Chapter 5:

CLIMATE ANALYSIS

Full credit for this chapter to Prof. Leonard Bachman of the University of Houston

"CLIMATE AS A DETERMINANT OF VERNACULAR FORM AND ARCHITECTURAL RESPONSE..."

TYPES OF CLIMATES:

There are many ways to characterize the patterns of weather behavior that make up the climates of the world. General methods include zoning by latitude (equatorial, tropic, temperate, arctic and polar), by geography (desert, steppe, coastal, prairie, tundra, etc.), and by vegetation (forest, jungle, plains, marsh, and so forth). Descriptive classifications rely on temperature and rainfall distribution through the year. The former description is too general for architectural use. The latter statistical method requires that a good data source be available and that a method to convert to useful information is ready at hand. Architects most commonly understand climates in relation to their clients needs, i.e. comfort. Comfort in turn is generalized as a product of temperature and humidity. As a result, we often talk of four distinct climate types as hot-humid, hot-arid, temperate and cold. The United States and Canada are mostly comprised of temperate climates, having both a hot and a cool season. Key West, Florida is the only true hot-humid region of the U.S.. Some very scientific classifications of climate due exist, most notably one of Thornwaith and one more popular as described by Koppen. While their specific climate maps are useful for comparison, they do not represent tools that can be applied to design decision making. For our purposes, two 'bioclimatic' approaches will be useful. The first is from Victor Olgyay's book DESIGN WITH CLIMATE. Olgyay draws a simple xy graph with temperature as the x-axis and relative humidity as the y-axis. On this coordinate system he plots the comfort zone and regions where certain architectural strategies will be useful. The second bioclimatic tool is from Baruch Givoini's MAN, CLIMATE AND ARCHITECTURE. Givoini overlays the comfort zone on a sophisticated chart of temperature and absolute humidity called the 'psychrometric chart'. Givoini's graph is both more complicated and more useful because it fits the way in which climate records are kept and is more detailed regarding passive design strategies.

DYNAMICS:

Our global climate is powered by the sun. Due to the tilt of the earth's axis we receive an uneven distribution of solar energy across the surface of the planet. As a result of the difference in surface temperatures, the convective patterns of winds and hydrological cycle of rain and snow introduce future variation. Finally, the constant tilt of the earth's axis creates seasonal variations at each latitude (Summer in the northern hemisphere is thus winter in the south.).

So while the sun powers the wind and rain, it is the tilt of the earth's axis at 23.45^{o} relative to the plane of orbit which accounts for seasonal variation (not distance from the sun). In principle it is the varying length of atmosphere through which the sun must penetrate which actually causes seasons. As the sun's rays pass more obliquely to meet the ground more tangentially, the path through the atmosphere is much longer. It is the atmospheric reflection and absorption of solar energy which varies the amount impacting the surface. The relative path length of a direct sun ray through the atmosphere is referred to as 'air mass'. When the sun appears to be directly overhead, it travels straight through an air mass of 1.0 (by definition). At sunrise and sunset, the path is quite long, approaching air mass of 50.0. The geometry holds for the low path of winter sun when the surface is tilted away from normal to the sun. Note that the latitude of the Tropic of Cancer (23.5 ^{o} N) and the Tropic of Capricorn (23.5 ^{o} S) match the constant tilt of the earth's axis.

MEASURES

Temperature, relative humidity, rainfall, wind speed, and wind direction are the main factors measured for climate information. Long range (20 year) averages are useful for predicting and simulating building performance and energy requirements. But for architectural decision-making, some other factors are important as well.

Average summer conditions would only give us an air conditioner that was adequate 50% of the time. But if we design for the worst condition then our tonnage is oversized all except for one day. As a compromise between average and extreme weather, we use 'design conditions' statistically selected to meet a high percentage of the expected climate behavior without needlessly buying an extravagantly large mechanical system. These design conditions are given for most cities and are separated for winter and summer conditions. Generally they are given for the 90%, 95%, and 97.5% condition and the designer will choose according to how critical control of interior conditions is for the building in question. The conditions are also labeled as 10%, 5%, and 2.5% conditions and are the same as their compliment of 100%. Note that in summer, the coincident wet bulb temperature may be given or the design wet bulb may be stated separately.

As a measure of temperature, daily averages and extremes are hard to digest and use on comparative analysis. Imagine having to do 365 days of 24 hourly calculations to check a buildings preliminary energy profile every time you changed the design slightly! Instead, we use a number called the degree-day. Degree-days are the difference between the average daily temperature and the 'balance point' of a building (usually assumed to be 18 ^{o} C or 65 ^{o} F). If the average daily temperature is below the balance point, then we will get degree-days heating. When the daily average temperature is above the 18 ^{o} C or 65 ^{o} F, we tabulate degree-days cooling.

Degree-days are tabulated for each day and totaled for each month. Note that any month can have both heating and cooling degree-days (DDH and DDC) if there is both cold and hot weather that month. Degree-days for most cities have been published from average weather data. Some degree-days are available at bases other than 18 ^{o} C for internally load dominated buildings. In fact, the old 18 ^{o} C base is only accurate for a typically inefficient house. Even houses now, with better insulation and construction techniques, wail have balance points closer to 15 ^{o} C or 60 ^{o} F. The lower the building balance point, the more 'free' internal heating is received, the more cooling is required and the higher the possibility of meeting cooling needs through natural or forced ventilation.

Degree-days are also totaled for the year. We not only use this measure for monthly and annual calculation shortcuts, we also use it as a quick comparative measure of climate type. Houston, for example has 2745 F average degree-days cooling per year and 1435 F degree-days heating- indicating a 2 to 1 ratio in favor of cooling needs. Seattle on the other hand has 134 F DDC and 5184 F DDH.

CORRELATIONS:

Independently, climate measures only hint at the character of weather patterns. When we begin to look at relationships of the data, we not only get a better idea about the situation, we also begin to see the potential for climate-based solutions to thermal comfort needs. Some important considerations would include:

- temperature:wind- when it is warm, are there breezes? from where?
- temperature:wind- when it is cold, what direction are the winds coming from?
- temperature:sun- cold:sun and hot:shade times and solar position.
- temperature:sun- clear, cloudy and overcast days, days with rain.
- hot:cold- what are the relative severity and duration of each?
- diurnal flux- daily variation of temperature
- inter-diurnal variation- how variable is the weather
- temperature:humidity- will evaporative cooling be helpful?

BIN DATA AND GRAPHIC REPRESENTATION:

The US military maintains a special climate database from its installations around the world. This data set lists the hourly occurrences of weather in 5 ^{o} F temperature ranges (bins) and the mean coincident wet bulb for each bin. This data is listed by month and annually. Daily observations for each month are also broken down by 8-hour periods.

By using Givoini's bioclimatic overlay of the psychrometric chart, we can plot the number of hours in each bin against climatic needs and architectural response. In this way, we obtain a numerical priority list of approaches to comfort.

COMFORT:

The shaded area on the bioclimatic chart shows the conditions generally associated with thermal comfort. This is for a healthy person, comfortably dressed, in light activity like desk work (met rate of 1.3, summer clo of 1.4, winter clo of 0.8). It assumes that under these conditions of temperature and humidity, most people would report feeling 'comfortable'. It should be noted that becoming acclimated to a particular climate or even a certain season has the effect of broadening the comfort zone. Of course, we know that the Mean Radiant Temperature of the surroundings must be very close to the air temperature for this to hold.

The graph also indicates that our test occupant is in shade and that some small air motion (like that associated with indoor ventilation standards) is provided. For a more complete discussion see Egan, CONCEPTS IN THERMAL COMFORT, Olgyay, DESIGN WITH CLIMATE.

VENTILATION:

In humid but not too warm environments, air motion is employed to restore conditions to comfort. The shaded area on the graph represents a range of 0.85 (just outside comfort) to 20.0 feet per second of air motion. This is the same as a range of 0.58 to 13.5 mph.

Air motion cools by convection against a warmer surface like human skin and to some extent by evaporation of moisture (perspiration). The warmer the air is, the faster it must move to provide the same cooling. In buildings we generally bring in outside air by natural or forced ventilation to accomplish this. Ceiling fans are another method of making air-flow faster across the skin when ventilation is not sufficient.

As conditions get warmer, our bodies rely more on evaporation and less on convection/radiation for cooling. After about 90 ^{o} F or 32 ^{o} C, no amount of air motion will help much. In fact, 20.0 feet per second of air velocity is enough to blow papers around and feel uncomfortably gusty.

MECHANICAL COOLING:

A practical passive method for dealing with humid weather over 90 ^{o} F or 32 ^{o} C has yet to be devised. But mechanical relief is effective when passive and defensive design measures cannot fully handle the load.

Mechanical cooling usually uses electrical power to provide mechanical energy to run a refrigerant cycle compressor. In the process of cooling the air down before re-mixing it with room air, it is driven below its dew point. At those temperatures, water in the air condenses and the air is dried. A good rule of thumb is that about one third of the work an A/C does is dehumidification. In this way, we can provide the supplementary cooling for both sensible (temperature) and latent (humidity) loads.

EVAPORATIVE COOLING:

Evaporation provides a real way of reducing room air temperatures directly, without the necessity of mechanical energy. From a physics point of view, what happens is a trade of latent heat for sensible. When hot dry air becomes more saturated, the cooler wet air which results actually has the same amount of total enthalpy (sensible + latent energy content). All moist air mixtures of the same enthalpy lie on the same wet bulb line and so have the same wet bulb temperature. The difference between the dry bulb and wet bulb temperature is the potential cooling effect attained by saturation. This wet bulb ‘depression' tells us how many degrees we can theoretically cool the air. In fact, a 90% wet bulb approach is more practical.

Aside from direct evaporative cooling there are a number of indirect and isolated evaporative techniques. While direct evaporative is only effective in dry climates, indirect/isolated methods can be useful elsewhere.

THERMAL MASS:

Dense, high heat capacity building materials do not provide insulation. Earth, adobe, brick, etc. are actually good thermal conductors. What mass does provide is a large thermal 'battery' which takes time to charge and discharge its temperature.

In dry climates, a great deal of solar heating occurs by day and the same energy must re-radiate to the sky at night by long wave (infrared) radiation. In places like Albuquerque, New Mexico, this can mean 110^{o}F afternoons followed by a quick striking 35^{o}F chill as soon as the sun goes down. The Anasazi Indians were one of many pre-industrial peoples who learned that about 12" of adobe was just enough to delay the day's heat until the chill of the night and to store the night's "coolth" for the next day.

This battery effect can also be thought of as a thermal 'flywheel' which will keep a relatively constant temperature despite variations in outdoor conditions.

MASS WITH NIGHT VENTILATION:

Internal mass of the building that is not exposed to the night sky can be 'flushed' with cool night air. This is accomplished by mechanical or natural ventilation of structural spaces like attics and floor/ceiling plenums. For interior load dominated buildings this can make use of outdoor air to flush interior zones that do not have envelope loads to the outdoors. These interior zones will be in the cooling mode year-around because of internal heat from people, lights, and equipment.

The Bateson State Office Building in Sacramento, California is an often-cited example of night flush ventilation. The same strategy was considered for Lloyd's of London in the much colder climate of England.

In Arizona, some residential experiments have been performed using large numbers of milk-carton size water bottles and night ventilation with evaporative cooling fans.

SOLAR GAIN: The most popularized notion of passive design is the direct conversion of winter sun into heat for living spaces. Whenever outdoor conditions are below comfortable temperature, some solar gain should be introduced. This is best accomplished by south facing glass. Vertical glass is easier to shade and sloped glass will receive more radiation. Care must be taken to find the correct balance for each situation. In colder climates, double-glazing is necessary to prevent more heat from escaping by conduction than is gained by solar. Architects often overlook the thermal nature of the building and apply passive solar heating to everything. The Illinois State Office Building for example, is an interior load dominated building with little need for the solar gain strategies applied to it. For residential buildings with little gain, winter sun is more useful. Be careful of climates (like Houston, for example) where changes from hot to cold and cold to hot weather are rapid and extreme.

OVERLAPPING DATA:

Some dry bulb/wet bulb bins overlap regions of passive strategies. The 85-90^{o}F dry bulb bin with a mean coincident wet bulb of 67^{o}F for example, would fall into all of the following strategies: ventilation, mass, night ventilation, and evaporative cooling. Bin data that satisfies multiple strategies should be counted in the cumulative total hours for ALL of the strategies that would be viable under those climatic conditions. Note also that shading overlaps all comfortable and overheated conditions and that still air overlaps all underheated bins.