperate, and cold climate areas.

Sources: Victor Olgyay, *Design with Climate*, (Princeton, N.J.: Princeton University Press, 1963.)

Maxwell Fry, and Jane Dew, *Tropical Architecture*, (New York: Reinhold Publishing Corporation, 1964.)

R. L. Fullerton, *Building Construction in Warm Climates*, (London: Oxford University Press, 1967.)

B. Givoni, Man, *Climate and Architecture*, (New York: Elsevier Publishing Company Limited, 1969.)

Housing Research, *Application of Climatic Data to House Design*, (Housing andHome Finance Agency, Washington, D.C., January, 1954.)

Dr. Douglas Lee, *Physiological Objectives in Hot Weather Housing*, (Washington, D.C.: Housing and Home Finance Agency, 1953.)

United Nations, *Climate and House Design*, (Department of Economic and Social Affairs, New York: United Nations Publications, 1971.)

Georg Lippsmeier, *Building in the Tropics*, (Germany: Verlag Georg, D.W. Callwey, Munchen, 1969.)

Amos Rapoport, *House Form and Culture*, (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969.)

TABLE VI

TYPES OF CLIMATE	EFFECTS ON PEOPLE	SUGGESTED APPOARCH TO DESIGN
HOT HUMID	. Climate difficult to tolerate, symptoms of fatigue . The greater in intensity of solar radiation, the greater the heat discomfort for human . Low bodily evaporation because of high humidity and slight air movement . High humidity causing the efficency of sweating . Necessary continous ventilation and air movement for the primary comfort . Danger of sunstroke . High death rate . Low rate of health and vigor efficency . High population density	**Layout** . East-west axis . Single line of rooms facing North and South . Kitchen and bathroom unit to the lee of living rooms, separating from the rest of structure with covered verandahs or passages . Opened plan or less internal walls . Individual noue layout--desirabale . Air movement through and around building **Opening** . Large opening, but protection from insects --important . Large window in bedrooms--necessary . Shading the opening from direct solar radiation, and diffused radiating from the sky, and also from rain . Free ventilation--most important and necessary in design elements **Roof** . Lightweight roofs, covered with tiles or sheets of asbestos cement or aluminum sheets . Roof ventilation necessary . Double roof--desirable . High inclined roof for fast drainage--desirable . Bitumen and asphalt for roof--undersirable . Deep overhangs protection against both sun and rain, allow ventilation during rain . Minimum mass to avoid heat built up and subsequent reradiation **Wall** . Light weight wall . Well-insulation and "breathing" wall --preferable . Air movement through and around the wall --desirable **Others** . Heat and moisture producting areas--ventilation required . Method of construction--light, open construction . Important for opening--screening, louvers, jalousies, and grills admitting air flow and to protect from sun and rain and insects . Raising the floor to protect against pests, vermin and insects, . Raising the floor for flood protection and away from the damp ground . Raising the floor for better exposure to breezes

TABLE VII

TYPES OF CLIMATE	EFFECTS ON PEOPLE	SUGGESTED APPROACH TO DESIGN
<u>HOT</u> <u>DRY</u>	. Relatively tolerable climate . Activity impossible during the hottest part of the day . High rate of evaporation of body . Moderate heat exchange from ground to human body . Promotes heat loss when vapor pressure high, but gain when temperature very high . Heat gains in body from direct and reflected of solar radiation . Convective heat loss from the body --low . Air movement by day--unnecessary . Adaptation of individual living habits---sleeping out doors in the internal courtyards or on roofs,---restricting outdoor activity to the morning, late afternoon and evening to avoid the intense midday heat	<u>Layout</u> . East-west axis . Cubical forms, minimum surface expose to radiation . Rooms arranging around the internal court yard . High building preferable . North or South for habilable rooms if no courtyard available . Porch or patio facing East or South or South-east <u>Openings</u> . Small opening, but direct view to the blue clear sky . Large opening protected by movable insulated shutters . Large glass wall protected by some kinds of shading device . Tall and narrow openings on North . Closing door and windows during the day and opening at night--general practice in many areas <u>Roof</u> . Heavy weight roof for delaying the entry of heat and for sleeping . White or light color roof surface for heat reflection <u>Wall</u> . Possible massive wall or well-insulated wall . Light color wall surface . Heat-storing wall material for daytime living area . Light heat capacity wall material for nighttime living area <u>Other</u> . Carport, garage or tool room, located on West to take the worst sun and sheilding off the rest of the house . Fountains and pool in the courtyard adding moisture and cooling effect . Possible no West opening at all . Method of construction-- heavy, closed construction . External shades--preferable . Location of the opening--South, North, to a lesser degree, on East

TABLE VIII

TYPES OF CLIMATE	EFFECTS ON PEOPLE	SUGGESTED APPROACH TO DESIGN
TEMPERATE	. Very desirable living relationship between outdoor and indoor . High population density . Highly active people . Low rate of death . High rate of health and vigor efficiency . Sun shine desirable in all winter and most of the summer . Air movement --necessary . Mechanical heating --necessary in the winter . Cooling systems in the summer--desirable	**Layout** . East-west axis . Bedrooms location --Easterly sides . Open porch on South and Southeast . Building to act as sun trap in the winter and a shaded shelter in the hottest days in the summer . Breeze utilization in warm periods-- important . Cooperation of indoor and outdoor living design--perferable **Opening** . Desirable sun penetration in the winter . South exposed opening working well on seasonal bases . . Location of opening allowing cross ventilation . Adequate cross ventilation in the summer-- necessary . Eggerate type of sunshade on East and West, vertical fins on North side protecting higher buildings **Roof** . Eave and gable ventilation needed . Attic fan effectively creating air wash through attic . Insulation in ceiling --necassary . Snow and rain pockets --avoided . Reflective color for roof surface **Wall** . Well-insulated wall, and protection from condensation --necessary . Light color surface for summer solar radiation **Others** . Desirable evergreen windbreaks against winter Northwest wind . Evergreen trees best for wind protection, deciduous for shading purpose

TABLE IX

TYPES OF CLIMATE	EFFECTS ON PEOPLE	SIGGESTED APPROACH TO DESIGN
COLD	. Indoor living period about 70 % of annual hours . High rate of health and vigor efficency . Low deathrate . Less population density . Highly endurable to climatic conditions . Mechanical heating systems --necessary for indoor comfort . Cooling systems in the short summer --desirable . Air movement-- necessary for living comfort in summer	**Layout** . East-west axis . Middle or lower middle of slope of building site-- preferable to prevent excessive wind effect and to aviod cool air pools . Building to act as sun trap . Layout providing sheltering effect against winds . Larger building units grouping close together but to utilize sun heat effects. **Opening** . Small opening avoiding heat loss . Large opening with double glazing . Desirable shading in summer, but not to interfere with solar impact during the winter periods. . Sun windows providing good heat sources except on the South and East side **Roof** . Thick roof insulation and low thermal capacity insulation . Low-pitched shingle that allow some dry snow to act as insulation . Preventing a large amount of snow piling on the roof . Snow load and roof load (dead load) for design consideration . Ventilation to get rid of the moisture in the winter in the roof --necessary **Wall** . Dark absorbent colors surfaces, if summer shade provided . Keep out of water and sewer pipes from exterior wall . Compact structures with minimum exterior surface--desirable . Thick wall insulation and low thermal capacity insulation **Others** . Central heat for small structure-- desirable . Evergreen windbreak in Northeast and South west direction at distance of about 20 times the tree hight . Floor insulation for slab on grade --necessary . Increasing indoor heat production, and radiation absorption . Decrease radiation loss by insulating wall and roof . Reduce conduction and evaporation loss

EXPLANATION OF TABLE X

Building Materials Used in Various Climates

Sources: R. L. Fullerton, *Building Construction in Warm Climates*, (London: Oxford University Press, 1963.)

Maxwell Fry, and Jane Dew, *Tropical Architecture*, (New York: Reinhold Publishing Corporation, 1964.)

Georg Lippsmeier, *Building in the Tropics*, (Germany: Verlag Georg, D.W. Callway, Munchen, 1969.)

Vidal de la Blache, *Principle of Human Geography*, (London: Constable Publishers, 1952)pp. 238-257.

B. Givoni, *Man, Climate and Architecture*, (New York: Elsevier Publishing Company Limited, 1969.)

TABLE X

BUILDING MATERIALS USED IN VARIOUS CLIMATES

TYPES OF MATERIALS	AREAS IN USE	REACTION TO CLIMATIC CONDITIONS
Cane straw, leaves, grass, thatch, organic waste products	. Hot humid and all tropical forest countries	. Water proof . Little heat insulation . No heat storage . Storm, wind and fire risks . Good ventilation . Durability--low for all soft materials except bamboo . Easy to repair and replace . Cheap materials
Timber	. All tropical forest countries . Cold climatic regions . Temperate regions	. Little effect by climate on hardwoods . Very resistant to rain and periodical water . Medium heat insulation . Limited heat storage capacity . Resistant to wind, and storms . Good structural stability . Easy to repair and replace . Medium fire resistant . In hot dry climates the continual expansion and contraction of timber causing deterioration
Soils, Clay, Sand, Shell Adobe	. Hot dry areas	. Risk of damage from direct exposure to continuous rain . Good heat insulation . Large heat-storage capacity . Wind and dust storm proof . Medium resistance to structural damage . Low resistance to himidity . High resistance to fire . Repair necessary at the end of the rainy season

TABLE X (continued)

TYPES OF MATERIALS	AREAS IN USE	REACTION TO CLIMATIC CONDITIONS
Stone	. All climatic types . Most in temperate and cold regions that are near rivers or seas	. Water and rain proof . Wind and storm proof . Fire proof . Low thermal conductivity and high heat storage capacity . High earthquake stability . High resistance to structural damage . Highly used for foundations that are near the water front
Concrete reinforced, concrete	. All climatic conditions	. Extreme adaptability to most climatic conditions . Water and rain proof . Wind and storm proof . Fire-resistant . Low thermal conductivity . Very high heat storage capacity . High earthquake stability . Resistant to structural damage
Concrete blocks	. All climatic conditions	. Low thermal conductivity . Medium heat-storage capacity . Effects of humidity causing creep, reduced by surface treatment (rendering) . Heat expansion important only in hot, dry regions with high temperature differences . Wind and storm proof . Water resistant . Fire resistant . Easy to repair . Limited structural damage

TABLE X (continued)

TYPES OF MATERIALS	AREAS IN USE	REACTION TO CLIMATIC CONDITIONS
Copper	. Excellent in Hot humid regions	. High thermal conductivity . Very high heat storage capacity . Storm and earthquake proof . Air tight . Water proof . Very good durability in all climatic regions . Little danger of corrosion to copper material laid in the ground . Undamaged by plants or animals . Excellent for all corrosion resistant wall and ceiling cladding
Glass	. All types of climatic regions	. Known to deteriorate more rapidly in hot humid than in hot dry . Rain and water proof . Wind proof . Low thermal conductivity . Good heat storage capacity . High risk of breakage during transport, earthquakes, fire impact and deflection . Surface deterioration from dust or sand storm . Double glazing glass window excellent for thermal insulation
Paints	. All climatic regions	. Repainting more frequent in hot humid than hot dry . Extremely varied, depending upon chemical composition . Tendency to chalking with rapid changes between rain and sunshine . Considerable deterioration from continual humidity . Good heat-storage capacity . Low thermal conductivity . Water proof

TABLE X (continued)

TYPE OF MATERIALS	AREAS IN USE	REACTION TO CLIMATIC CONDITIONS
Plastics	. All climatic regions	. Not too desirable for exterior building materials in hot dry zones . Rain and damp proof . Low heat storage capacity . Low thermal conductivity . Air and wind proof . Deterioration accelerated by high and rapid temperatures change . Non-flammable to combustible . Resistance to termites
Asbestos cement sheeting	. All climatic regions, especially in tropical regions	. Water and rain proof . Limited thermal conductivity . Good heat-storage capacity . Wind proof . High resistance to corrosion . Breakable material . Fire resistant . Self-supported roof covering . Becomes brittle in hot dry
Bitumen (Asphalt)	. All climatic regions	. Protecting timber against rot, fungi, and insects . Water proof . Low thermal conductivity . Good heat storage capacity . Air tight . Deterioration through strong sunlight and high temperatures . Good roof insulated materials, but not for tropical climates

TABLE X (continued)

TYPES OF MATERIALS	AREAS IN USE	REACTION TO CLIMATIC CONDITIONS
Plaster and Mortar	. Hot dry and hot humid . Temperate	. Clay mortar usable only on large roof overhangs . Water repellent to waterproof . Relatively low thermal conductivity . Good heat-storage capacity . Fire retarding to fire resistant . Easy repair possible . Durability--drastically reduced by: periodically changing weather conditions, abrasion from sandstorms, extreme solar radiations, and high temperature differences and effects of salt content of air
Aluminum, aluminum sheets	. All temperate and cold regions . Imported goods to tropical regions	. Difficulties of protection against corrosion occurred in hot humid areas . Air-tight and water proof . High thermal conductivity and high heat-storage capacity . Storm and excellent earthquake proof . Greatest deterioration to unalloyed steel by corrosion in hot humid areas . No excessive corrosion in hot dry zones . Low fire-resistant . Risk of ground corrosion, according to composition soil

3. Section and Plan Layout of Suggested Schematic Design for Various Types of Climates

The study of the characteristics of the various types of climates leads us to design for better environment. The study of solar control, wind control, site selection, location and orientation with respect to climate can be used to improve our shelter design, as we mentioned in the previous section (see Climate Controls by Non-mechanical Means in Part IV). With this information in mind, our last section of this study introduced the schematic design of section and plan layouts. These suggested design elements are to help establish a favorable environment, in various climates, by using natural resources (see Plates LIII - LX).

VIII. CONCLUSION

Climate must be an important factor in design for environmental comfort of the residence. In this study we are especially concerned with "natural" means of comfort control For economical reasons, many houses in hot-dry and hot-humid areas of the world are not equipped with mechanical control systems. These residences are designed, depending on natural controls such as sun control devices, weather barriers and ventilation. Site considerations that take advantage of orientation add to this concept of "total" design for a specific environment.

EXPLANATION OF PLATE LIII

Section of suggester schematic design for hot-humid areas.

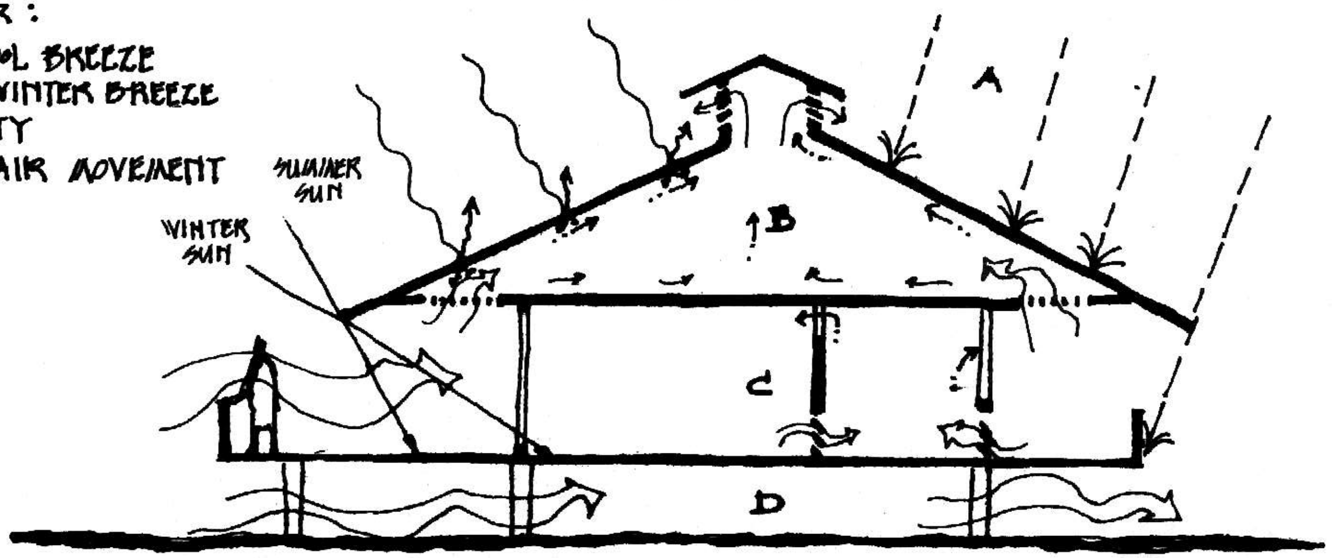
PLATE LIII

HOT-HUMID

SUGGESTED DESIGN ELEMENTS TO HELP ESTABLISH A FAVORABLE ENVIRONMENT IN HOT HUMID CLIMATES USING NATURAL RESOURCES.

DESIGN FOR :

- DIRECTIONAL COOL BREEZE
- DIRECTIONAL WINTER BREEZE
- HIGH HUMIDITY
- NECESSARY AIR MOVEMENT



←〰	SOLAR RADIATION & REFLECTIVE WAVE
←	RADIATION WAVE
←---	RAIN FALL
←·· ←··	HOT AIR (INTERIOR)
← ←	COOL AIR (INTERIOR)
←〰	COOL BREEZE OR AIRWASH
←〰	HOT OR COLD WINTER BREEZE (UNDESIRABLE)

A – LIGHT COLORED SURFACE TO REFLECT HEAT, DEEP OVERHANG TO PROTECT AGAINST RAIN AND SUN, ALSO ALLOWED VENTILATION DURING RAIN

B – VENTILATED AREA TO DISSIPATE CONVECTED HEAT AND MOISTURE

C – OPENED PLAN TO ALLOW AIR VENTILATED THROUGH LIVING AREA, BUT INSECT SCREEN MUST BE PROVIDED

D RAISING FLOOR FOR BETTER EXPOSURE TO BREEZE, AND AWAY FROM DUMP GROUND

EXPLANATION OF PLATE LIV

Section of suggested schematic design for hot-dry areas.

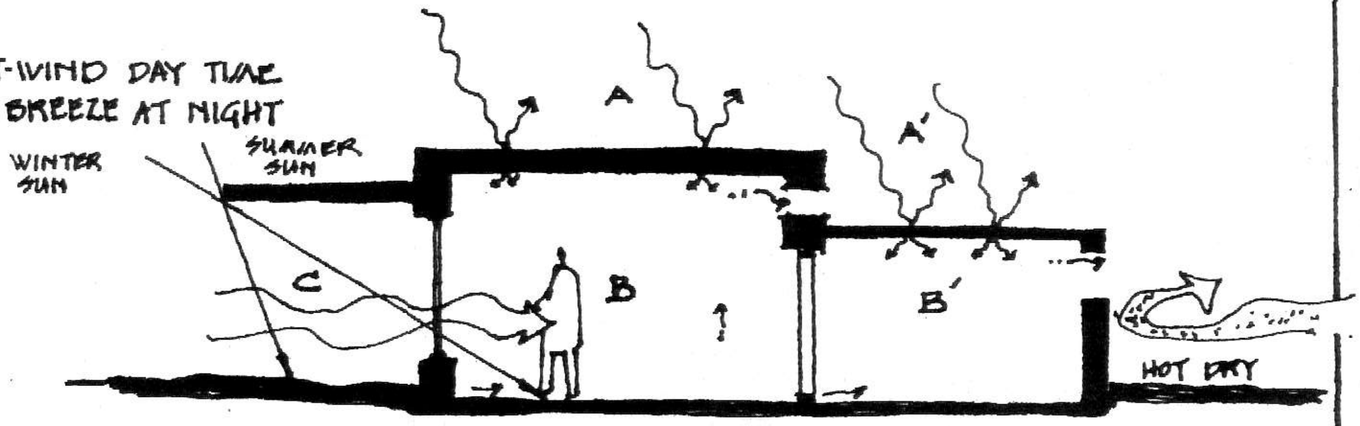
PLATE LIV

HOT-DRY

SUGGESTED DESIGN ELEMENTS TO HELP ESTABLISH A FAVORABLE ENVIRONMENT IN HOT-DRY CLIMATES USING NATURAL RESOURCES.

DESIGN FOR :

- EXTREMELY HOT DAY TIME
- COOL AT NIGHT
- LOW HUMIDITY
- DIRECTIONAL HOT-WIND DAY TIME
- DIRECTIONAL COOL BREEZE AT NIGHT



↜	SOLAR RADIATION & REFLECTIVE WAVE
←----	RAIN FALL
←~	RADIATION WAVE
←.. ←..	HOT AIR (INTERIOR)
← ←	COOL AIR (INTERIOR)
⟸	COOL BREEZE OR AIR WASH (DESIRABLE)
⟸	UNDESIRABLE HOT BREEZ (DAY TIME)

A - WELL-INSULATE OR MASSIVE AND LIGHT OR BRIGHT SURFACE TO DELAY THE ENTRY OF HEAT

A' - LOW HEAT STORAGE CAPACITY MATERIAL TO ALLOW RAPID ACCESS

B - LIVING AREA FOR DAY-TIME USED, WALLS & ROOF RADIATE HEAT AT NIGHT

B' - LIVING AREA FOR NIGHT-TIME USED, NO HEAT STORED OR RADIATED AT NIGHT

C - LARGE OPENING MAY BE PROVIDED, IF IT IS WELL SHADED FROM SOLAR RADIATION.

EXPLANATION OF PLATE LV

Section of suggested schematic design for temperate areas.

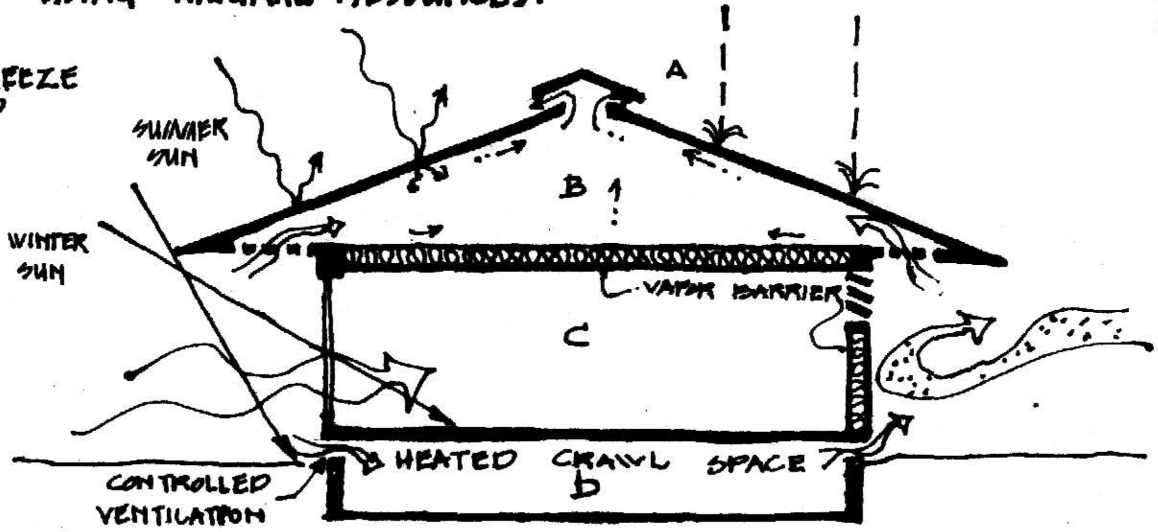
PLATE LV

TEMPERATE

SUGGESTED DESIGN ELEMENTS TO HELP ESTABLISH FAVORABLE ENVIRONMENT IN TEMPERATE CLIMATES USING NATURAL RESOURCES.

DESIGN FOR:

- DIRECTIONAL SUMMER BREEZE
- DIRECTIONAL WINTER WIND
- MODERATE HUMIDITY
- COLD IN THE WINTER
- HOT IN THE SUMMER



- SOLAR RADIATION & REFLECTIVE WAVE
- RADIATION WAVE
- RAIN FALL
- HOT AIR (INTERIOR)
- COOL AIR (INTERIOR)
- COOL BREEZE & AIR WASH
- UNDESIRABLE COLD WINTER BREEZE

A. – LIGHT OR BRIGHT SURFACE TO REFLECT HEAT

B. – VENTILATED AREA TO DISSIPATE CONVECTED HEAT AND MOISTURE.

C. – WELL-INSULATED WALLS, AND CEILING TO PREVENT HEAT LOSS OR GAIN. VENTILATED TO PREVENT MOISTURE CONDENSATION, ALLOW SUMMER BREEZE THROUGH LIVING AREA

D. – VENTILATED AND INSULATED WALLS OF CRAWL SPACE TO PREVENT MOISTURE, AND HEAT LOSS TO THE EARTH

EXPLANATION OF PLATE LVI

Section of suggested schematic design for cold areas.

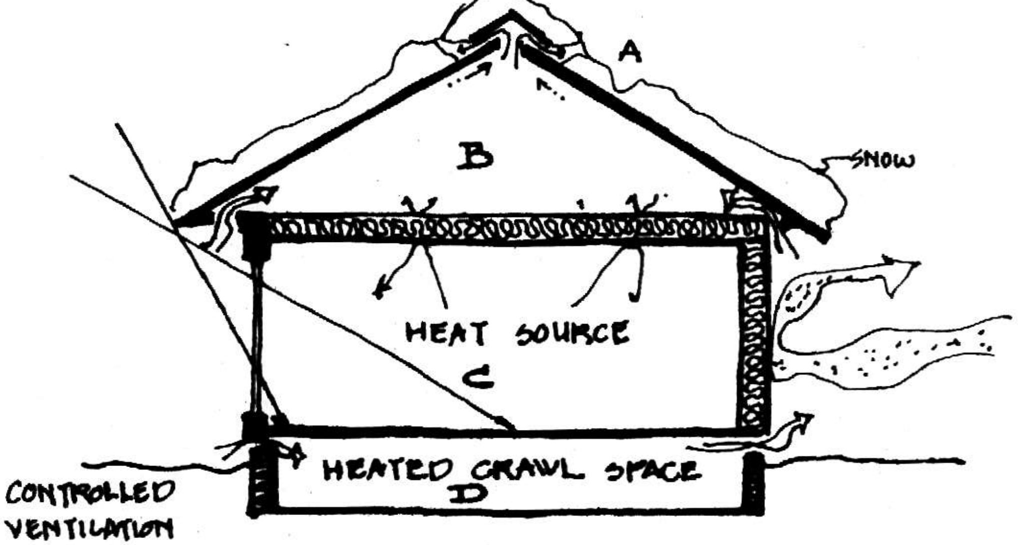
PLATE LVI

COLD

SUGGESTED DESIGN ELEMENTS TO HELP ESTABLISH A FAVORABLE ENVIRONMENT IN COLD CLIMATES USING NATURAL RESOURCES.

DESIGNED FOR:

- EXTREMELY COLD IN WINTER
- WARM WET IN SUMMER
- DIRECTIONAL COLD WIND
- DIRECTIONAL SUMMER BREEZE
- MODERATE HUMIDITY



← SOLAR RADIATION & REFLECTIVE WAVE
← RADIATION WAVE
←--- RAIN FALL
←·· HOT AIR (INTERIOR)
← COOL AIR (INTERIOR)
← DESIRABLE COOL BREEZE
← HOT OR COLD WINTER WIND (UNDESIRABLE)

A – MAY BE A NON REFLECTIVE SURFACE TO ALLOW SOLAR RADIATION INTO THE STRUCTURE. ADDITIONAL STRENGTH TO HOLD UP SNOW

B – VENTILATED AREA TO PREVENT MOISTURE, GABLE LOUVER VENTILATOR MAY ALSO BE USED

C – WELL-INSULATED WALLS AND CEILING TO PREVENT MOISTURE TRANSFER AND HEAT LOSS

D – INSULATED WALLS OF CRAWL SPACE AND ALSO VENTILATED TO PREVENT HEAT LOSS TO THE EARTH, AND PREVENT MOISTURE CONDENSATION

EXPLANATION OF PLATE LVII

Suggested Schematic Plan Layout for Hot-Humid Areas
(Northern Hemisphere)

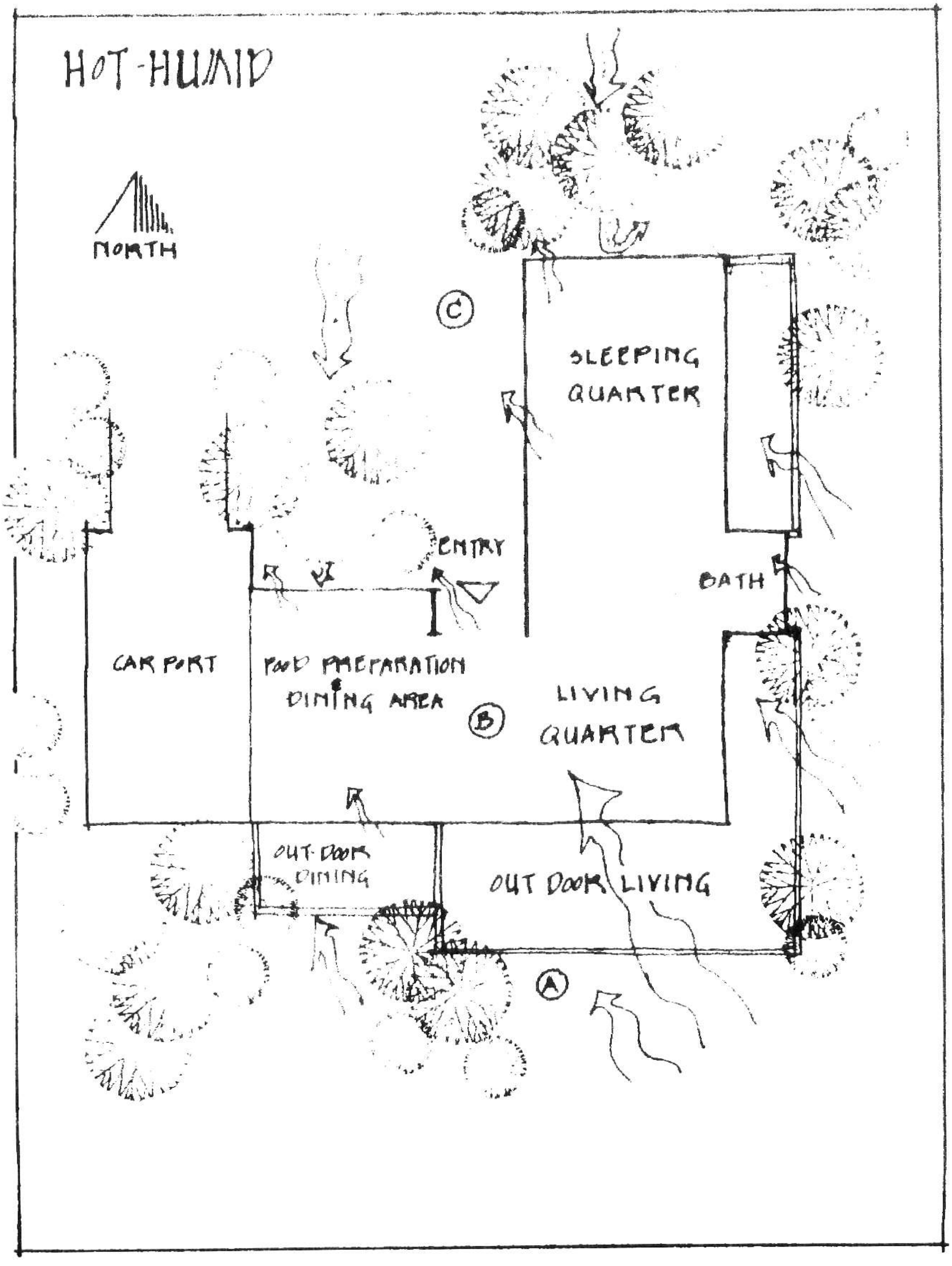
In hot-humid areas, air movement through and around the building is extremely important for relative comfort. Therefore, the arrangement of interior space should be an open plan to admit the summer breeze as much as possible. Outdoor activities and living areas are also important to people in such areas.

(A) In this illustration, large covering of outdoor living and dining areas are provided and oriented to receive the maximum summer breeze from the southeast. They are also protected from solar radiation and rain by the covering roof.

(B) The living area is located on the southeast corner of the building for better exposure to the prevailing breeze and for establishing visual contact with the exterior when the large openings are used. Heat production areas, such as the kitchen, are located on the northwest where the ventilation picks up the heat, moisture, and odor through the north side. The carport is located to block the strong western sun. However, sun protection, such as a louver, should be used in the west wall of the sleeping quarter to stop radiation and at the same time, allow sufficient ventilation. Large openings on this side should be minimized.

(C) The cold winter wind from the north should be stopped by the north walls, however, openings should be designed to allow hot air to escape during the summer, but stop the entering of cold air in the winter. Arrangement of trees can be employed in such a way that they can interrupt the cold winter wind and prevent it from penetrating into the interior space. However, trees should be the type that retain foliage during the winter.

PLATE LVII


HOT-HUMID
NORTH
C
SLEEPING QUARTER
ENTRY
BATH
CAR PORT
FOOD PREPARATION DINING AREA
B
LIVING QUARTER
OUT-DOOR DINING
OUT DOOR LIVING
A

EXPLANATION OF PLATE LVIII

Suggested Schematic Plan Layout for Hot-Dry Areas
(Northern Hemisphere)

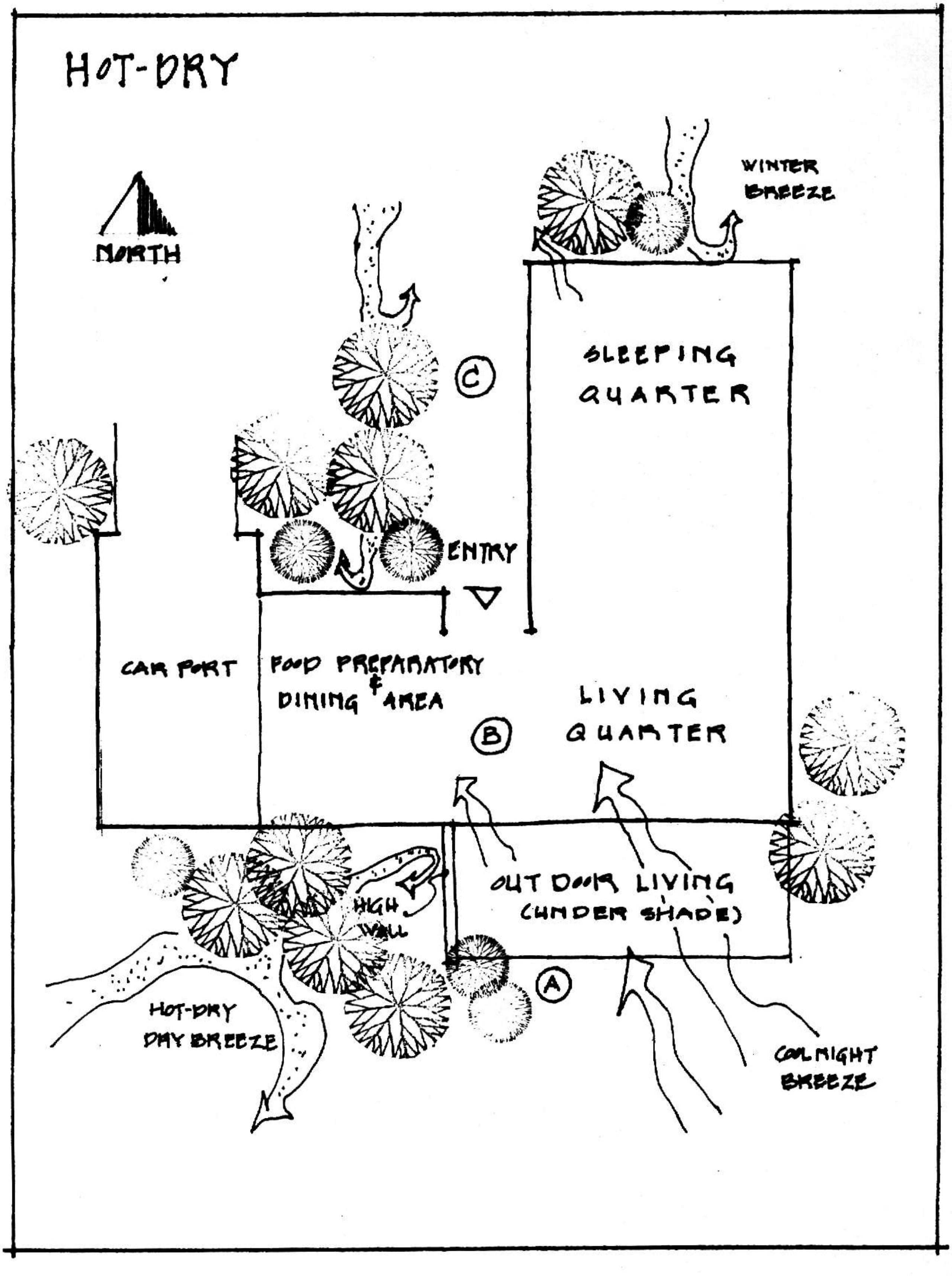
In hot dry areas, shading the openings and proper insulation of the building components are the most important design factors.

(A) It is desirable to have outdoor activities protected by shading devices from the solar radiation and the hot dry breeze from the southwest. Cool breezes usually occur at night from the southeast, where the outdoor living areas should be located. High walls on the west side of this area are employed to block hot dry breezes.

(B) Large openings can be used on the south side of the building, if they are shaded. Ventilation is desirable to dissipate heat and odors from the building through the small openings on the north side of the building.

(C) Openings on the west side should be minimized as much as possible because of the strong western solar radiation. The carport is located on the west side in order to block such radiation. Carefully designed openings have been used on the north side to allow ventilation, but to reject the winter breeze.

PLATE LVIII


HOT-DRY
NORTH
WINTER BREEZE
C
SLEEPING QUARTER
ENTRY
CAR PORT
FOOD PREPARATORY & DINING AREA
B
LIVING QUARTER
HIGH WALL
OUT DOOR LIVING (UNDER SHADE)
A
HOT-DRY DAY BREEZE
COOL NIGHT BREEZE

EXPLANATION OF PLATE LIX

Suggested Schematic Plan Layout for Temperate Areas
(Northern Hemisphere)

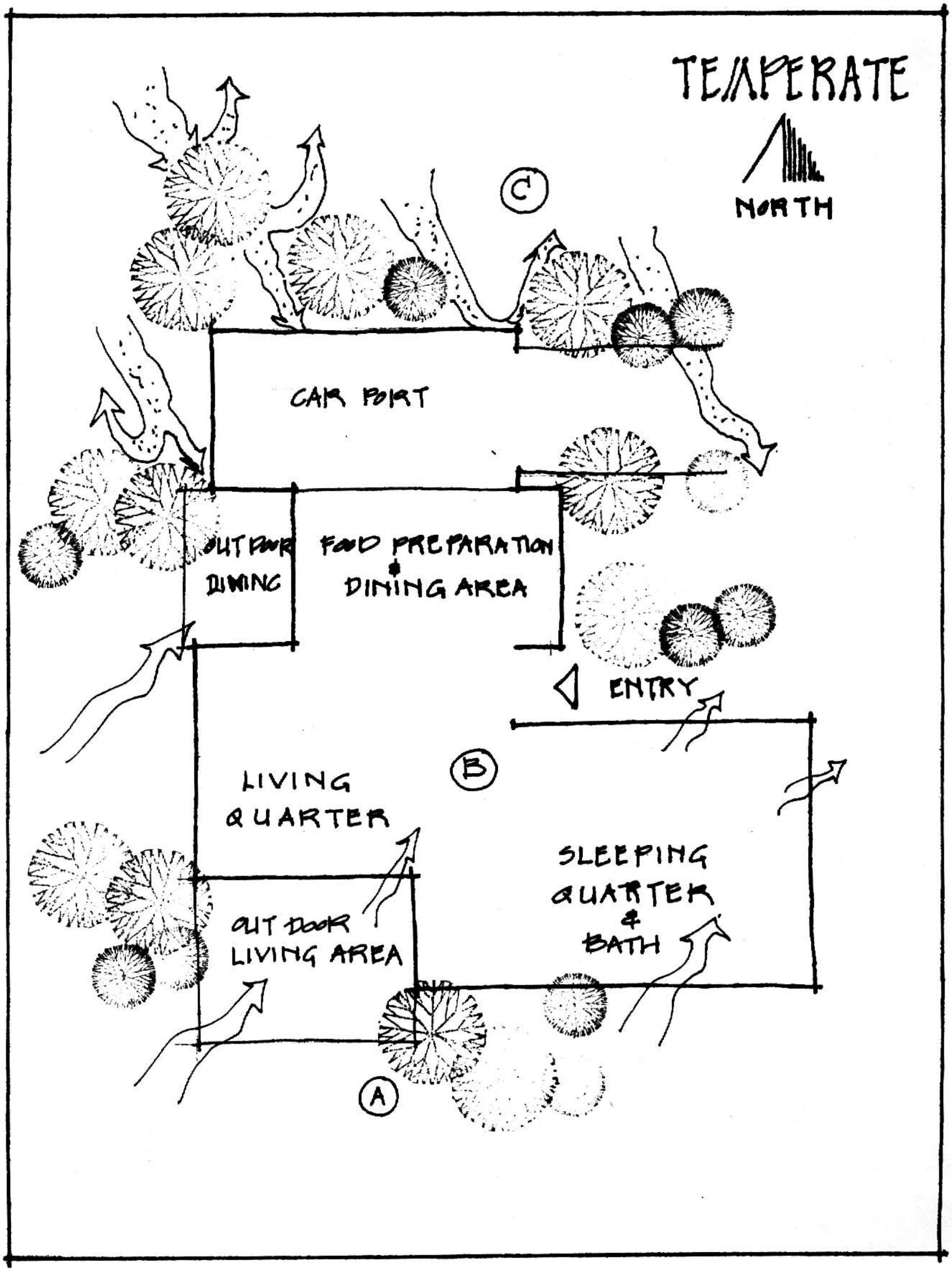
Cooling and heating in the temperate areas are equally important in design consideration. However, the relationships between indoor and outdoor living are also very pleasant in this climate.

(A) In the evening, cool summer wind is desirable to allow in the outdoor and indoor living areas. In this illustration, it blows from the southwest where the living quarters are located.

(B) Sleeping quarters and the bathroom are also exposed to the breeze. Ventilation is necessary to pick up heat, moisture, and to expel odors out of the house in the summer, while in the winter, it helps to get rid of moisture.

(C) The carport is located on the north side. It acts as a barrier by blocking the cold winter wind from the northwest. Natural elements such as trees, can be arranged to cut down, or slow, the cold winter wind velocity. They also provide the shade to the building on the west side in the summer. However, trees should be the type that retain foliage during the winter.

PLATE LIX


TEMPERATE
NORTH
C
CAR PORT
OUT DOOR DINING
FOOD PREPARATION & DINING AREA
ENTRY
B
LIVING QUARTER
SLEEPING QUARTER & BATH
OUT DOOR LIVING AREA
A

EXPLANATION OF PLATE LX

Suggested Schematic Plan Layout for Cold Areas
(Northern Hemisphere)

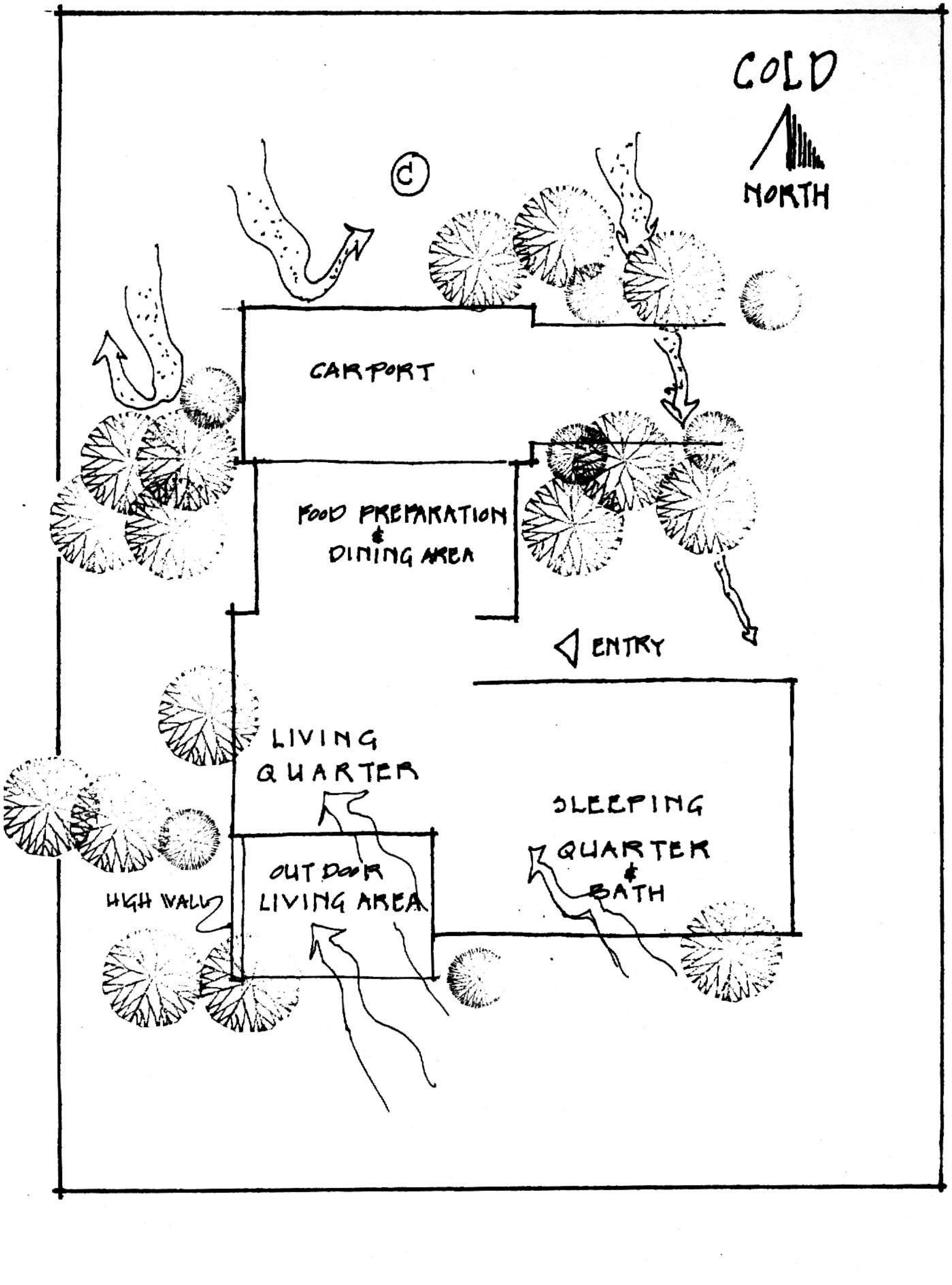
Like the temperate climatic areas, the layout of the plan in cold climatic areas must not allow the cold winter wind to penetrate into the interior space, while solar radiation is very present in this type of climate. Outdoor activities are desirable only during a short period of time during the year.

(A) Outdoor living area may be provided on the south side to take advantage of the summer breeze. High walls on the west side of these areas are used to block the winter breeze.

(B) Sleeping quarters and bathrooms should be well ventilated (to get rid of moisture condensation) in both winter and summer. Sufficient insulation of walls, roof, and floors throughout the structure is extremely necessary. The carport is located to block the winter breeze.

(C) There should be minimum opening areas on the west side because of strong solar radiation and the cold winter wind.

PLATE LX


COLD
NORTH
C
CARPORT
FOOD PREPARATION & DINING AREA
ENTRY
LIVING QUARTER
SLEEPING QUARTER & BATH
OUT DOOR LIVING AREA
HIGH WALL

The investigation of historical examples illustrates a widespread knowledge of "design for environment" developed by man through the ages. Because primitive people lacked efficient insulating materials and modern technology, they were forced to develop designs that incorporated the use of all of these natural elements and principles. They became experts in the use of "natural" means of providing environmental comfort. It is, therefore, advantageous to study the historical development of man's shelters in various climates, including the uses of available materials, and the adaptation of primitive materials and techniques used to provide comfort control.

Now that man has developed many efficient insulating materials and sophisticated temperature control devices, he often neglects to incorporate these basic "Natural" principles of good design. A designer that recognizes natural means of comfort control may help to save considerable energy when deciding upon heating and cooling devices, and thus may also save money in future operating expenses.

In the early part of the schematic design study (Part V), the general requirement of houses in all climatic types are suggested, including those of the roof, walls, and the floors. These building elements which protect the interior space are clearly illustrated in the diagrams. The remainder of the schematic design study is devoted to information and suggestions for the approach to design in four different climates of the Northern Hemisphere, namely: hot-humid, hot-dry, temperate and cold climates. These include the study of the characteristics of each type of climate, the effects of the climate on the people residing in it, efficient building materials for different climates, and finally, the suggested sections and plans of a schematic design for each climatic type.

Following the selection of the site, the orientation of the building, with respect to prevailing wind and solar radiation, should also be taken into design consideration in order to assure relative internal comfort. The suggested plans for different climates are illustrated in diagrams, which include the general arrangement of the interior spaces, the utilization of plants and the orientation of the building in order to receive the maximum advantage of the cool prevailing summer breeze and the minimum amount of the cold winter wind. Furthermore, it is assumed that there is no mechanical air-conditioning systems in the house, and that the houses are located in the Northern Hemisphere. Although the same approach can be taken to design, if mechanical air-conditioning is used, designers should carefully study the climate when selecting materials and developing design techniques, in order to achieve relative comfort at reasonable costs, to the individual and to his society.

BIBLIOGRAPHY

Books

- A -

American Society of Heating, Refrigerating and Air Conditioning Engineers, the ASHRAE Handbook of Fundamentals, 345 East 47th Street, N.Y. 10017, 1967.

American Society of Heating, Refrigerating and Air Conditioning Engineers, the ASHRAE Guide and Data Book, Systems 1970, 345 East 47th Street, N.Y. 10017, 1970.

Andrews, F.T., The Architect's Guide to Mechanical Systems. New York: Reinhold Publishing Corporation, 1966.

Anderson, Cardwell Ross, Primitive Shelter, The Bulletin of Engineering and Architecture, No. 46. Lawrence, Kansas: University of Kansas Publications, 1960.

Angus, T.C., The Control of Indoor Climate. Progressive Architecture Book. New York: Reinhold Publishing Corporation, 1968.

Aronin, Jeffery Ellis, Climate and Architecture. Progressive Architecture Book. New York: Reinhold Publishing Corporation, 1953.

- B -

Bacon, Edmund, Design of Its City. New York: Viking Press, 1967.

Banham, Reyner, The Architecture of the Well-tempered Environment. London: The Architectural Press, 1969.

Bates, Marston, Man in Nature. Foundations of Modern Biology Series, Second Edition. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964.

Battan, Louis J., The Unclean Sky. New York: Doubleday and Company, Inc., 1966.

Berry, F.A. Jr.; Bollay, E.; and Beers, Norman R., Handbook of Meteorology. First Edition, Third Impression. New York: McGraw-Hill Book Company, Inc., 1945.

Blache, P. Vidal de La, Principle of Human Geography. Edited by Martonne, Emmanuel De and translated from the French by Millicent Todd Binghan. London: Constable Publishers, 1952.

Brooks, Charles E.P., Climate in Everyday Life. New York: Philosophical Library, 1951.

Brooks, Charles Franklin, Why the Weather? New York: Harcourt, Brace and Company, 1938.

Building Research Advisory Board, Weather and the Building Industry, BRAB Conference Report No. 1. Washington, D.C.: National Research Council, April 1950.

Building Research Advisory Board, Windows and Glass in the Exterior of Buildings. Publication 478. Washington, D.C.: National Research Council, 1957.

Building Research Station, Some Factors in Window Design. London: Ministry of Technology, March 1966.

- C -

Carrier Air Conditioning Company, Handbook of Air Conditioning System Design. New York: McGraw-Hill Book Company, 1965.

Clayton, Henry Helm, Solar Relations to Weather and Life. Vol. I. Caton, Mass.: The Clayton Weather Service, 1943.

Close, Paul Dunham, Sound Control and Thermal Insulation of Buildings, New York: Reinhold Publishing Corporation, 1966.

Competitive Service Committee, The, Electrical Space Conditioning Concepts. Edison Electric Institute, 750 Third Ave., New York, N.Y., 1965.

Conrad, Victor, Methods in Climatology. Cambridge: Harvard University Press, 1944.

- D -

Daniels, Farrington, Direct Use of the Sun's Energy. New Haven: Yale University Press, 1964.

Danz, Ernst, Sun Protection. New York: Frederick A. Praeger, Publishers, 1967.

Dubos, René, Man Adapting. New Haven and London: Yale University Press, 1965.

- E -

Eckbo, Garrett, The Art of Home Landscaping. New York: F.W. Dodge Corporation, 1956.

- F -

Fenton, Carroll L. and Fenton, Meldred A., Our Changing Weather. Garden City, N.Y.: Doubleday and Company, Inc., 1954.

Fitch, James Marston, American Building: the Historical Forces that Shaped It. Second Edition. Boston: The Riverside Press, 1966.

Fitch, James Marston, American Building: The Environmental Forces That Shape It. Boston: Houghton Mifflin Company, 1972.

Flynn, John E. and Segil, Arthur W., Architectural Interior Systems, New York: Van Nostrand Reinhold Company, 1970.

Fortune, Editors of, The Environment. New York: Harper and Row, Publishers, 1970.

Fry, Maxwell and Dew, Jane, Tropical Architecture. New York: Reinhold Publishing Corporation, 1964.

Fullerton, R.L., Building Construction in Warm Climates. Tropical Handbooks, Vols. I - II. London: Oxford University Press, 1967.

- G -

Gay, Charles M. and Fawcett, Charles De Van, Mechanical and Electrical Equipment for Buildings. Second Edition. New York: John Wiley and Sons, Inc., 1948.

Geiger, Rudolf, The Climate Near the Ground. Cambridge, Mass.: Harvard University Press, 1966.

Givoni, B., Man, Climate and Architecture. New York: Elsevier Publishing Company Limited, 1969.

- H -

Haines, John E., Automatic Control of Heating and Air Conditioning. Second Edition. New York: McGraw-Hill Book Company, Inc., 1961.

Hall, Edward T., The Silent Language. Greenwich, Conn.: Fawcett Publications, Incs., 1961.

Hall Edward T., The Hidden Dimension. Garden City, N.Y.: Doubleday and Company, 1966.

Hann, Dr. Julius, Handbook of Climatology. New York: Harper and Row, Publishers, 1963.

Haurwitz, Bernhard and James M. Austin, Climatology. First Edition. New York: McGraw-Hill Book Company, Inc., 1944.

Hilberseimer, Ludwig, The Nature of Cities. Chicago: Paul Theobald and Company, 1955.

Housing Research, Application of Climatic Data to House Design. Housing and Home Finance Agency, Washington, D.C., 1954.

Huntington, Ellsworth, Civilization and Climate. Third Edition. New Haven: Yale University Press, 1924.

Huntington, Ellsworth, Mainsprings of Civilization. New York: John Wiley and Sons, Inc., 1945.

- I -

Ingles, Margaret, Willis Haveland Carrier, Father of Air Conditioning. Garden City: Country Life Press, 1952.

- J -

Jones, W.R., Air Conditioning Engineering. Glasgow, England: Edward Arnold (Publishers) Ltd., 1967.

- K -

Kell, J.R. and Faber, Oscar, Heating and Air-Conditioning of Buildings. Fourth and Revised Edition. London: The Architectural Press, 1958.

Kendrew, W.G., Climatology. Second Edition. Oxford: Clarendon Press, 1957.

Kinzey, Bertram Jr. and Sharp, Howard M., Environmental Technologies In Architecture. Englewood, N.J.: Prentice-Hall, Inc., 1965.

Koenigsberger, Otto and Lynn, Robert, Roofs in the Warm Humid Tropics. Paper No. I. London: Architectural Association, 1965.

- L -

Lee, Dr. Douglas, H.K., Physiological Objectives in Hot Weather Housing. Washington, D.C.: Housing and Home Finance Agency, 1953.

Longstreth, Thomas Morris, Knowing the Weather. New York: The Macmillan Company, 1943.

- M -

Markham, S.F., Climate and the Energy of Nations. London: Oxford University Press, 1944.

McAdie, Alexander, Man and Weather. Cambridge: Harvard University Press, 1926.

McGuinness, William J.; Stein, Benjamin; Gay, Charles M.; and Fawcett, Charles De Van, Mechancial and Electrical Equipment for Buildings. Fourth and Fifth Editions. New York: John Wiley and Sons, Inc., 1967 and 1971.

McHale, John, The Future of the Future. New York: Battantine Books, Inc., 1971.

Muschenheim, William, Elements of the Art of Architecture. London: Thames and Hudson London, 1965.

- N -

Neuberger, Hans H. and Stephens, F. Briscoe, Weather and Man. New York: Prentice-Hall, Inc., 1950.

Neghswonger, James J., Plants, Man and Environment. Cooperative Extension Service, Kansas State University, Manhatten, Kansas, March 1972.

Nevins, R.G., Criteria for Thermal Comfort. IER Reprint No. 12. Institute for Environmental Research, Kansas State University, Manhattan, Kansas, July-August 1966.

- O -

Olgyay, Victor, Design with Climate. Princeton: Princeton University Press, 1963.

Olivieri, Joseph B., How to Design Heating - Cooling Comfort Systems. Birming, Mish.: Business News Publishing Co., 1970.

Owens-Corning Fiberglas Corporation, The Economics of Sensible Heat Control. Industrial and Commercial Division, Owens-Corning Fiberglas Corp., 717 5th Ave., New York 22, N.Y.

- P -

Proshansky, Harold; Ittelson, William H.; and Rivlin, Leanne G., eds., Environmental Psychology. New York: Holt, Rinehart and Winston, Inc., 1970.

- Q -

- R -

Ramsey, Melvin A., Tested Solutions to: Design Problems in Air Conditioning and Refrigeration. New York: Industrial Press, Inc., 1966.

Rapoport, Amos, House Form and Culture. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969.

Rohles, Frederick H., Jr., Thermal Sensations of Sedentary Man in Moderate Temperatures. IER Reprint No. 34. Institute for Environmental Research, Kansas State University, Manhattan, Kansas, December 1971.

Rohles, Frederick H., Jr., The Ecosystem Complex. IER Reprint No. 35. Institute for Environmental Research, Kansas State University, Manhattan, Kansas, December 1971.

- S -

Saini, Balwant Singh, Architecture in Tropical Australia. Architectural Association Paper No. 6. New York: George Willenborn, Inc., 1970.

Schoenauer, Norbert and Seeman, Stanley, The Court-Garden House. Montreal: McGill University Press, 1962.

Semple, Ellen Churchill, Influences of Geographic Environment. New York: Henry Holt and Company, 1911.

Sert, J.I. and C.I.A.M., Can Our Cities Survive? Cambridge: The Harvard University Press, 1942.

Shapley, Harlow, ed., Climatic Change. Cambridge: The Harvard University Press, 1953.

Sibyl Moholy-Nagy, Native Genius in Anonymous Architecture. New York: Horizon Press Inc., 1957.

Simonds, John Ormsbee, Landscape Architecture. New York: McGraw-Hill Book Company, Inc., 1961.

- T -

Trane Company, The, Trane Air Conditioning Manual. LaCrosse, Wisc., 1958.

Turner, D.F., ed., Windows and Environment. Pilkington Environmental Advisory Service. London: Pilkington Brothers Limited, 1969.

- U -

United Nations, Climate and House Design. Design of Low-Cost Housing and Community Facilities, Vol. 1. Department of Economic and Social Affairs, New York: United Nations Publication, 1971.

- V -

- W -

Wolgensinger, Bernard, Villas in the Sun. Rutland, Vermont: Charles E. Tuttle Company, Inc., 1971.

World Meteorological Organization, Building Climatology. Secretarial of the World Meteorological Organization, Geneva, Switzerland, 1970.

World Meteorological Organization, Urban Climates. Secretarial of the World Meteorological Organization, Geneva, Switzerland, 1970.

Periodicals, Bulletins and Handout Sheets

Burton, Charles, Lecture materials and handouts. Thermal Systems Course. Department of Construction Science, College of Architecture and Design, Kansas State University, Manhattan, Kansas, Spring, 1972.

Emerick, Robert H., "Comfort Factors Affecting Heating Design," Progressive Architecture, October 1951, p. 92.

Emerick, Robert H., "Comfort Factors Affecting Cooling Design," Progressive Architecture, December 1951, p. 97.

Fitch, James M., "How to Live with Western Sun," House Beautiful, November 1951, p. 234.

Holmes, James R., "Harnessing the Sun's Shadows," American Institute of Architecture Journal, January 1961.

Langewieshe, Wolfgang, "Watch Your House," House Beautiful, September 1951.

Langewieshe, Wolfgang, "Different Places Need Different Houses," House Beautiful, January 1951, p. 58.

Langewieshe, Wolfgang, "Your House in Florida," House Beautiful, January 1950, p. 70.

Langewieshe, Wolfgang, "How to Control the Sun," House Beautiful, March 1956, p. 105.

Langewieshe, Wolfgang, "How to Live Comfortably in the Southwest Desert," House Beautiful, April 1950, p. 151.

Langewieshe, Wolfgang, "Summer Heat is Man-Made," House Beautiful, June 1955, p. 112.

Siple, Dr. Paul A., "How to Live with America's Worst Climate," House Beautiful, March 1951, p. 96.

Wright, Henry, "How to Put a Harness on the Sun," House Beautiful, October 1949, p. 130.

Wright, Henry, "When You Air Condition Watch Out for Sun Heat," House Beautiful, March 1954, p. 136.

Wright, Henry Jr., The Thermal Theory of Ventilation. An unpublished manuscript written by Henry Wright Jr., ex-professor of the Environmental Seminar Course, Department of Architecture, College of Architecture and Design, Kansas State University, Manhattan, Kansas, Fall 1971.

______, "Climate Control," Design and Environment, Summer 1971.

______, "Environment and Building Shape," Architectural Forum, August 1954, pp. 104-108.

______, "Heat of Light," American Institute of Architecture Journal, January 1966, pp. 57-68.

______, "How a House Invites the Wind," House Beautiful, May 1953, p. 184.

______, "Micro-Climate," Architectural Forum, Whitney Publication, Inc., March 1947.

______, "Microclimatic Research in Relation to Building Construction," Architectural Forum, March 1947, pp. 114-119.

______, "The Best and the Worst Weather," House Beautiful, April 1954, p. 146.

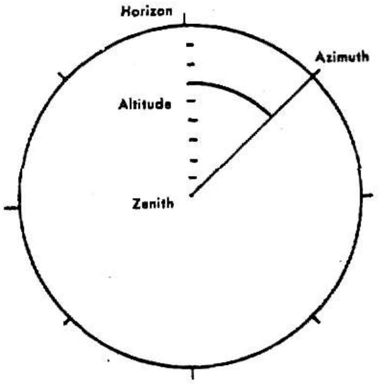
APPENDICES

APPENDIX I

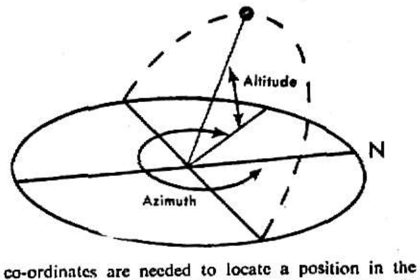
SUN PATH DIAGRAM AND SHADOW ANGLE PROTRACTOR

Solar radiation is welcome when the weather is cold, unwelcome when it is hot. The information in this annex explains how the architect can protect buildings, especially the openings, against direct solar radiation and how he can encourage sun penetration when it is needed to warm the interior.

THE SUN PATH DIAGRAM



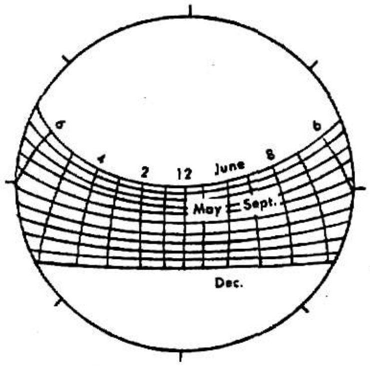
The sun's position as it moves across the sky can best be shown on a map of the sky, the sun path diagram. This diagram consists of a circle, the periphery of which represents the horizon while the centre represents the zenith directly overhead.

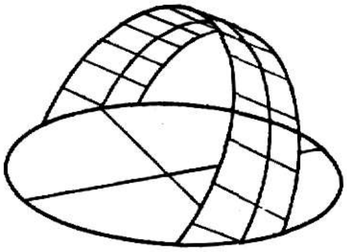


Two co-ordinates are needed to locate a position in the sky. They are called azimuth and altitude. In the sun path diagram the azimuth is shown on an angular scale 0-360° around the circle. It is measured clockwise from the north. The altitude of the sun's position is shown by a series of concentric rings, and is measured upward from the horizon (0°) to the zenith (90°).

SUN'S PATH AND HOUR LINES

The path of the sun across the sky is shown by a series of lines which start at the eastern edge of the circle (sunrise) and finish on the western edge (sunset). The northernmost line represents the sun's path on June 22 (the summer solstice) and the southernmost line represents it on December 22 (the winter solstice). The lines between these represent the sun's path at intervals throughout the year. Each of these lines represents the sun's path for two days of the year, one day during the period from January to June, when the sun's path moves further to the north each day, and the second during the period from June to December when the sun's path moves back to the south.





Sun's path across the sky

The shorter lines that cross the sun's path represent the hours of the day. They show that the sun rises around six o'clock in the morning, crosses the line due north-south at mid-day and sets in the evening around six o'clock. The times given are solar times, which may vary slightly from local time, but the designer can safely ignore this difference. The effect of the difference is negligible.

In theory, a different sun path diagram should be used for each degree of latitude. In practice, one can manage with fewer diagrams. The solar charts for 4° intervals (figure XXXII) will provide sufficient accuracy for most applications.

THE SHADOW ANGLE PROTRACTOR

The shadow angle protractor (figure XXX) is used to find the sizes of vertical and horizontal projections (or reveals) which

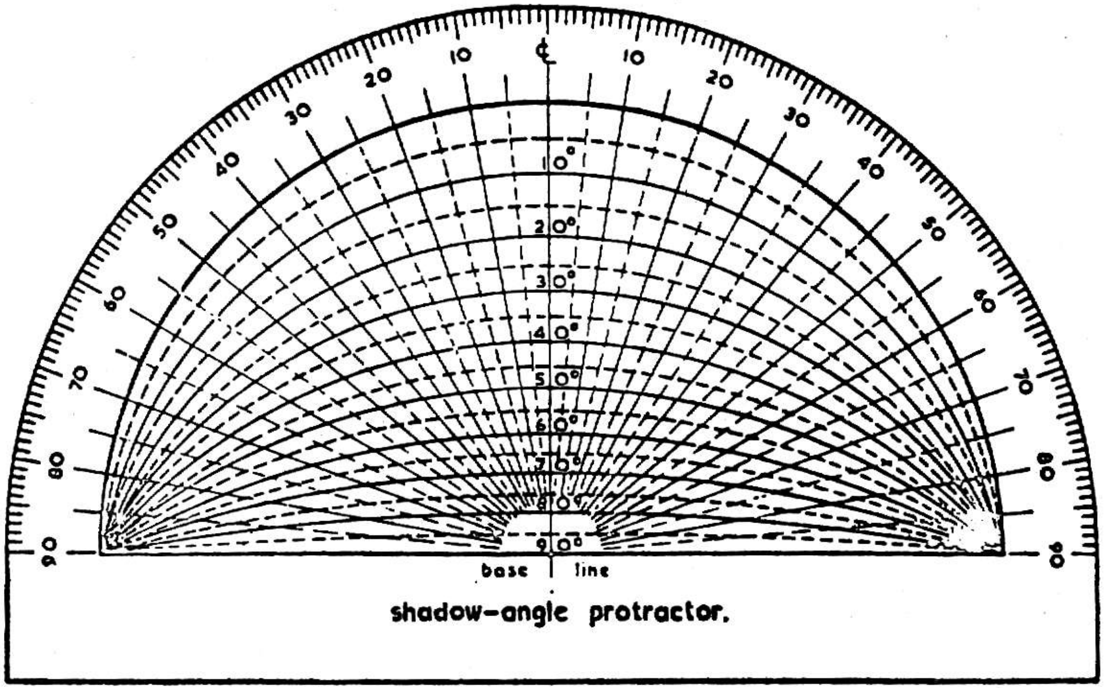
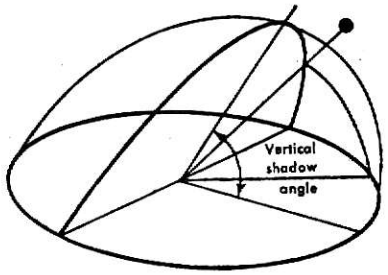
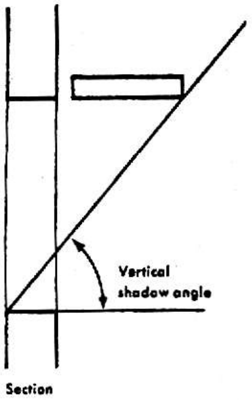


Figure XXX. The shadow angle protractor

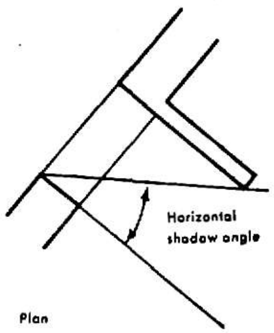


are required to exclude the sun when it is not needed. The shadow angle protractor consists of two series of lines marked on a transparent semi-circle which has the same diameter as the sun path diagram. The first series of lines are curved and show the vertical shadow angles. The second series of lines, which radiate out from the centre, show the horizontal shadow angles. The diameter of the protractor is called the base line.

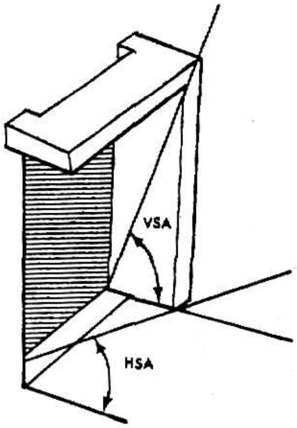
The curved lines represent a number of hypothetical sun paths. If the sun were to follow these paths it would always appear to have the same altitude when seen in section perpendicular to the base line. The angle of the sun seen in section is the vertical shadow angle. It is measured from the horizon (0°) up to the zenith (90°). It should be noted that the sun's vertical shadow angle is equal to the solar altitude only when the sun's rays are perpendicular to the base line.



The shadow angle protractor is placed on the sun path diagram and rotated so that the base line and the curved line, which represents the vertical shadow angle, cover the area of sky obscured by a horizontal projection. The extent of the projection is determined by the vertical shadow angle which is measured in a vertical section at right angles to the wall. It is the angle between the horizontal and a line drawn from the edge of the projection to the sill or the lower edge of the opening.



It is not always possible to exclude the sun by horizontal projections alone. The second series of lines can be used to find the horizontal shadow angles. The horizontal shadow angle is the angle shown on the plan between a line from the inner edge of the opening to a vertical projection beyond it and a line perpendicular to the base line.



A shadow angle protractor may be found in the pocket at the end of this volume.

SHADING PERIODS

When the sun's path for the correct latitude has been found, it is necessary to determine the periods when protection is needed. There are places with some hot and some cold months (see example C. New Delhi, India, in chapter III) where a simple inspection of table 3 will show the months when sun is needed. These months can be marked on the sun path diagram.

There may be other cases where maximum temperatures during the day are comfortable or hot but the nights are cold and some sun may be welcome in the mornings when the air temperature and the interior of the buildings are still cool. This situation is often found in tropical upland climates.

If the sun is to be excluded when it causes discomfort and allowed to penetrate into the interior when it aids comfort, the temperature for each hour of the day has to be found. As hourly readings are not normally published by meteorological observatories, the daily shading time chart (figure XXXI) can be used to find the times when complete sun protection is needed. The steps to find the shading time are explained below:

(*a*) Find the lower limit of the day comfort zone for the month from table 3. This is the shading temperature. A line should be drawn vertically joining this shade temperature on the top and bottom scales;

(*b*) Find the monthly mean maximum and the monthly mean minimum temperature for the month from table 1;

(*c*) Mark the maximum on the top scale and the minimum on the bottom scale and join the two points with a diagonal line;

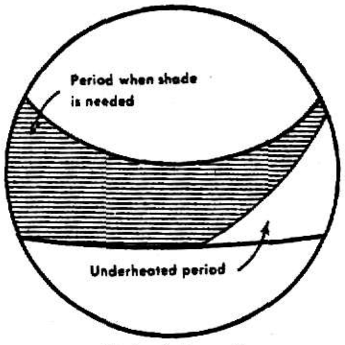
(*d*) Find the point where the diagonal maximum-minimum line crosses the shading time line. From this point draw a horizontal line parallel to the hourly lines to meet the time scale line on the left-hand side. The point of intersection gives the time when complete shading should start.

If the maximum-minimum line does not meet the shading line, it is necessary to differentiate between two possible situations:

(*a*) If the shading line is to the left of the maximum-minimum line, then shading is always needed. The air temperature is never below the comfort zone during this month;

(*b*) If the shading line is to the right of the maximum-minimum line, then complete shading is not essential as the air temperature is always below the comfort zone for this particular month.

The time when shading may end can be found by continuing to the right the line already drawn from the point of intersection. There are many cases where the sun sets before the temperature drops below the comfort zone.



The hatched sun path

Figure XXXI gives the shading times for the different months and these times can be marked on the sun path diagram. Those areas of the sky across which the sun moves when complete shading is needed should be hatched.

When designing shading devices it should be remembered that the change in the path of the sun is symmetrical to the solstices. Each sun path line represents the path of the sun across the sky at two different times of the year.

The same cannot be said about the air temperature. In the northern hemisphere the highest air temperature does not always coincide with the summer solstice nor the lowest with the winter solstice. In many regions, there is a time lag of a month or more. It may be too cold in March but too hot in September or, in composite climates, it may be still too hot in November but distinctly cold in February. In such cases, it is always preferable to provide adequate shading for the overheated period rather than to allow sun to penetrate during the cold period. In more expensive houses adjustable louvres are used to provide a potentially better solution; potentially, because its effectiveness depends on good maintenance and correct use of the adjustable louvres.

When air temperatures are low, the designer should not automatically assume that he needs as much sun penetration as possible. Overheating can occur when the sun shines through large windows even when the external air temperature is well below the comfort zone.

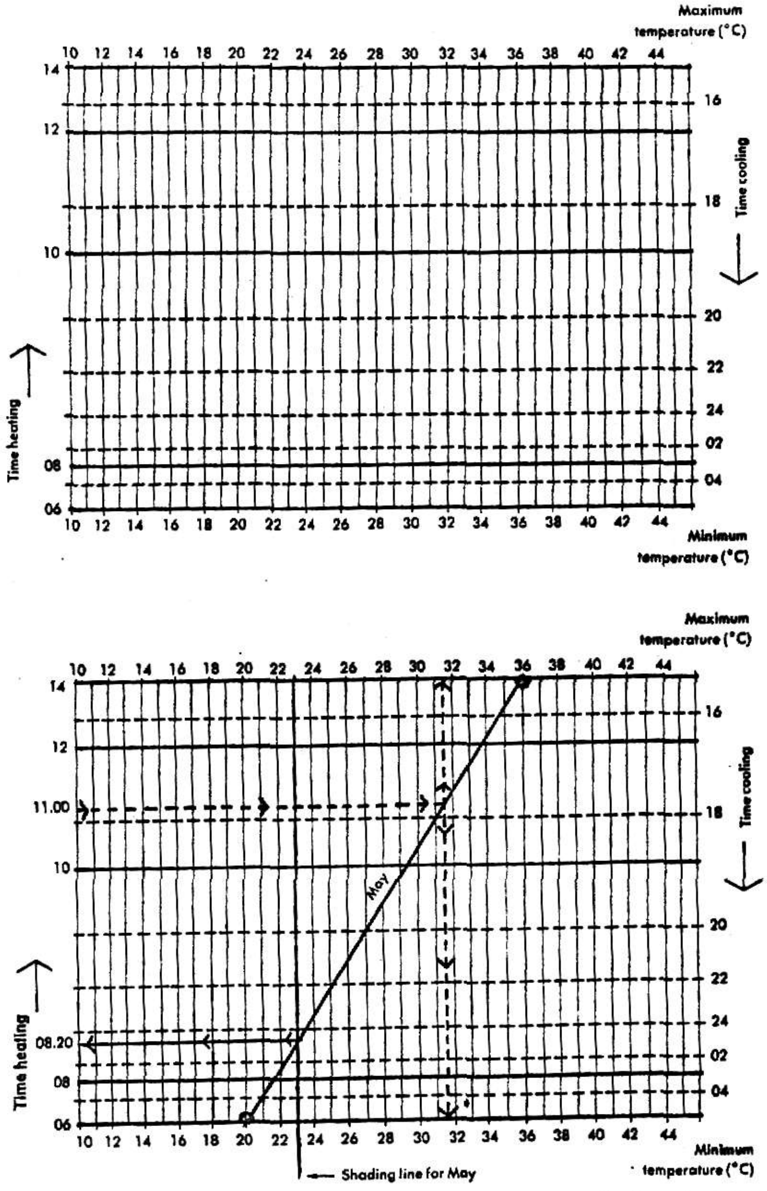
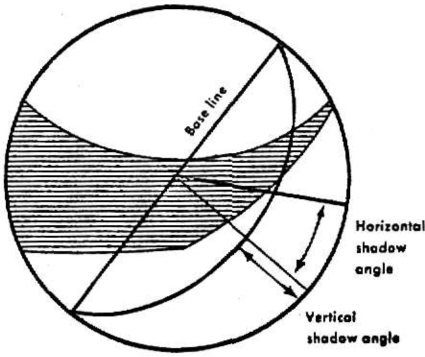


Figure XXXI. (*top*) **Diurnal variation and shading time chart;** (*bottom*) **example of completed chart for Baghdad, Iraq**

NOTE — The broken line with arrows shows how to find hourly temperature swhen they are not available from a meteorological office (*cf.* page 57, (*a*), (ii)).

The protractor is placed over the hatched sun path diagram to decide the horizontal and vertical shadow angles that will exclude the sun when it is not needed. As a rule, the designer can choose from a number of combinations which achieve the same effect, as far as sun protection is concerned. He can then take other considerations into account. In the warm humid tropics it may be desirable to use horizontal projections, such as large overhangs, to protect openings from rain and sky glare. In the hot dry tropics, vertical sun shades are often preferred because they allow a view of the blue sky. There is also the possibility of using a number of small louvres rather than one large one. *Egg-crate louvres are often used to give combined vertical* and horizontal shading. The possibilities are endless and the method for designing shading devices for windows outlined here gives the designer a large degree of flexibility.



Sun path diagram and protractor

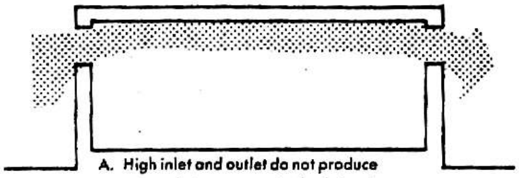
Three further points should be mentioned in conclusion. First, the shading device affects other window functions such as lighting and air flow. Secondly, the material used should be reflective and as light as possible to avoid the storage and reradiation of heat through the opening. Finally, it is extremely difficult, and often impossible to design effective sun shades for west-facing windows in tropical and subtropical regions.

The solar charts in figure XXXII are reproduced with the permission of the Director, Building Research Station, Garston, Watford, Hertfordshire, England.

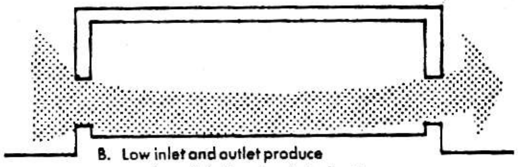
They are marked for the northern hemisphere, but can be used also for locations south of the equator by reading the charts upside down, reversing the N-S and E-W signs and the hour lines.

Source : United Nation, Department of Economic and Social Affair, Design of Low-Cost Housing and Community Facilities, Vol. I, Climate and House Design, (New York; United Nation Publication, 1971) pp. 67-72.

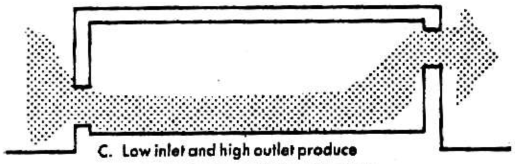
APPENDIX II



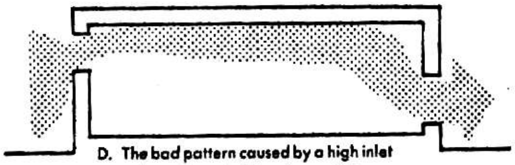
A. High inlet and outlet do not produce good air movement at body level



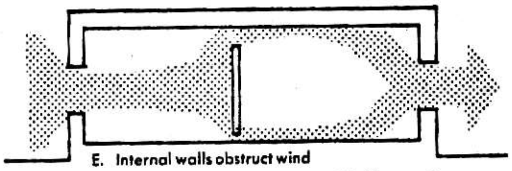
B. Low inlet and outlet produce a beneficial low-level wind pattern



C. Low inlet and high outlet produce a good pattern of air movement

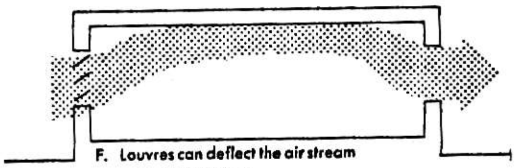


D. The bad pattern caused by a high inlet is not corrected by a low outlet

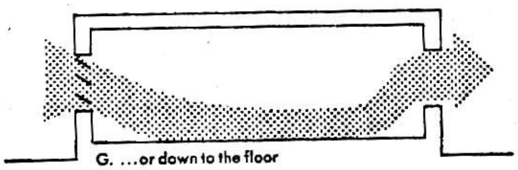


E. Internal walls obstruct wind

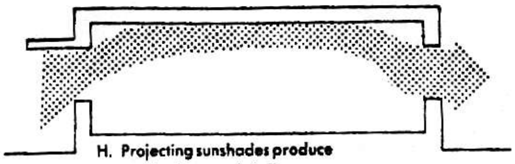
A to E: Sections showing cross-ventilation patterns



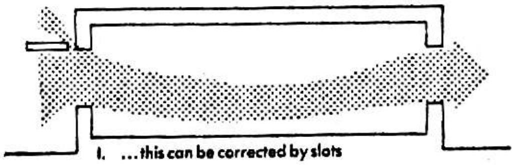
F. Louvres can deflect the air stream up to the ceiling...



G. ...or down to the floor

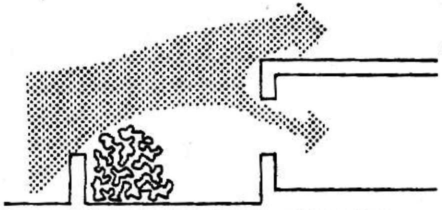


H. Projecting sunshades produce a bad upward air flow...

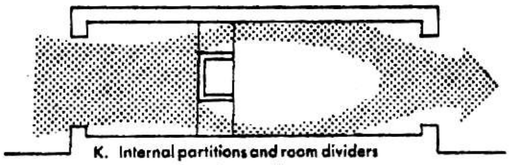


I. ...this can be corrected by slots in the projection

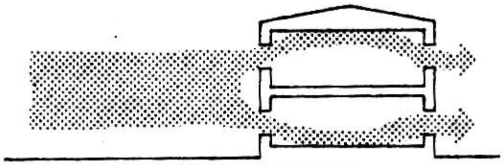
F to I: Sections showing the effect of louvres and sunbreakers on air movement



J. Bushes and other external obstructions can reduce the air flow



K. Internal partitions and room dividers can create large still areas



L. Air flows differ on different levels

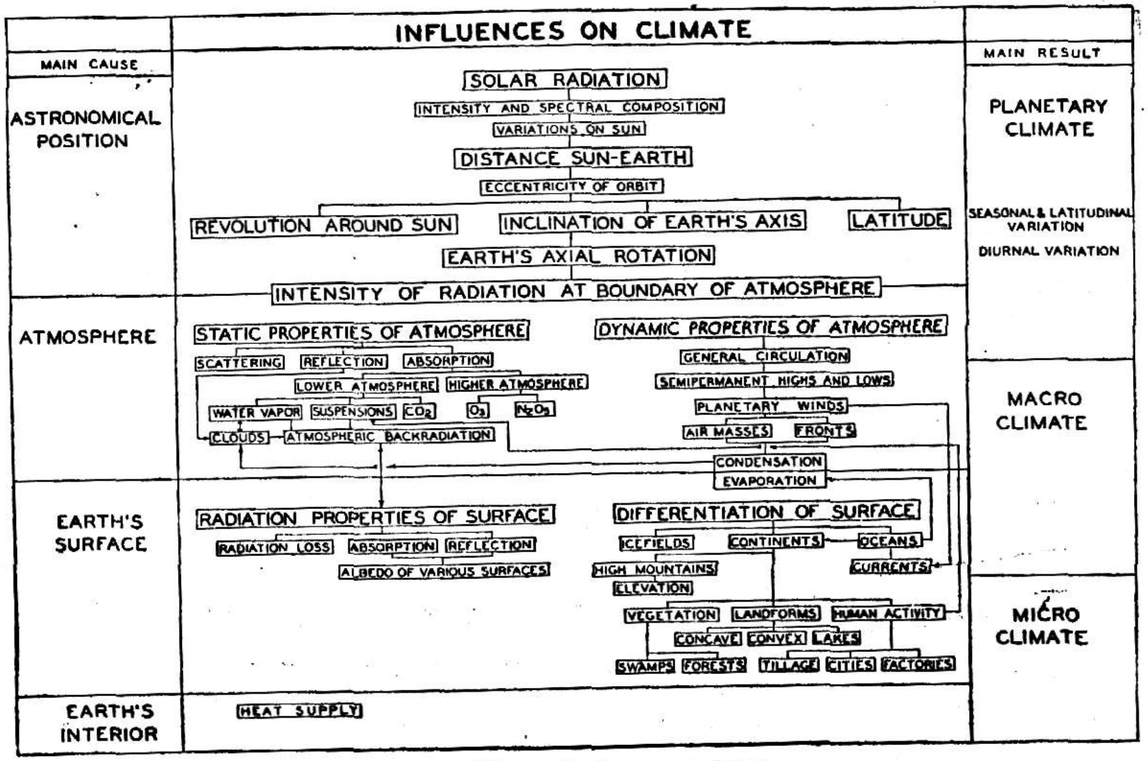
M. Clear-storey ventilation will not improve air movement at low level

J to M: Sections showing the effect of obstructions on air movement

Air flow patterns through single-banked rooms for various sizes and positions of openings and partitions

Source: United Nation, Climate and House Design, (New York; United Nation Publication, 1971) p. 62.

APPENDIX III

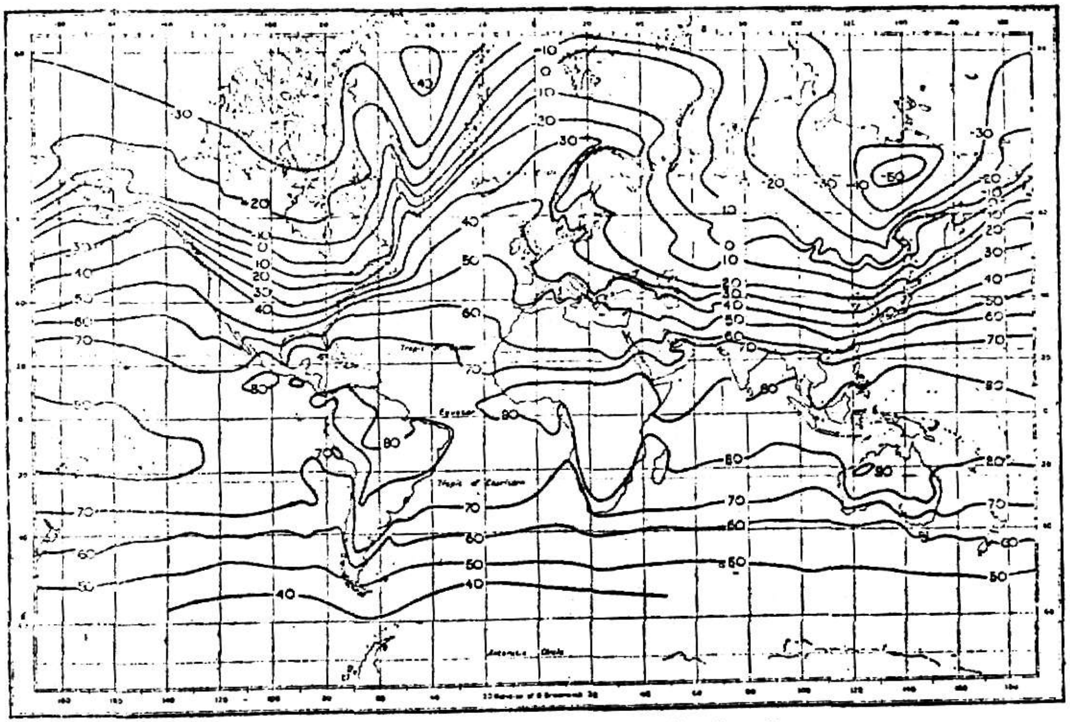


-Scheme of influences on climate.

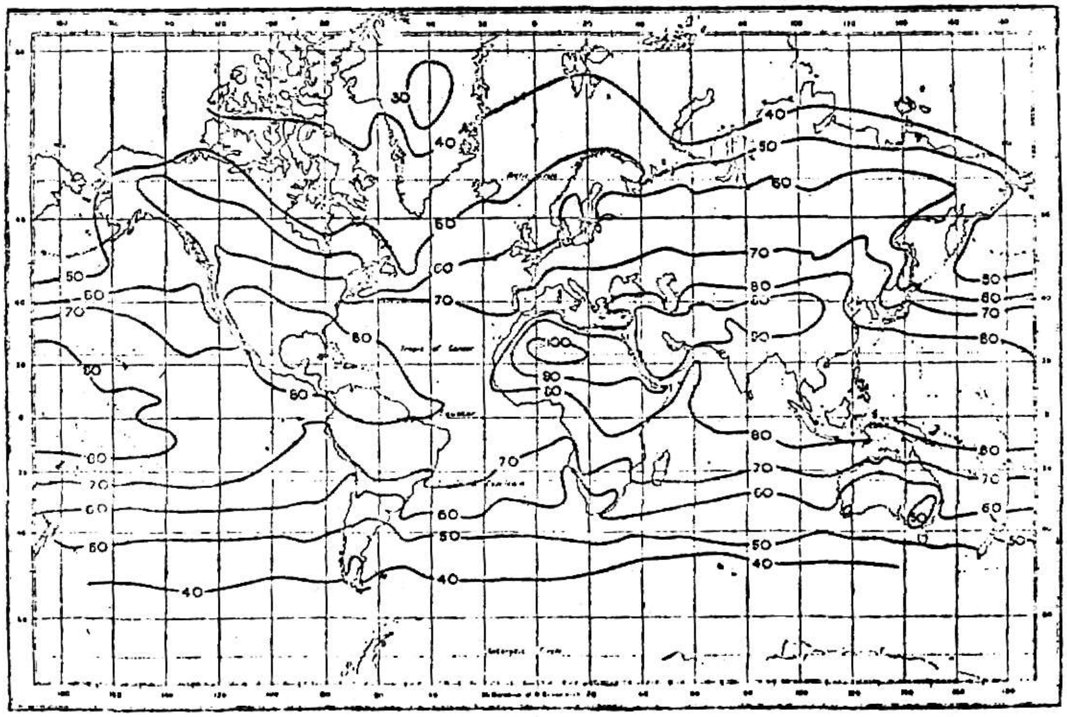
Source:

F. A. Berry, Bollay and Beers, Handbook of Meteorology, (New York; McGraw-Hill Book Company, Inc., 1945). p. 963.

APPENDIX IV

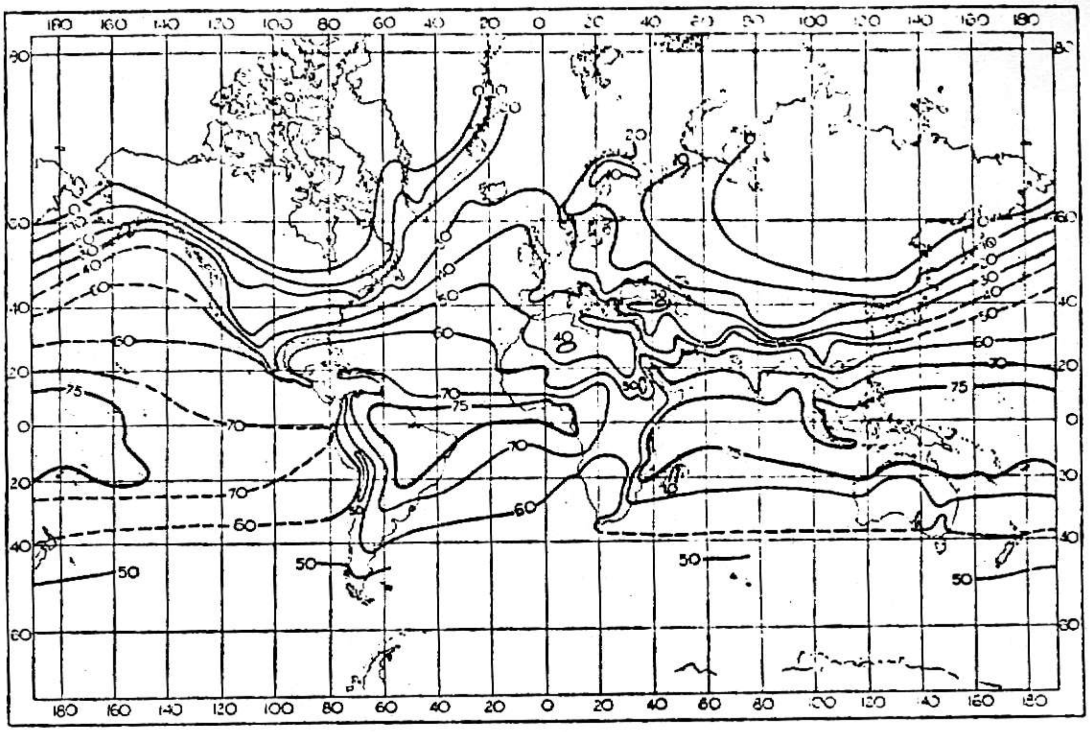


-Average temperature distribution, January.

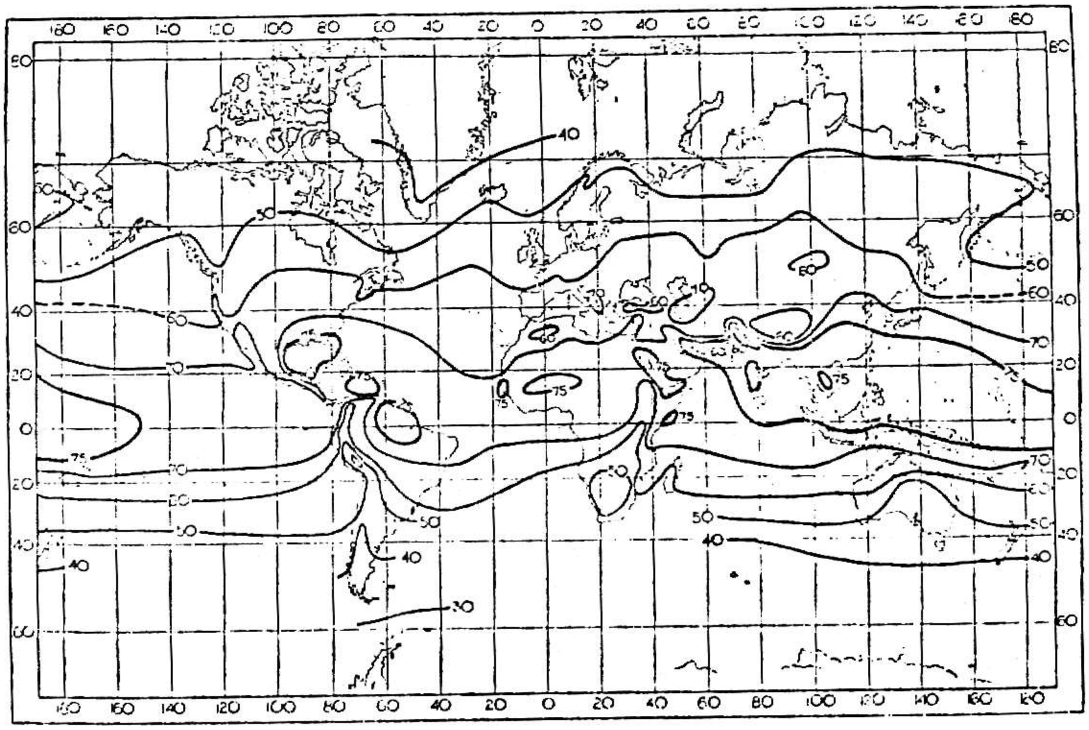


-Average temperature distribution, July.

APPENDIX V

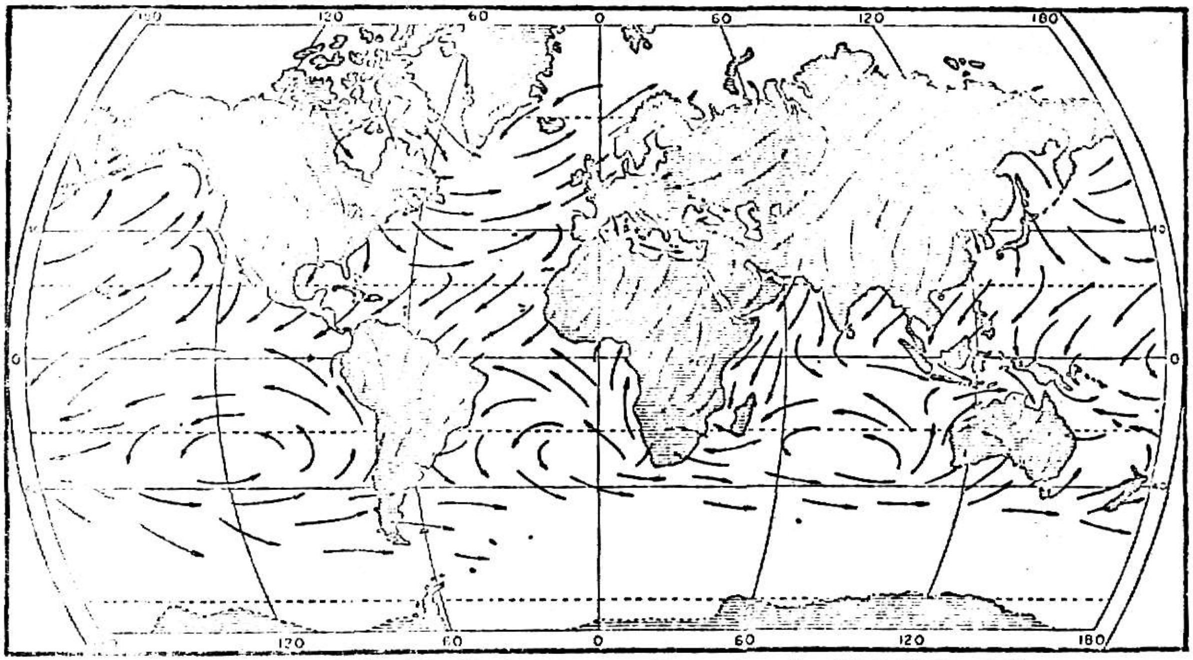


-Mean wet-bulb temperature, January.

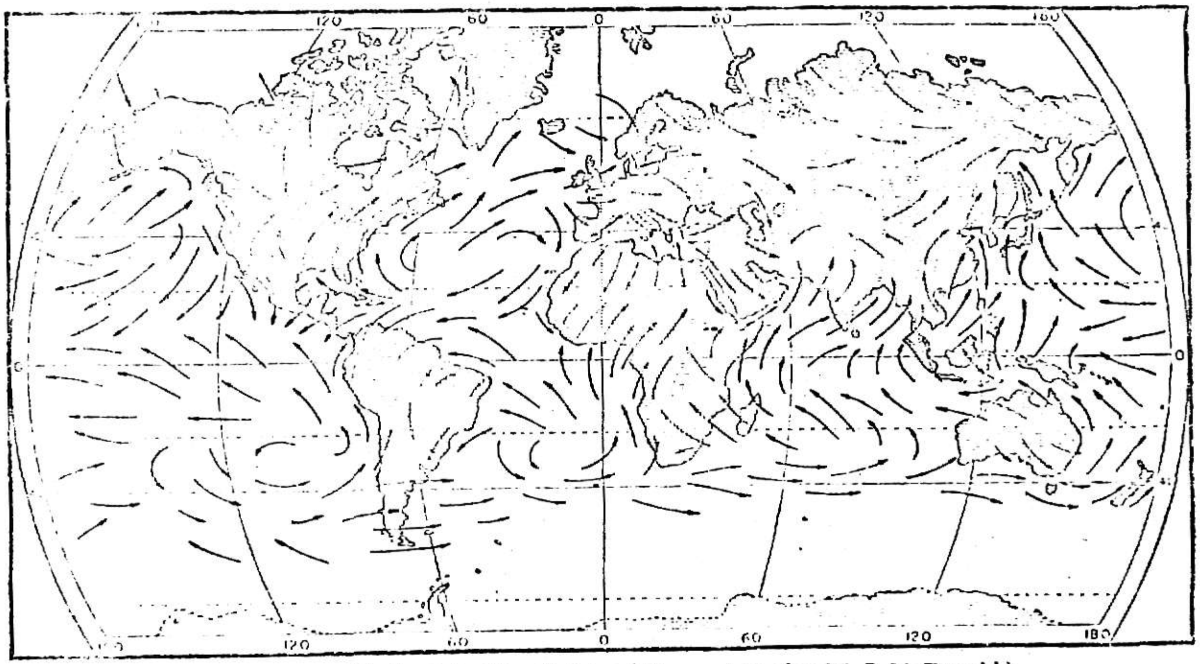


·Mean wet-bulb temperature, July.

APPENDIX VI



—Winds of the World, January. (Ocean data after W. F. McDonald.)



—Winds of the World, July. (Ocean data after W. F. McDonald.)

APPENDIX VII

WIND CHILL CHART

WHAT THE THERMOMETER ACTUALLY READS

WIND SPEED (MPH) ↓	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
	WHAT IT EQUALS IN ITS EFFECT ON EXPOSED FLESH											
CALM	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
5	48	37	28	16	6	-5	-15	-26	-36	-47	-57	-68
10	40	28	16	4	-9	-21	-33	-46	-58	-70	-83	-95
15	36	22	9	-5	-18	-36	-45	-58	-72	-85	-99	-102
20	32	18	4	-10	-25	-39	-53	-67	-82	-96	-110	-124
25	30	16	0	-15	-29	-44	-59	-74	-83	-104	-113	-133
30	28	13	-2	-18	-33	-48	-63	-79	-94	-109	-125	-140
35	27	11	-4	-20	-35	-49	-64	-82	-98	-113	-129	-145
40	26	10	-6	-21	-37	-53	-69	-85	-102	-116	-132	-148

DANGER

GREAT DANGER

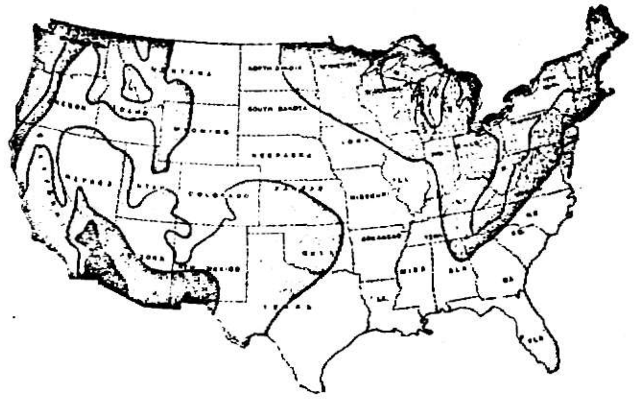
←LITTLE DANGER IF PROPERLY CLOTHED→ ← DANGER OF FREEZING EXPOSED FLESH →

Adapted from U. S. Army Chart

APPENDIX VIII

TEMPERATURE AND HUMIDITY - U.S.A.

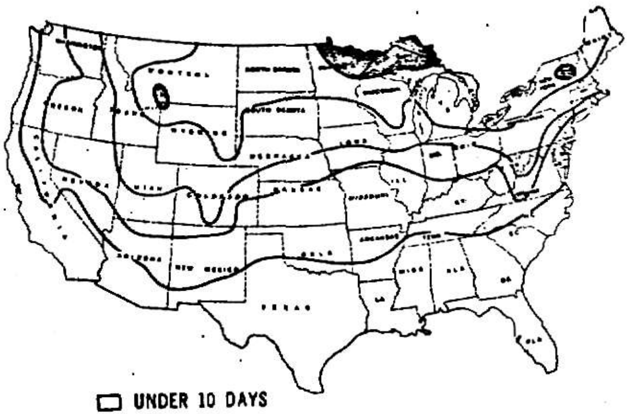
Sunshine



■ OVER 90%
▩ 80-90
▣ 70-80
☐ 60-70
▨ 50-60
▧ 40-50

Annual percentage of possible sunshine

Snowfall



☐ UNDER 10 DAYS
☐ 10-40
☐ 40-60
☐ 60-100
☐ 100-120
■ OVER 120

Average annual number of days with snow cover

(One inch or more)

We suggest that, when traveling in winter, you keep your radio tuned on weather reports.

Temperature and humidity

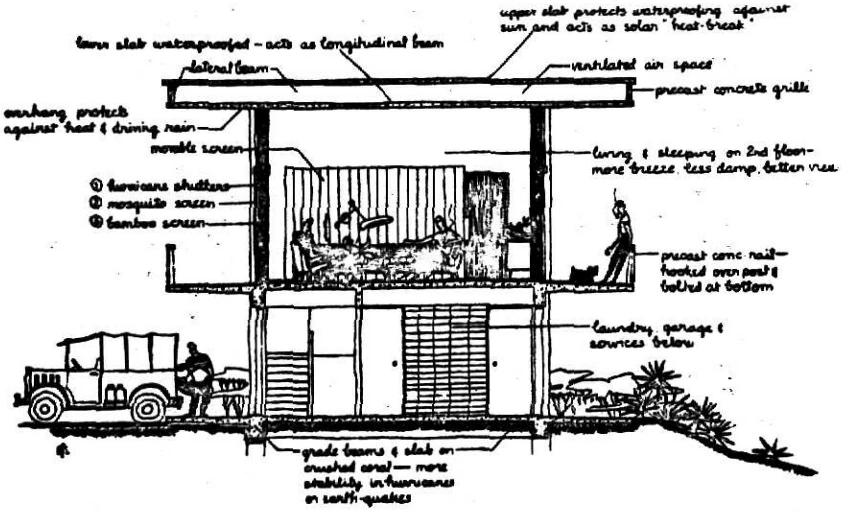
PRINCIPAL CITIES OF THE UNITED STATES	JANUARY Temperature Avg. Max.	JANUARY Temperature Avg. Min.	JANUARY Avg. Humid-ity	APRIL Temperature Avg. Max.	APRIL Temperature Avg. Min.	APRIL Avg. Humid-ity	JULY Temperature Avg. Max.	JULY Temperature Avg. Min.	JULY Avg. Humid-ity	OCTOBER Temperature Avg. Max.	OCTOBER Temperature Avg. Min.	OCTOBER Avg. Humid-ity
CHICAGO	33°	19°	75.5%	57.4°	40.5°	66.5%	84.1°	67.1°	66.5%	63.4°	46.7°	71.5%
DENVER	42.1	14.8	52.5	60.5	32.3	44	88.4	57.4	42	66.6	36.2	41
HOUSTON	63.6	43.6	76	78	59	78.5	92.1	73.8	67.5	82.3	60.4	77
LOS ANGELES	63.8	45	58	66.9	51.9	70.5	75.9	62.3	77.5	73	56.8	76
MIAMI	75.8	57.9	80	82.6	65.8	74.5	88.8	74.7	79.5	84.7	70.9	81
NEW ORLEANS	64.4	44.8	80	77.7	58.1	77	90.6	72.6	83	80.3	60.5	79.5
NEW YORK	39.5	26.9	64.5	59.6	43.1	63	85.3	68.2	70	66.3	50.3	69.5
SAN FRANCISCO	55.8	45.5	75	61.9	49.5	69.5	64.3	53.3	80	68.3	54.4	70
SEATTLE	45.6	36.8	77	59.4	44.1	74	75.1	56.1	68	60.4	48.3	79.5
WASHINGTON, D.C.	44.3	29.5	44	65.8	45.6	53.5	87.0	69.3	66.5	68.3	49.6	70
YELLOWSTONE NATIONAL PARK	25	1		44	17		78	39	34	52	27	51

The relationship between temperature and humidity usually affects personal comfort. The relative humidity figures shown in the chart indicate the average percentage of moisture in the air. When the relative humidity reaches 75% or more, the discomfort of high temperatures is increased. High temperatures are usually more tolerable when the humidity figure is low.

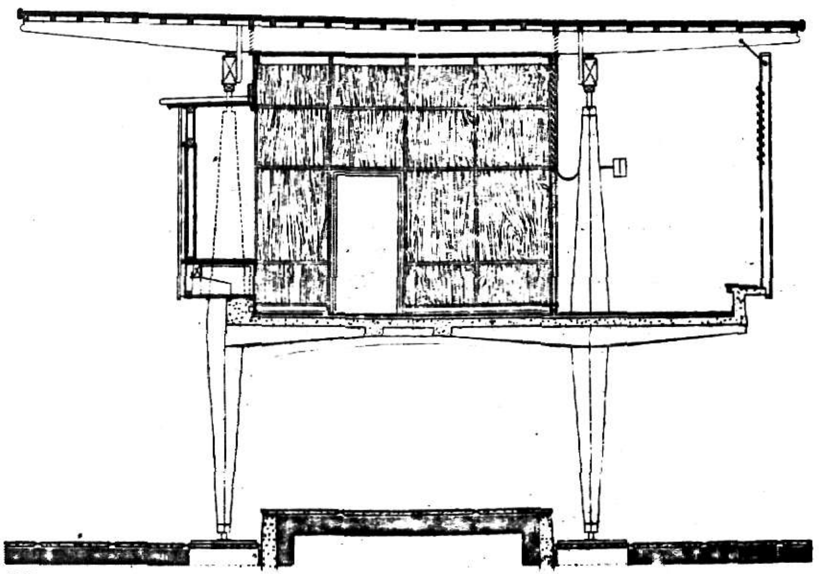
Source: Conoco Touraide, Interstate Travel Guide, U.S.A., 1969, p.5

APPENDIX IX

American recommendations for building houses for consultants in the humid



U.S.Embassy, Accra, Ghana (Architect Harry Weese & Associates)



Source: Georg Lippsmeier, Building in the Tropics, (Germany: Verlag Georg D.W. Callwey, Munchen, 1969)

APPENDIX X

TABLE XI—*Summary of Principles for Warm Humid Environments and Important Applications*

Principles	Important applications	Principles	Important applications
Reducing human heat production		*Promoting losses from body by evaporation*	
Convenience of arrangement. Ease of cleaning.	Convenient storage space. Convenient plan and conservation of floor space. Convenient facilities. Easily cleaned surfaces, especially floor.	Ventilation (volume flow). Air movement (velocity of flow). Dehumidification.	Wood, stone, or other material of low diffusivity for roof. Ceiling height generally not over eight feet. Maximum wall openings for breeze, with blinds, louvres, etc. against rain. Cross ventilation directed and without obstruction. Ventilation of roof space and spaces between successive roofing layers. Turbulence-producing fans. Dehumidification by refrigeration or absorption.
Reducing gain and promoting losses from body by radiation	Shade trees, especially to roof. Shade bushes etc., especially to E. and W. exposures, but without obstructing wind.	*Reducing heat liberation in building*	
External shade. Reduced ground reflection. Attached shade. Water cooling of exterior. Minimal solar projection. High reflectivity of exterior. Convection over surfaces exposed to radiation. Insulation (capacity type) to roof. Convection over inner surfaces. Low emissivity of inner surfaces. Moderate ceiling height.	Separation of buildings. Vegetation over ground. Eaves and other horizontal projections on equatorial exposures. Awnings, verandahs, etc., especially on equatorial exposures. Vertical projections beside window openings on equatorial exposure. Water spraying or water layer on roof in dry weather. Minimum solar projection of roof. Light color or polished metal for surfaces exposed to solar radiation. Avoid parapets and mutual interference of roof structures to wind.	Minimize heat and vapor liberation. Remove liberated heat and vapor.	Capacity insulation around oven and firebox. Narrow air space lined with aluminum foil in oven wall. Liquid or gas fuel, or power, where economically feasible. Vent to outside over stove. Vents and infrared screens for lamps.

Source: Dr. Douglas Lee, Physiological Objectives in Hot Weather Housing, (Washington D.C.; Housing and Home Finance Agency, 1953) p. 56

APPENDIX XI

TABLE XII —*Summary of Principles for Hot Dry Environments and Important Applications*

Principles	Important applications	Principles	Important applications
Reducing human heat production Convenience of arrangement. Ease of cleaning.	Convenient storage space. Convenient plan and conservation of floor space. Convenient facilities. Easily cleaned surfaces.	*Reducing gain and promoting losses from body by conduction* Insulation. Controlled ventilation. Ventilation of roof spaces. Ground cooling. Evaporative cooling. Refrigerant cooling.	Avoid parapets and mutual interference of roof structures to wind. Wood, earth, stone, or other material of low diffusivity for roof. Ceiling height generally not over 8 feet. Continuous walls, with capacity insulation where exposed to radiant load. Doors, windows, etc., fashioned for both tight closing and easy opening. Ventilation of roof space and spaces between successive roofing layers. Water blinds, or box coolers with fans. Air intake through earth tunnels. Basement construction. Air conditioning by refrigeration.
Reducing gain and promoting losses from body by radiation External shade. Reduced ground reflection. Attached shade. Water cooling of exterior. Minimal solar projection. High reflectivity and re-emission of exterior. Convection over surfaces exposed to radiation. Insulation (capacity type). Convection over inner surfaces. Low emissivity of inner surfaces. Moderate ceiling height.	Shade trees where possible, especially to roof. Shade bushes where possible, especially to E. and W. exposures. Contiguous building in E.-W. rows or consolidated. Noninhabited wings to E. and W. exposures to provide shade. Vegetation over ground where possible. Dark color for ground exposed to sun. Eaves and other horizontal projections on equatorial exposures. Awnings, external shades, shutters, etc., especially on equatorial exposures. Vertical projections beside window openings on equatorial exposures. Water spraying of roof and walls exposed to radiant load. Water layer on flat roof. N.-Facing slab or tall square shape for inhabited building. Light color for surfaces exposed to solar radiation.	*Reducing heat liberation in building* Minimize heat liberation. Remove liberated heat.	Capacity insulation around oven and firebox. Narrow air space lined with aluminum foil in oven wall. Liquid or gas fuel, or power where economically feasible. Vent to outside over stove. Vents and infrared screens for lamps.

Source: Dr. Douglas Lee, Physiological Objectives in Hot Weather Housing, (Washington D.C.; Housing and Home Finance Agency, 1953) p. 46.

DESIGNING FOR CLIMATE
AND ENVIRONMENTAL CONTROL

by

MANAD ARAYAPAT

B.Arch., Kansas State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF ARCHITECTURE

Department of Architecture

KANSAS STATE UNIVERSITY
Manhatten, Kansas

1973

Architecture, in general, is the art and science of building. It has also been defined as man's created response to the basic need for shelter. The architect has a responsibility to provide thermal, physical and psychological comfort for the environment which he creates. Therefore, developments in architecture are towards the improvement of human comfort.

There are many factors which affect human comfort, but one of the most important factors is climate. Climate affects our way of living, our social and cultural activities, and our food supply. The effects of climate on both internal and external environment are the subjects to be studied by the psychologist, engineer, and architect. The designer and architect should at first study the climatic condition of the local site as an important design element, before considering the mechanical systems necessary for comfort control.

There are three main objectives in this study. First, the objective is to introduce the nature of the climate, in general. Secondly, an architectural approach to design for various climates is developed. The third objective is the suggestion of an approach to the design of residences that will help to control objectionable natural elements, and which also uses favorable natural elements to create a suitable and pleasurable environment.