

A METHOD FOR ANALYSING CLIMATE IN TERMS OF ARCHITECTURAL RESPONSES

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INTRODUCTION

We have developed computer-aided techniques for analysing climates in terms of the combined effects of insolation, air temperature, wind speed, and relative humidity and have linked these to specific architectural responses in order to establish some passive building design techniques that can be used to achieve thermal comfort in various climatic regions, taking maximum advantage of available natural energies.

This analysis allows the designer to organize and prioritize the vast array of architectural responses in a way that is appropriate for particular climates. Even without using thermal lag techniques, the need for mechanical heating and cooling can be reduced by 15-45%, depending on location, solely by an architectural sensitivity to the immediate behavior of the sun and wind.

DATA CHARACTERISTICS

For a data base, we obtained computer tapes from the University of Wisconsin Solar Energy Laboratory because they recorded hourly insolation levels in addition to other climate variables. We therefore had concurrent information, on an hour-by-hour basis of the pertinent variables (air temperature, relative humidity, wind speed, and insolation) which interact to form a complete description of a micro-climate.

The tape contains hourly data for one year for fourteen locations around the country, including representative locations from the major climate zones.

For the purposes of this paper we have chosen 6 of those 14 locations to examine: 2 in the Northwest and 4 others which represent a broad range of climate types.

For these locations, only one year's data was used so we are less than certain that it is a true representative of the actual climate. However, we did have 9 years of information for one location -- Madison, Wisconsin -- and our analysis shows that the same major patterns (accounting for more than 70% of the year) recur each year, with only minor differences in their frequency of occurrence. A design based on the data from any single year may therefore be capable of responding to variations from one year to the next.

Further analysis of several years of data from each location will be necessary to determine exactly how much variation in patterns is likely to occur from year to year, and what the representative patterns for a particular location are.

At this point we are most interested in developing the method of analysis and cannot provide verified pattern descriptions for particular locations.

METHOD

Our work utilizes the thermal comfort zone as defined by Olgyay which lies roughly between 70° and 80°F and between 20-80% relative humidity. It assumes shading and still air but unregulated air changes. We defined the modified comfort zone (MCZ) to include those combinations of relative humidity, temperature, wind speed, and insolation which would result in a feeling of comfort even outside of that narrow zone. For example if the air temperature is below 70°F, the lower limit of the standard comfort zone, but there is sufficient insolation to balance the body's heat loss and there is no wind, then this point is within the modified comfort zone. This larger zone, which includes the standard comfort zone, can theoretically demonstrate comfort as low as 50°F or as high as 90°F.

Our definition of the modified comfort zone assumes that there are infinite air changes and that the cooling effect of the wind can be balanced by the warming effect of the sun.

There are, of course, conditions which are so extreme that they can be brought into the modified comfort zone (e.g., too hot, too cold, too humid, or too windy). Frequently, however, these conditions may be passively moderated by utilizing thermal lag techniques and controlled air change rates.

Outside of the built environment, thermal comfort results from a delicate balance of the several climate variables. This balance occurs relatively rarely in North American climates. However if some of the variables are manipulated architecturally, then the frequency of comfortable periods can be increased dramatically. The variables which can be controlled most easily architecturally are insolation and wind which can be blocked, filtered or admitted, when available. Humidity can also be modified to some extent. More complex architectural responses that utilize thermal lag for heating or cooling may also be used to moderate air temperature.

This data in this paper relies on Olgyay's comfort criteria however other definitions of comfort could easily have been used. Using a computer, we analyzed a year of six places' climate. For every hour in the year we looked at the combination of temperature, relative humidity, wind speed, and available insolation. On the basis of this data, and Olgyay's definitions, we were able to classify each hour of the year in terms of what would be architecturally necessary to produce comfort.

Here, as an example, is Medford, Oregon in June, as described by our computer program.

Table 1. MEDFORD, OREGON

| | | | | | | | | | | | |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 0 | C3 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 |
| 1 | C3 | C3 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 |
| 2 | C3 | C3 | C3 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 |
| 3 | C3 | C3 | C3 | C3 | C2 | C2 | C2 | C2 | C3 | C2 | C2 |
| 4 | C3 | C3 | C3 | C3 | C2 | C2 | C2 | C3 | C2 | C3 | C2 |
| 5 | C3 | C3 | C3 | C3 | C2 | C3 | C3 | C3 | C3 | C3 | C2 |
| 6 | C3 | C3 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 |
| 7 | C5 | C5 | C5 | C5 | C5 | C5 | C5 | 210 | 210 | 210 | C5 |
| 8 | 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| 9 | 210 | 210 | 210 | 210 | 210 | 210 | 210 | 220 | 220 | 220 | 210 |
| 10 | 210 | 020 | 210 | 210 | 210 | 020 | 020 | 020 | 020 | 020 | 210 |
| 11 | 210 | 020 | 020 | 020 | 020 | 020 | 020 | 020 | 020 | 020 | 210 |
| 12 | 020 | 020 | 020 | 020 | 020 | 020 | 020 | 020 | 120 | 220 | 020 |
| 13 | 020 | 020 | 020 | 020 | 020 | 120 | 120 | 120 | 120 | 120 | 020 |
| 14 | 020 | 020 | 120 | 020 | 120 | 120 | 120 | 120 | 120 | 220 | 020 |
| 15 | 220 | 120 | 120 | 120 | 120 | 120 | H1 | 120 | 120 | 220 | 020 |
| 16 | 220 | 120 | 120 | H1 | 120 | 120 | H1 | 120 | 120 | 220 | 020 |
| 17 | 220 | 02 | 120 | H1 | 120 | 120 | H2 | 120 | 120 | 220 | 020 |
| 18 | 000 | 000 | 000 | H1 | 120 | 120 | 120 | 120 | 220 | 000 | 000 |
| 19 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 120 | 120 | 210 | 200 |
| 20 | 210 | C2 | 210 | 210 | 200 | 200 | 200 | 200 | 200 | C2 | C2 |
| 21 | C2 | C2 | C2 | C2 | 200 | C2 | 200 | 200 | 200 | C2 | C2 |
| 22 | C2 | C2 | C2 | C2 | C2 | C2 | 200 | 200 | C2 | C2 | C2 |
| 23 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 | C2 |

The 3-digit code indicates times when the weather, though not ideal, can be directly architecturally moderated to produce thermal comfort. The two-character codes represent extremes in temperature (too hot or too cold) during which time either the lag properties of buildings or mechanical equipment is required to achieve comfort.

What follows is an interpretation of the codes for and a qualitative description of the weather on June 22, in terms of architectural responses.

Until 7 a.m., temperatures are cold, and buildings require some heat source (natural or mechanical, and moderated if the inhabitants are absent or under blankets) (C2 and C3); from 7 a.m. to 8 a.m., it's still cold, but the sun has come up enough to make the insolation collectable (opened drapes on the south and east windows) (C5); from 8 a.m. to 10 a.m., chilly temperatures are tolerable as long as the wind is blocked and the sun is admitted (interior or protected spaces, with direct solar gain) (210); from 10 a.m. until 1 p.m. the wind has died down, but the air temperature is rising, so the sun must be blocked for comfort (overhangs on southfacing windows, or lunch under a deciduous tree) (020); from 1 p.m. to 3 p.m., the direct sun must still be blocked, and although the temperature is still rising, the wind speed has picked up again, and if admitted, will provide comfort (indoors: an opened window, with closed venetian blinds; outdoors: an open structure with an opaque roof but no walls) (120); from 3 p.m. to 6 p.m., it is simply too hot for comfort (either because the wind has died again or because the temperature is so high that no amount of wind can cool effectively) (H1 & H2); from 1 p.m. to 8 p.m., like from 1 p.m. to 3 p.m. earlier, comfort is possible by blocking the sun and admitting the wind (120); from 8 p.m. to 11 p.m., even though the sun has gone down, the evening is pleasant as long as the wind is blocked (indoors: closed windows; outdoors: a walled-in barbecue area) (200); finally at 11 p.m., the ambient air temperature drops below the comfort level and will stay there until sunrise the next day (C2).

In order to facilitate pattern identification and comparison between different locations we have simplified the data by the smoothing technique of looking only at those codes which occur in two consecutive hours. Initial inspection indicates that the smoothed patterns which result are not significantly different than the "real" patterns in terms of architectural response, however the resulting simplification greatly reduces the problem of translating patterns into architectural design criteria. Since the frequency of uncomfortable, unmodifiable weather outweighs the frequency of the "modified comfort zone" in every climate we've examined, error in this smoothing technique will tend to underestimate the hours which fall in the MCZ.

COMPARISON OF ANALYSIS TECHNIQUES

Climate analysis for architectural design in the past has been based on the use of averaged data usually in combination with a description of the extremes for some time period. This data is used to construct an average day or month which is then used as a basis for determining architectural response. While this information is at some levels valuable it does tend to disguise the dynamic character of climate. For example an average day could be constructed from a month's averages for each hour. The resulting "day" might exhibit one of several patterns that we have identified for that month. But the conclusion to draw from this "day", for the purposes of architectural design will be misleading because a) it encourages the belief that weather changes seasonally instead of daily and ignores the subtle variation that climate-sensitive architecture might easily respond to; b) it ignores the interactive effect of the several climate variables which is of critical importance when designing for a dynamic climate.

A more common (and still more misleading) climate analysis technique is one in which averages are calculated for an entire month at a time, or even a whole year (e.g. annual degree days). Most climatic realities are washed out in the process, and the potential for balancing sun and wind with air temperature is lost.

THE CHARACTERISTICS OF SIX CLIMATES

We found that thermal comfort, except in extremes of weather, was possible to achieve with relatively little assistance from mechanical systems. While a very small proportion of the time in any climate falls within Olgay's standard comfort zone, a surprisingly high percentage of hours of the year fall in the MCZ.

Table II. POTENTIAL THERMAL COMFORT INCREASES THROUGH CLIMATE-SENSITIVE ARCHITECTURE FOR SELECTED LOCATIONS

| Location | % of time in stand-ard comfort zone | % of time in mod-ified comfort zone |
|------------------------|-------------------------------------|-------------------------------------|
| 1. Dodge City, Kansas | 0 | 28 |
| 2. Madison, Wisconsin | 1 | 20 |
| 3. Medford, Oregon | 1 | 22 |
| 4. Miami, Florida | 1 | 44 |
| 5. Phoenix, Arizona | 4 | 35 |
| 6. Seattle, Washington | 0 | 15 |

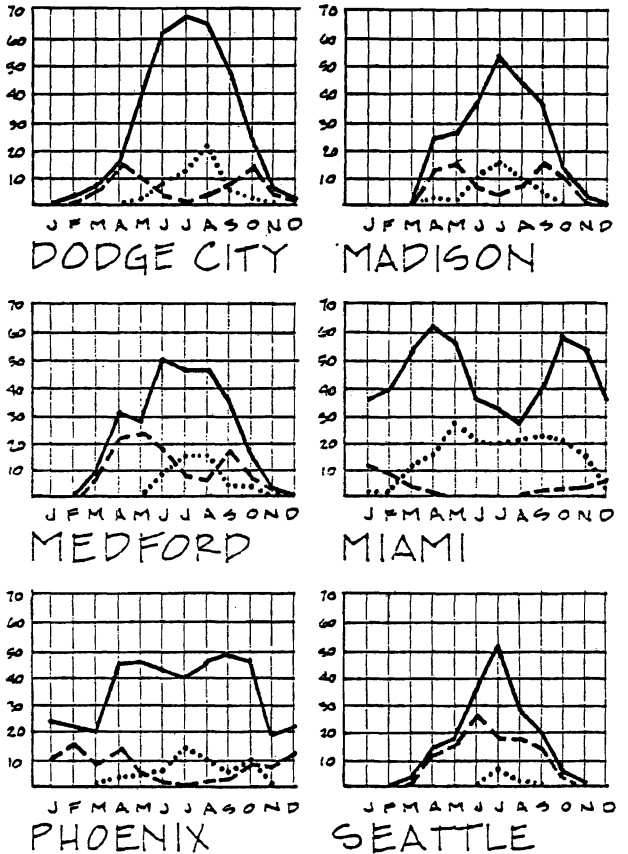
The following graphs show the distribution of these potentially comfortable periods for the six locations under consideration. As would be expected, the summer is most comfortable in temperate climates and the spring and fall in warmer ones. It is important to note that all of the points plotted would be times of thermal discomfort without appropriate architectural or other controls.

Of the several architectural response types that we have identified, two have emerged as the most important for most climates.

The first of these is the response to sunny but chilly weather such as is common in the Northwest on clear days in the spring and fall, and on summer mornings. Comfort is achieved from direct solar radiation as long as the wind is blocked. According to Olgay, air temperatures as low as 50°F can be comfortable during these periods. This 210 "Block wind - admit sun" response can be put to one's advantage in any temperate climate, for much of the year, with a minimum of architecture (e.g. an unshaded wind break), and independently of any higher technology. Note that it is also appropriate in warmer climates, in the winter.

The second predominant response type is opposite the first: when air temperatures go higher than normally comfortable levels, thermal comfort can be achieved by blocking the sun while admitting the wind (120). Most summer over-heating problems in the Northwest fall in this category and can be solved by a nice shade tree.

Fig. 1. Frequency of MCZ, 120 & 210.



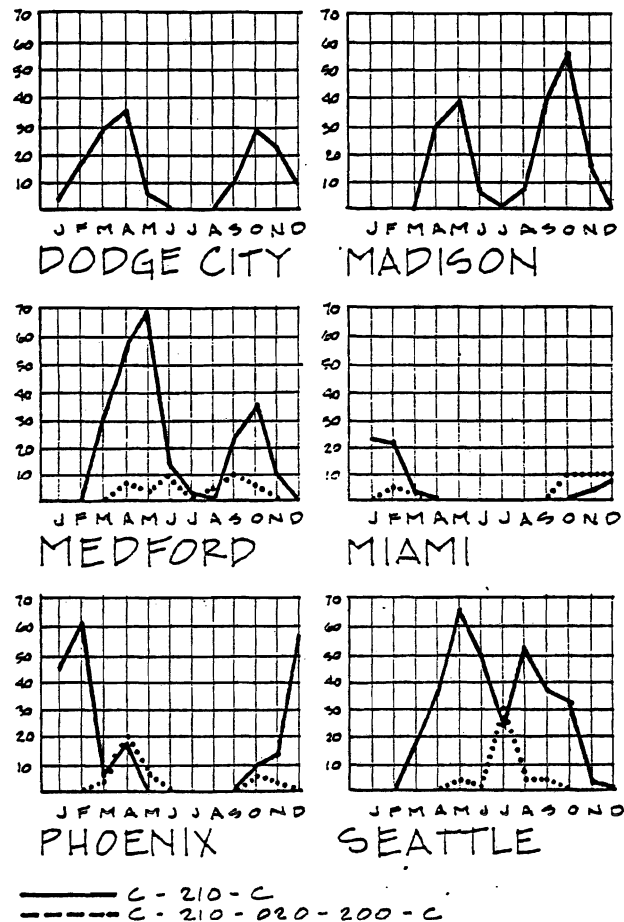
————— MODIFIED COMFORT ZONE - MCZ
 - - - - - IN MCZ IF WIND BLOCKED & SUN ADMITTED-210
 IN MCZ IF SUN BLOCKED & WIND ADMITTED-120

In looking at how these responses and others combine into recurring patterns throughout a day we found that many pattern sequences were common to most or all locations -- but with distinct variations in seasonal frequency, depending on the location.

One of the most common patterns (C-210-C) is one in which nights are cold but some portion of the day is comfortable if the wind is blocked and the sun admitted. [These are times when the passive collection of solar energy is possible and desirable.] This pattern occurs frequently in the Northwest in the spring and fall, but also, to a lesser extent in the winter in warmer climates.

Another "universal" but less frequent pattern (C-210-020-200-C) is one in which again, nights are cold, and mornings and evenings are comfortable if the wind is blocked, but afternoons are so warm that the sun must be blocked, with wind admitted, to achieve thermal comfort without air-conditioning. In one day the weather changes from heating phase to cooling phase and back again. [This "reversal" shows how important it is to design environments which can change from hour to hour as well as season to season.] And it is clear that the potential for thermal lag to moderate these extremes is enormous.

Fig. 2. Frequency of C-210-C & C-210-020-200-C Patterns.



————— C - 210 - C
 - - - - - C - 210 - 020 - 200 - C

We were surprised to discover that a similar daily climatic pattern occurred in other locations we investigated, only with calendar variations: Madison's summer, Miami's winter, Phoenix's autumn, etc., are all like Medford's spring. We speculate that similar architectural patterns could be developed for these varied climates without neglecting the particular problems each has in its extremes.

It may be that it will be more useful from a building design standpoint to stress the similarities rather than the differences between climates if we can identify universal constants to investigate the differences.

ARCHITECTURAL DESIGN IMPLICATIONS

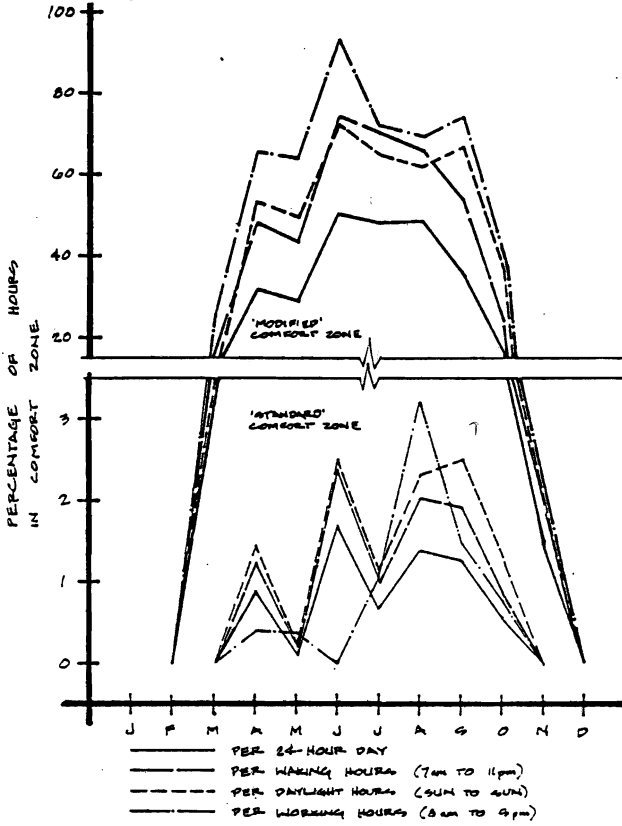
Looking at one of these places more closely, it becomes immediately apparent why and when climate-sensitive architecture is important.

Here is a breakdown by month of the standard and modified comfort zones for Medford, Oregon. Note that in Table II, Medford fares poorly, relative to other parts of the country. Even so, in Figure 3, we show that even in Medford, the number of potentially comfortable hours is far higher (especially during the day) than is normally assumed.

This graph demonstrates how the periods of thermal comfort can be substantially increased (except from November through February) through direct architectural methods.

They also show how the reliance on mechanical systems can be reduced still more if the design context is one in which full conditioning is required primarily during waking hours (housing) or primarily during working hours (office buildings).

Fig. 3. The Comfort Zone in Medford



We have begun to look at how responses vary throughout the year. In the following example, the hour between noon and 1 p.m. is examined (as it might be by someone interested in designing a lunch room).

Each of the six identifiable "seasons" was found by choosing calendar intervals during which 95% of the climatic variation could be accounted for by 2 or 3 dominant responses. Table III shows a gradual shifting of these patterns through

Table III. MEDFORD AT NOON -- A SUMMARY OF A YEAR'S CLIMATE RESPONSE FROM NOON TO 1 P.M. (VALUES GIVEN ARE PERCENTAGES PER SEASON.)

| Identifiable Seasons (# of Days) | Medford Climate Responses | | | | | |
|-------------------------------------|---------------------------|-----|-----|-----|----|-----|
| | C2 | C8 | 210 | 120 | H | TOT |
| Oct. 21 - March 4 (135) | 29 | 70 | | | | 99 |
| March 5 - April 11 (38) | | 42 | 58 | | | 100 |
| April 12 - June 6 (56) | | 14 | 71 | 11 | | 96 |
| June 7 - July 8 (32) | | | 16 | 81 | | 97 |
| July 9 - Aug. 31 (54) | | | | 78 | 19 | 97 |
| Sept. 1 - Oct. 20 (50) | | 6 | 48 | 42 | | 96 |
| Total # of Days | 39 | 118 | 91 | 95 | 10 | 97 |

- C2 Too cold; no collectable insolation
- C8 Too cold, but with collectable insolation
- 210 In MCZ if wind is blocked and sun is admitted
- 120 In MCZ if sun is blocked and wind is admitted
- H Too hot, even with sun blocked and wind admitted
- TOT Percent of hours accounted for

time. Within each season, a structure would ideally be capable of responding interchangeably to the several dominant responses, at least one of which would also be dominant in the season preceding and/or following.

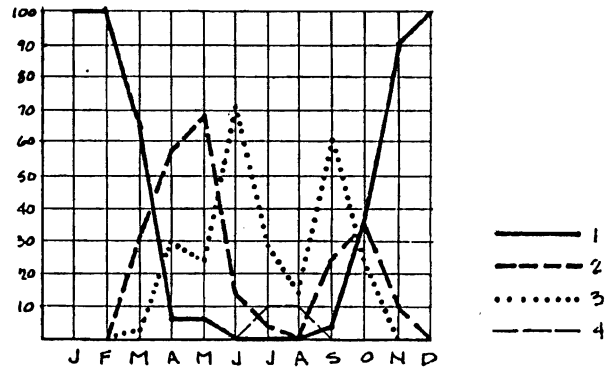
This suggests a design which not only changes through time, but which has a number of changeable elements that can be controlled, on a day-to-day basis, independently of one another. Architectural variation throughout the year, then, takes on a more organic character in that no change is sudden; rather each season gradually introduces a new response while gradually phasing out an old one.

The characterization of climate in terms of recurring daily patterns is valuable to the designer because it organizes the existing array of architectural responses to climate (roof overhangs, operable windows, wind blocks, solar heating, etc.). The existence of a certain set of patterns within a particular climate tells the designer three important pieces of information. First, what are the appropriate architectural responses to that climate; second, how important are they relative to each other; and thirdly, when do they occur in terms of time of day and time of year.

A review of the patterns that characterize Medford, Oregon indicates that 85% of the year can be described by just four architectural response pattern types. These are, in order of importance:

- 1) Too cold all day, but with periods of collectable insolation.
- 2) Too cold at night, but in the MCZ during the day if wind is blocked.
- 3) Too cold at night but in the MCZ in the morning and evening if wind is blocked, and in the afternoon if sun is blocked.
- 4) Same as (3) but with overheating in the afternoon.

Fig. 4. The Distribution of Pattern Types in Medford



Using these response pattern types, with an understanding of sun position and wind direction, one can optimize a building which creates a large modified comfort zone and utilizes thermal lag for heating and cooling.

CONCLUSION

This method of climate analysis allows the designer to establish, for a particular location:

- 1) What architectural responses to climate are important.
- 2) How important these responses are relative to each other.
- 3) When the responses occur during the day and year.
- 4) How the responses are related to each other.

Preliminary analysis of six locations indicates that the patterns formed by these responses occur in all locations but at varying times and with different frequencies. Several of the architectural responses (not including a building shell) utilize the immediate behavior of the wind and sun, and can provide comfort for large portions of the year in each location.