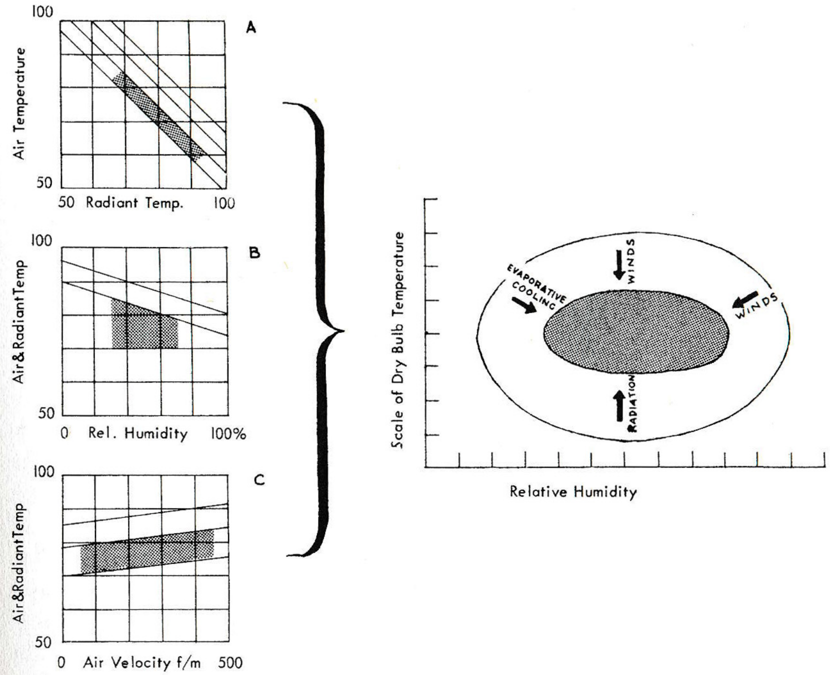
DESIGN WITH CLIMATE

BIOCLIMATIC APPROACH TO ARCHITECTURAL REGIONALISM

BY VICTOR OLGYAY



38. Interrelationship between climate elements.

The actual relative magnitude of body heat production and heat interchange with the environment may vary within wide limits. The vital processes of the body are accompanied by considerable energy exchange. This energy is derived from the oxidation of foodstuffs and is utilized with a gross efficiency of the order of 20%, the remaining 80% of the energy is expended as heat. Even when the body is completely at rest and in warm surroundings its heat production does not fall below a certain minimum level—the basal metabolism—usually taken as about 290 Btu/hr for an average person. This figure rises to 400 Btu/hr for sedentary activities, to 760 walking 2 mph, to 1,400 walking 4 mph, and to 3,000–4,800 at maximum exertion.

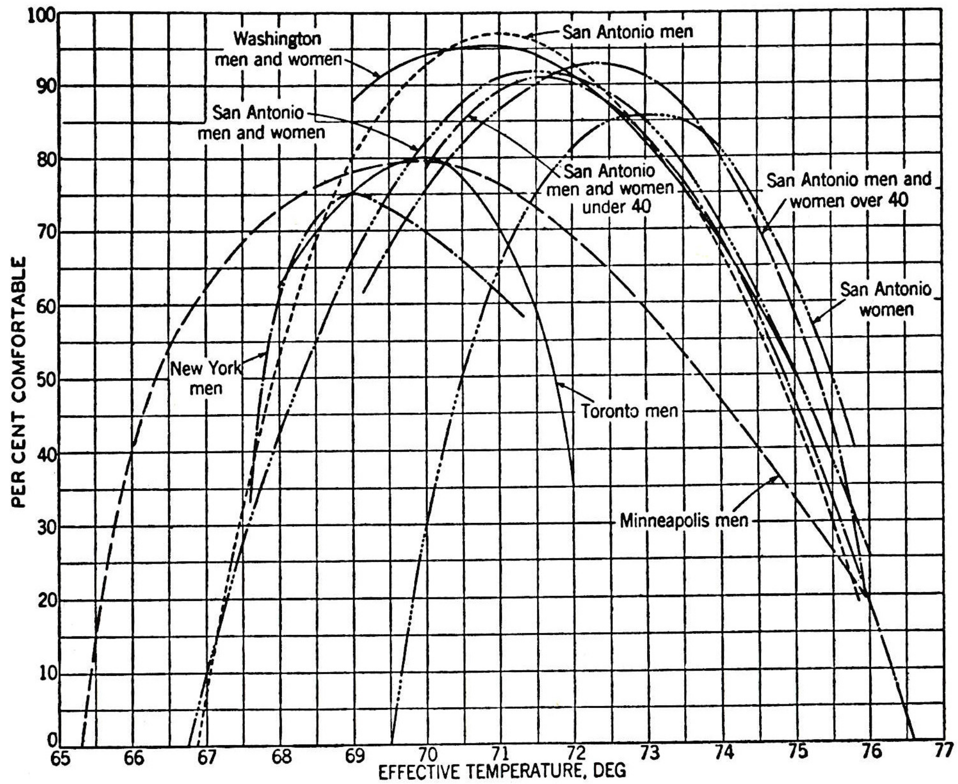
The architect's problem is to produce an environment which will not place undue stress upon the body's heat-compensation mechanism. The approach should be rephrased in terms of comfort; the presentation should be in graphic form; and, to be easily applicable, the data should derive from the empirical findings available to the practicing architect.

THE COMFORT ZONE

Some writers consider sunstroke or heatstroke as the upper temperature limit for man's existence, with the freezing point as the lower limit.[7] The ideal air temperature may be assumed to be midway between these extremes. Experiments on animals in a variable-temperature tunnel at the John B. Pierce Foundation showed that animals prefer to stay at 70° F, about midway between the points calling for maximum expenditure of energy in adjustment to the environment.[8] Therefore, some writers believe that the human being, with a body temperature averaging 98.6° F, seeking a comfortable temperature condition, picks by intuition an area where the temperature is about halfway between what he can tolerate in cold without being grossly uncomfortable, and the point which would require real effort on the part of his circulatory and sweat secretion system in order to permit him to adapt to heat.

The British Department of Scientific and Industrial Research, headed by Drs. H. M. Vernon and T. Bedford, arrived at certain conclusions in their investigations and experiments to define comfort conditions. Vernon states that the ideal temperature with slight air movement (50 fpm or less) is 66.1° F in summer, and 62.1° F in winter. Bedford gives the ideal indoor air temperature as 64.7° F in winter, and defines a comfort zone which ranges from 55.8° to 73.7° F.[9] A German suggested standard is 69.5° F with 50% relative humidity.[10] S. F. Markham proposes a range of temperature from 60° to 76° F as constituting an ideal zone, with relative humidities at noon varying from 40 to 70%.[11] C. E. P. Brooks shows that the British comfort zone lies between 58° to 70° F; the comfort zone in the United States lies between 69° and 80° F; and in the tropics it is between 74° and 85° F; with relative humidity between 30 and 70%.[12]

The Australian Commonwealth Experimental Building Station conducted physiological experiments which suggest that, in given climatic conditions, the dry-bulb temperature would provide a satisfactory index for the sensation of warmth up to the beginning of general perspiration.[13]



39. Relation between Effective Temperature and percentage observations indicating comfort.

American scientists have tried to establish a physiological measurement, combining the effects of temperature, humidity, and air movement, called the effective temperature scale (ET).[14] They place the comfort zone between 30 and 70% relative humidity. According to Houghton and Yaglou, optimum ET lies at 66°, with a range of 63–71° for both men and women (winter nonbasal, at rest, normally clothed). Yaglou and Drinker found a 71° optimum, with a range of 66–75° for men (summer nonbasal, at rest, normally clothed). Laboratory and field workers have found that the ET index overestimates the influence of humidity on sensations of warmth and comfort at ordinary temperatures, and underestimates this influence at very high temperatures.[15] Yaglou later offered a method for improving the ET index on a basis of mean skin temperature.[16]

The sources mentioned above were used as a basis for the outline of the "comfort zone." However, it should be mentioned that considering the range of observations and opinions there is no precise criterion by which comfort can be evaluated. Maybe it can be defined negatively as the situation where no feeling of discomfort occurs. Such a zone, which is very similar to the zone of thermal neutrality, differs with individuals, types of clothing, and the nature of activity being carried on. Further, it depends on sex, as women in general prefer an effective temperature for comfort 1 degree higher than men. Age plays a role also in the thermal requirements as persons over 40 years of age generally prefer 1 degree ET higher than men and women below this age. Acclimatization according to geographical locations shifts the comfort zone warmer climatic conditions elevating the thermal requirements.

The comfort zone does not have real boundaries; as, diverging from the center of the comfort zone, the thermal neutrality subtly turns to a slight degree of stresses, and from this to situations of discomfort. Therefore any definite comfort perimeter outline must be based on arbitrary assumptions. In case of mechanical conditioning the desired situation should aim toward the middle of the thermal neutrality. In cases where the ambient conditions of the building strive to be balanced by natural means, evidently no such strict conditions can be required. Here the criterion was adopted that conditions wherein the average person will not experience the feeling of discomfort can constitute the perimeter of the comfort zone.

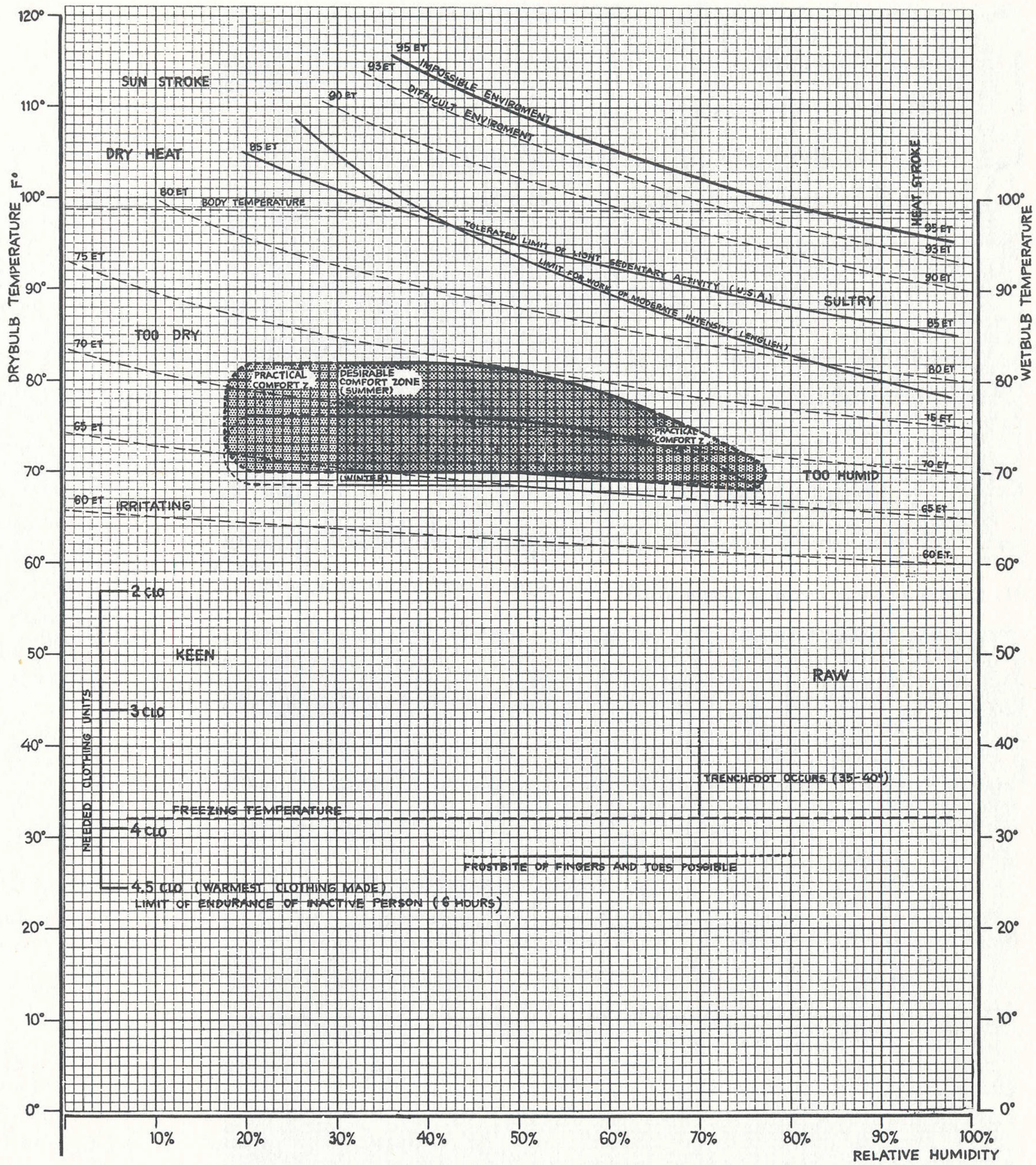
The values of effective temperature used in the chart were adjusted to the mean skin temperature index. The desirable comfort zone indicated lies between 30 and 65% relative humidity. For practical purposes the summer zone was enlarged to include those lower and higher humidity regions where no thermal stresses occur—not, however, recommended for prolonged periods. The winter comfort zone is charted somewhat lower. The use of the chart is directly applicable only to inhabitants of the temperate zone of the United States, wearing customary indoor clothing, engaged in sedentary or light muscular work, at elevations not in excess of 1,000 feet above sea level. To apply the chart to climatic regions other than approximately 40° latitude, the lower perimeter of the summer comfort line should be elevated about $\frac{3}{4}$° F for every 5° latitude change toward the lower latitudes. The upper perimeter may be raised proportionately, but not above 85° F.

Outside the comfort zone the indications of the different sensations on the chart are in agreement with C. E. P. Brooks' observations.[17] The limit to moderate work at high temperatures is indicated with a curve on the chart, which was based on D. Brunt's description.[18] This curve follows approximately the 85° ET curve. The "Difficult Environment" (93°–96° ET) and the "Impossible Environment" (95°–97° ET) curves are based on results of studies made at Pittsburgh (ASHVE-USBM) and Fort Knox (AMRL).[19]

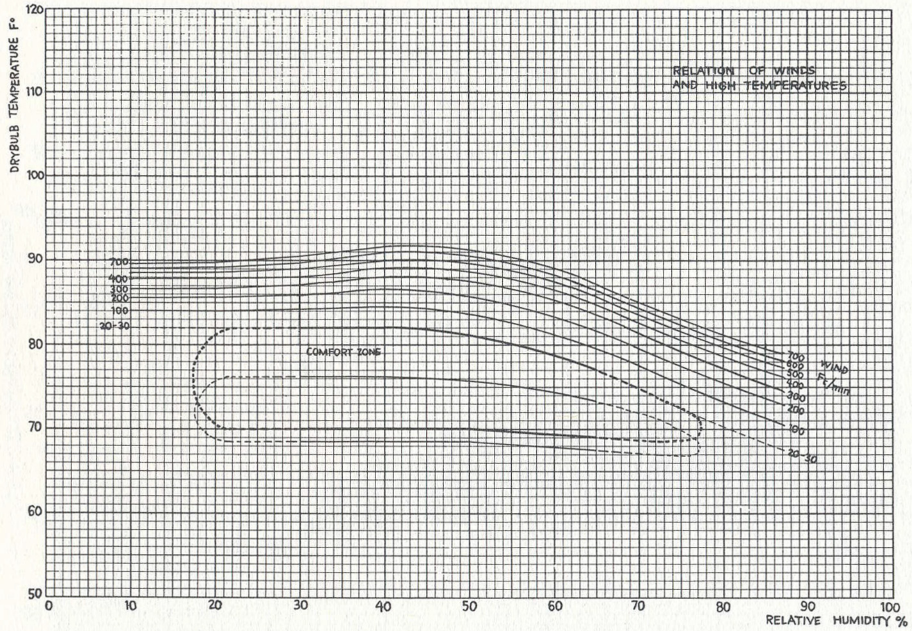
The scale for measuring the thermal effect of clothing on the human body is based on the unit of one *Clo*.[20] *Clo* is an arbitrary unit of clothing insulation. It is assumed to be the insulation of men's ordinary indoor clothing, capable of maintaining comfort in still air of 70°, with relative humidities less than 50%, and without much physical activity. The warmest practical clothing made has an insulation value of about 4.5 *Clo*.

RELATION OF CLIMATIC ELEMENTS TO COMFORT

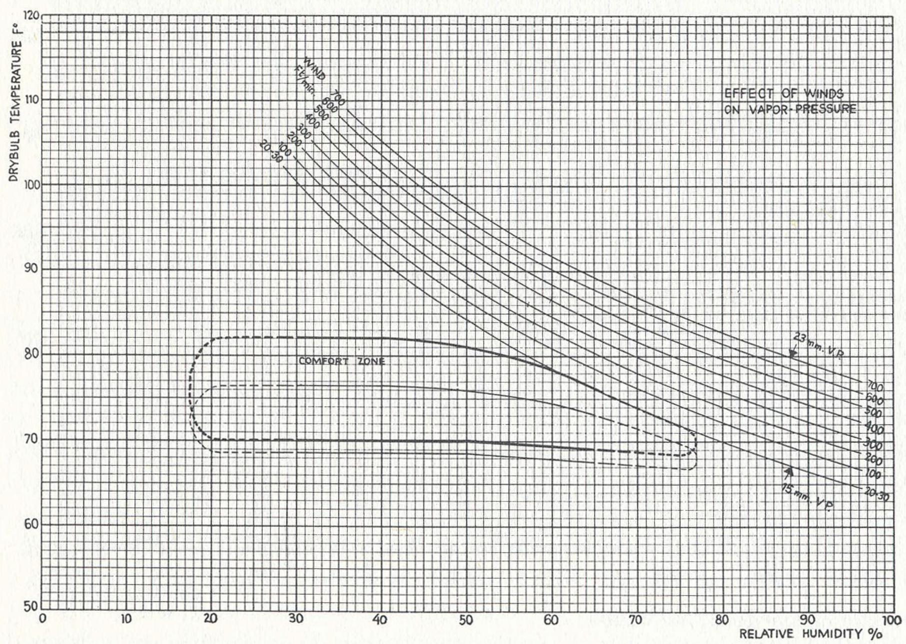
Air movement affects body cooling. It does not decrease the temperature but causes a cooling sensation due to heat loss by convection and due to increased evaporation from the body. As velocity of air movement increases, the upper comfort limit is raised. However, this rise slows as higher temperatures are reached.



40. Atmospheric comfort and danger zones (for inhabitants of moderate climate zones).



41. Relation of winds and high temperatures.



42. Effect of air movement on vapor pressure.

The figure shows wind velocities theoretically needed to restore comfort when temperatures and relative humidities are outside the comfort zone. The desirable range of wind velocities is, of course, limited by the effect on the human being.[22]

VELOCITY	PROBABLE IMPACT
Up to 50 fpm	Unnoticed
50 to 100	Pleasant
100 to 200	Generally pleasant but causing a constant awareness of air movement.
200 to 300	From slightly drafty to annoyingly drafty
Above 300	Requires corrective measures if work and health are to be kept in high efficiency.

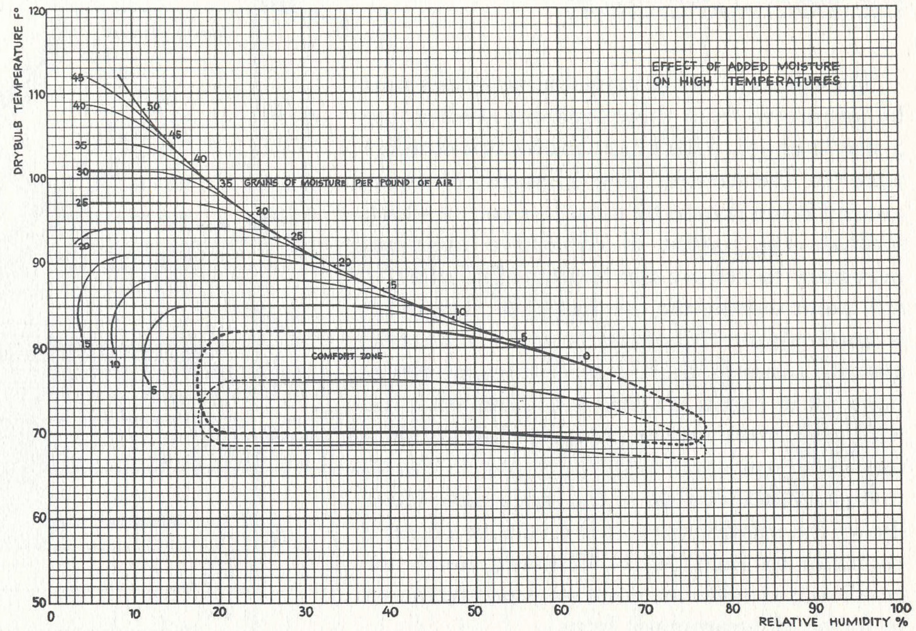
Vapor pressure is exerted by a variable quantity of water vapor contained in atmospheric air. People usually notice a "close" or depressed feeling if vapor pressure surpasses the 15 mm mercury mark. Dr. Paul Siple states that over 15 mm vapor pressure, each additional millimeter of pressure can be counteracted with one mph (88 fpm) wind effect.[23] The John B. Pierce Foundation at Yale University has worked out more detailed calculations on this effect, but accepts the above approximation as adequate in practice. The figure shows the range from 15 to 23 mm vapor pressure counteracted with wind velocities from still air (20–30 fpm) up to 700 fpm.

Evaporation decreases dry-bulb temperature. The curves shown in the figure are calibrated in 5 gr moisture/lb air intervals. The temperature decrease caused by evaporation of added moisture will restore comfort temperatures to the outer limit of the comfort zone. Calculations were based on the assumption that the latent heat is supplied entirely by the air. The Carrier Psychometric Chart was used (barometric pressure 29.92 inches mercury; vapor pressures are those of water) to determine the amount of grains of moisture per pound of dry air in obtaining lower temperatures.[24]

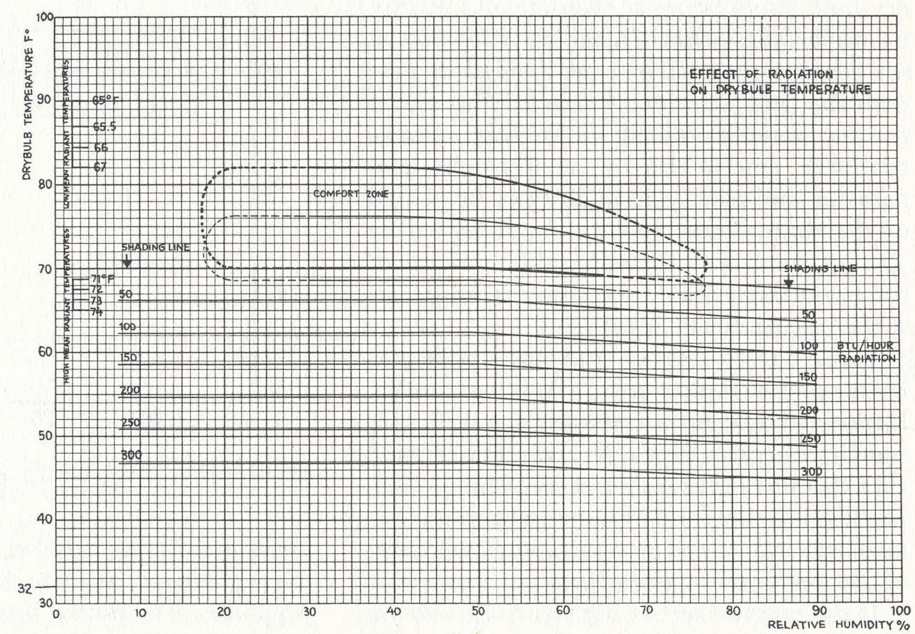
Evaporative cooling can be achieved by mechanical means, and also, to a certain degree, through the use of trees, vegetation, pools, or fountains. It is of importance in dry and hot climate zones, where wind effect is of little help in lowering high temperatures.

Radiation effect of inside surfaces can be used to some extent to balance higher or lower air temperatures. This means that we can be comfortable at low temperatures if the heat loss of the body can be counteracted with the sun's radiation. At lower temperatures (under 70° F) a drop of 1° F in air temperature can be counteracted by elevating the mean radiant temperature by 0.8° F.[25] However, this possibility of counteraction has its limitations. In practice we shall not find more than 4° or 5° F difference between air and wall temperatures.

Radiation curves shown in the figure and expressed in Btu, refer to outdoor conditions only. Calculations indicate that 50 Btu of sun radiation can counteract a 3.85° F drop in dry-bulb temperature. (See Appendix A-2.)



43. Effect of added moisture on high temperatures.



44. Relation of radiation and drybulb temperature.

THE BIOCLIMATIC CHART

The effects of the climatic elements can now be assembled from these separate studies into a single chart. This chart shows the comfort zone in the center. The climatic elements around it are shown by means of curves which indicate the nature of corrective measures necessary to restore the feeling of comfort at any point outside the comfort zone. The chart is applicable to inhabitants of the moderate climate zones in the United States, at elevations not in excess of 1,000 feet above sea level, with customary indoor clothing, doing sedentary or light work.

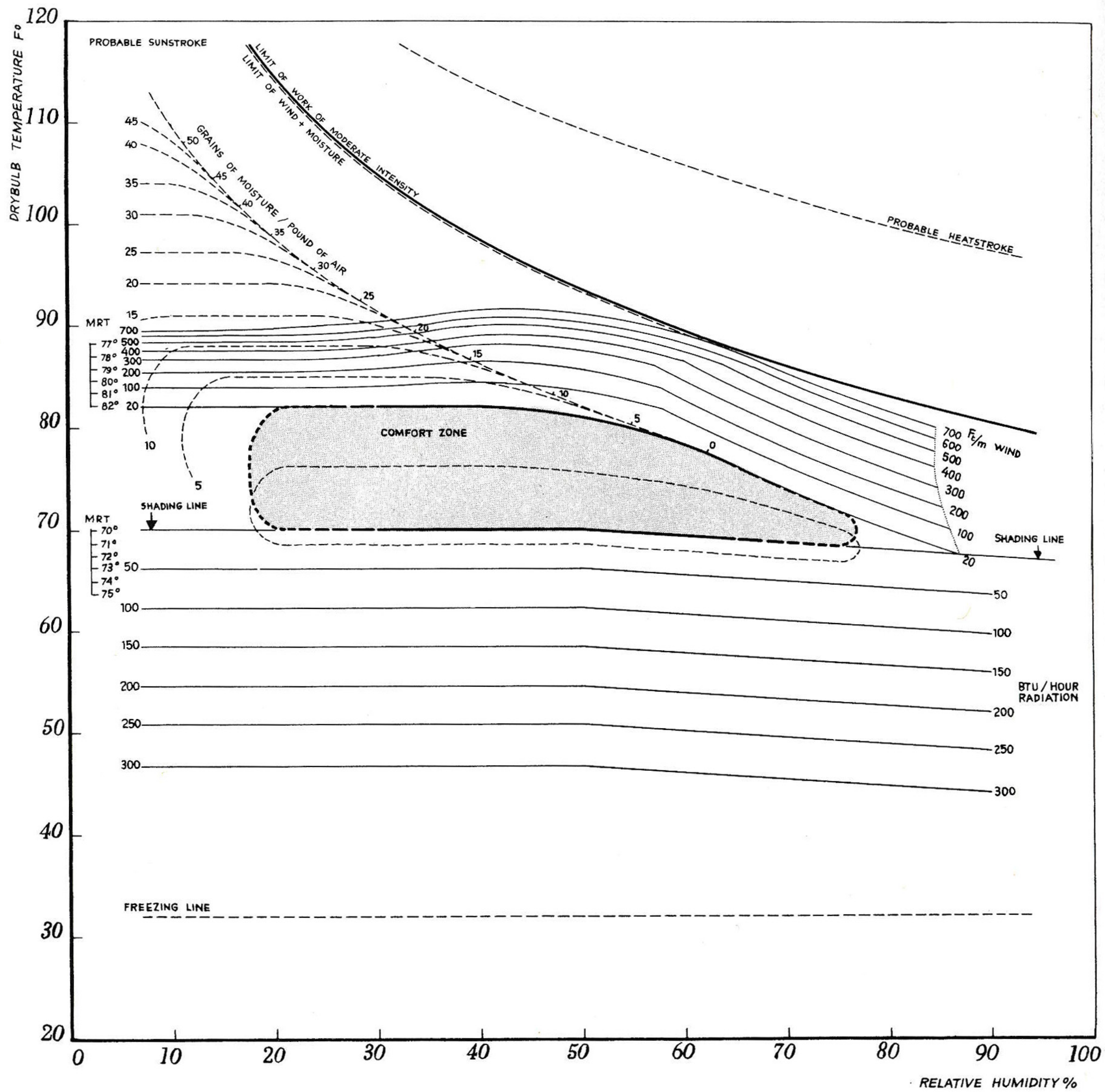
A simplified version of the bioclimatic chart shows the relationships of the various climatic elements to each other. Climatic needs for conditions outside the comfort zone are shown in simple diagrammatic form.

The bioclimatic chart was built up with dry-bulb temperature as ordinate and relative humidity as abscissa. In the middle, we can see the summer comfort zone divided into the desirable and practicable ranges. The winter comfort zone lies a little lower. Any climatic condition determined by its dry-bulb temperature and relative humidity can be plotted on the chart. If the plotted point falls into the comfort zone, we feel comfortable in shade. If the point falls outside the comfort zone, corrective measures are needed.

If the point is higher than the upper perimeter of the comfort zone, winds are needed. How wind effects can restore the feeling of comfort and offset high temperatures is charted with the nearly parallel lines following the upper limit of the comfort zone perimeter. The numbers indicate the needed wind velocities in feet per minute value (fpm).

If the temperature is high and the relative humidity is low, we feel too dry and hot, and winds are of little help here. Evaporative cooling is the tool with which to fight high temperatures. The dotted lines indicate grains of moisture per pound of air needed to reduce temperatures to the level at the upper comfort perimeter.

At the lower perimeter of the comfort zone is the line above which shading is needed.



45. Bioclimatic Chart, for U.S. moderate zone inhabitants.

Conversely, radiation is necessary below the line to counteract lower dry-bulb temperatures. The amount of Btu needed by "solair" action to restore the sensation of comfort is tabulated for outdoor conditions only.

At the left are charted the mean radiant temperature values (mrt) necessary to restore the feeling of comfort by either radiant heating or cooling (control of surface temperatures of the surroundings).

USE OF THE BIOCLIMATIC CHART

No corrective measures are necessary for any point of known dry-bulb temperature and relative humidity which falls within the boundaries of the comfort zone. For any point falling outside this zone, corrective measures needed to restore the feeling of comfort can to taken directly from the chart.

For example, at dry-bulb temperature, 75° F; relative humidity, 50%, *Need* is: none, the point is already in the comfort zone.

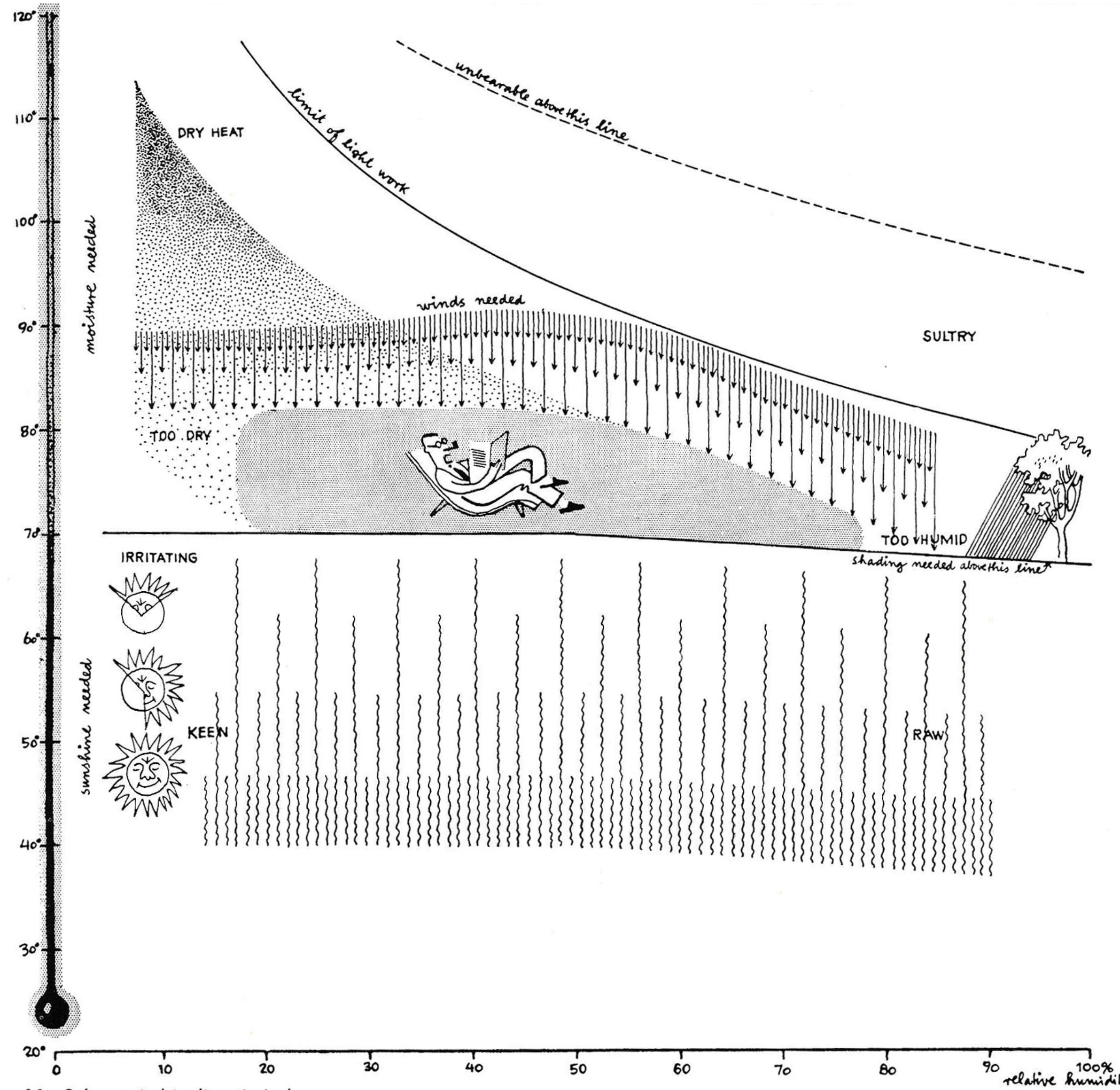
At dry-bulb temperature, 75° F; relative humidity, 70%, *Need:* 280 fpm wind to counteract vapor pressure.

At dry-bulb temperature, 50° F; relative humidity, 56%, *Need:* 260 Btu/hr sun radiation.

At dry-bulb temperature, 87° F; relative humidity, 30%, *Need:* counteraction by either of two means: (1) 300 fpm wind; or (2) evaporative cooling by adding 8 gr moisture/lb of air.

At dry-bulb temperature, 95° F; relative humidity, 20%, *Need:* cannot be achieved with winds alone. Even 700 fpm wind would still have to be supplemented by 9 gr moisture/lb of air. However, evaporative cooling could bring down the temperature to the level of comfort by adding 22 gr moisture/lb of air.

Bioclimatic evaluation is the starting point for any architectural design aiming at environmental climate balance. Prevailing climatic conditions can easily be plotted on the chart, and will show the architect what corrective measures are needed to restore comfort conditions. A good many of these measures may be achieved by natural means, that is, by adapting architectural design to utilize the climatic elements. Other problems, which fall outside the natural possibilities, will have to be remedied by mechanical means, such as air conditioning. It is the task of the architect to make utmost use of the natural means available in order to produce a more healthful and livable house, and to achieve a saving in cost by keeping to a minimum the use of mechanical aids for climate control.



46. Schematic bioclimatic index.