

Climate Responsive Earth-Sheltered Buildings

G.Z. Brown
Assistant Professor

Barbara-Jo Novitski
Research Associate

Department of Architecture, University of Oregon
Eugene, Oregon 97403

■ An understanding of the impact of climate on the built environment can lead to the design of more fuel-efficient buildings. The authors present a methodology for analyzing climate conditions in terms of the architectural response required for thermal comfort. They used hourly climate data for several locations, and from these data determined diurnal and seasonal climate patterns. Although climate varies widely in different locations, several patterns — such as cold morning, comfortable midday, cold night — are common throughout North America in different seasons. Through proper architectural and site treatment, buildings can be designed to accommodate these patterns, effectively increasing the amount of thermally comfortable time. The authors find that earth-sheltered buildings can be designed in response to dynamic climate conditions. In this way, the outside spaces associated with underground buildings as well as the inside spaces can also be designed for thermal comfort, thereby increasing the livable space of the buildings.

Early people's discovery of the temperature-moderating benefits of caves grew from an understanding of climate that comes only from a direct and constant experience of the elements. Through urbanization, industrialization, geographic mobility, and a reliance on mechanically produced comfort, we in the 20th century have largely lost that first-hand experience of climate. As a result, we no longer understand how buildings respond to particular climates.

Only recently, pressured by fuel shortages, have we begun to re-examine the nature of climate and its impact on the built environment. But now it is a self-conscious study, frequently lacking in subtlety; conventional descriptive techniques are not as sensitive to the dynamics of climate as direct human experience is.

An understanding of climate is important in the design of earth-sheltered buildings in two ways. First, of course, is the primary decision concerning what degree of earth-sheltering to include, and second, to determine which thermal performance design criteria apply to the building. The more we know about the dynamics and subtleties of climate, the more precisely we can define the thermal requirements of buildings — not just in the extremes of summer and winter, but also in spring and fall. In short, the more we understand about the nature of the appropriate architectural response for all seasons the more effectively we can design fuel-efficient buildings.

In the past, climate analysis for architectural design has been based on the use of averaged data, usually in combination with a description of the extremes for some time period. Because the analysis tends to ignore the subtle daily and seasonal variations that climate-sensitive architecture might easily accommodate, the conclusions drawn from these data are often misleading. In

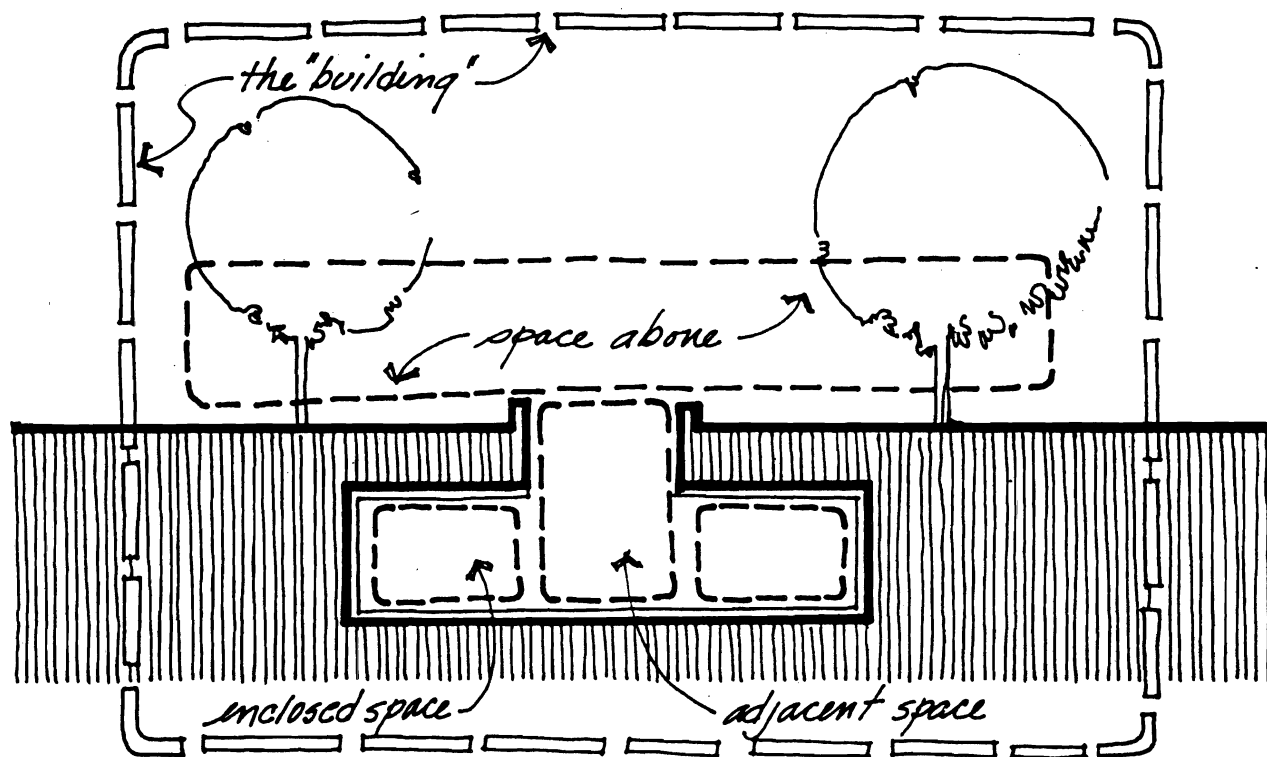


Fig. 1. The Atrium Type

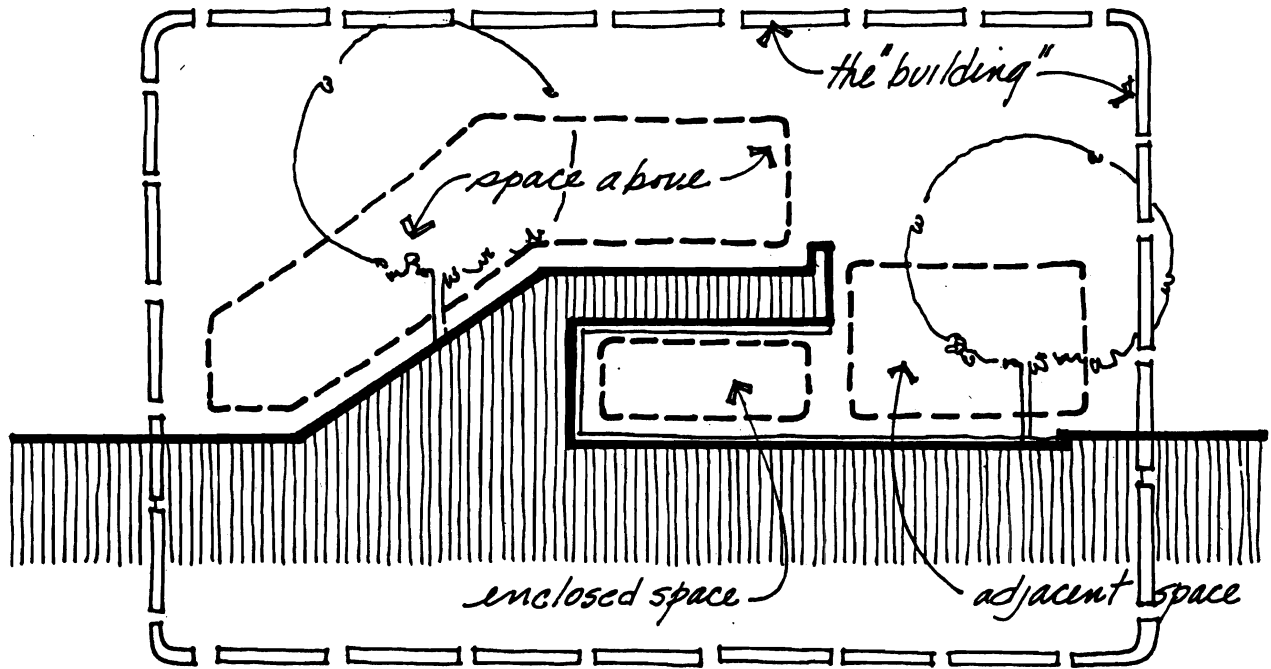


Fig. 2. The South-Facing Court Type

addition, past analysis has understated the interactive effect of several climate variables — a factor of critical importance when designing for a dynamic climate.

We have developed a methodology for analyzing climate in terms of the architectural responses required for thermal comfort. In this paper, we will use it to describe the character of a typical temperate climate, and show how the methodology is useful in the design of earth-sheltered buildings.

We will examine two generic types of underground designs: the atrium type, which has living spaces below ground; and the south-facing court type, which has living spaces at surface level, covered by earth berms (Figures 1 and 2).

Both types have associated outdoor spaces above and adjacent to the enclosed spaces. If we expand our conception of habitable

space, we can consider the "building" to cover the entire site, including these relatively inexpensive outdoor areas. We will show how an understanding of climate can be used to design a thermally comfortable environment, not only in the enclosed, earth-sheltered space, but also in the associated outside spaces.

A dynamic definition of climate

Victor Olgyay (1963) has defined a comfortable climate, or the standard comfort zone (SCZ), as lying roughly between 21°C (70°F) and 27°C (80°F), and between 20 and 80% relative humidity for a lightly clad adult at rest outdoors in shade and still air. According to Olgyay, lower temperatures could also be comfortable depending on the amount of available solar radiation and higher temperatures could be comfortable given varying levels of wind speed. We call this the modified comfort zone (MCZ), which results from certain combinations of temperature, relative humidity, solar gain, and wind speed. Theoretically, given the right conditions, temperatures from 10°C (50°F) to 32°C (90°F) can fall within this modified comfort zone (Brown and Novitski, 1979). The MCZ deals particularly with outside or semi-enclosed spaces where infiltration is not controlled.

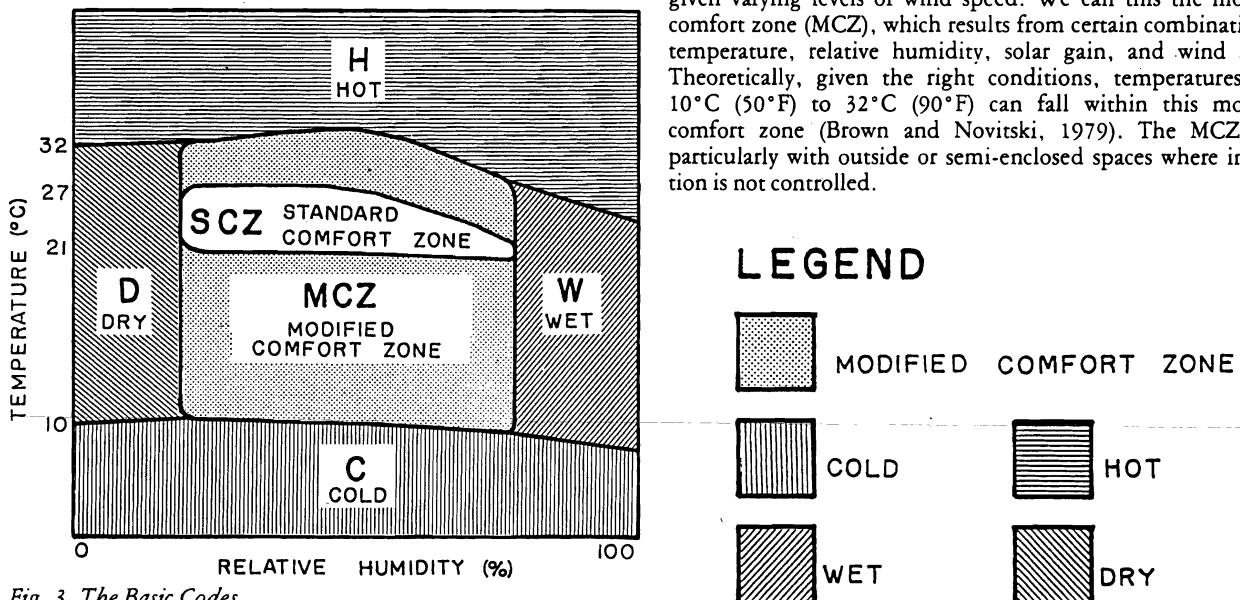


Fig. 3. The Basic Codes

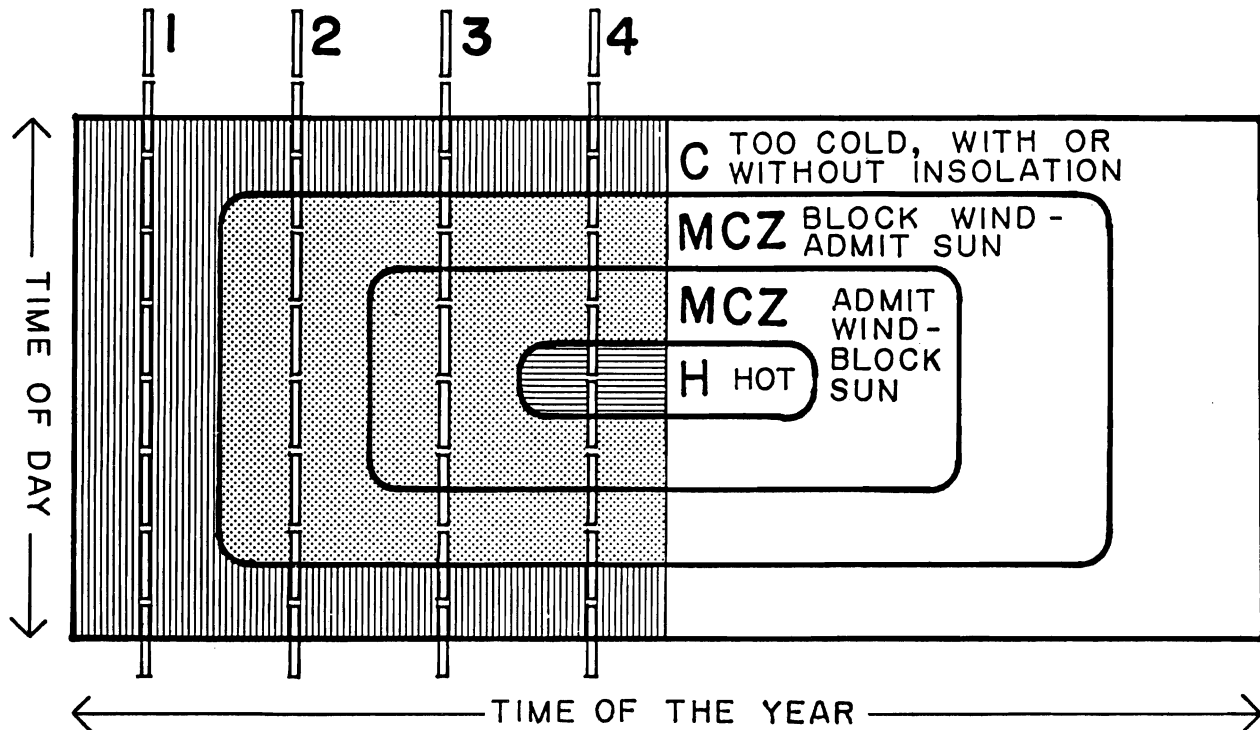


Fig. 4. A Generalized Year Time Table

Outside the built environment, thermal comfort results from a delicate balance of several climate variables — a balance that occurs rarely in North America. However, if some of the variables are manipulated architecturally, the frequency of comfortable periods can be increased dramatically. The variables that can be controlled most easily through architecture are solar gain and wind — which can be blocked, filtered, or admitted when available.

To determine the appropriate architectural response for different conditions, we used data on solar radiation and wind for each hour in a year in several locations. A computer program calculated the interaction between these variables. With this information, we were able to classify each hour of the year in terms of what design features would be necessary to produce comfort. For example, the best treatment for a chilly but sunny morning hour would be to block wind and admit sun; for a warm, breezy afternoon, it would be to admit wind, block sun. Given this architectural treatment, both conditions would fall within the modified comfort zone; without the appropriate architectural response, they would be uncomfortable, and some other means of heating and cooling would be required.

There are hours, of course, when it is simply too cold, too hot, too humid or too dry to achieve comfort by the relatively simple architectural moderation of sun and wind behavior. Figure 3 shows the range of these classifications.

While a very small portion of time in any climate falls within Olgyay's standard comfort zone, a surprisingly high percentage of hours of the year fall in the modified comfort zone. This percentage is higher still if we look only at the hours between 8 a.m. and 5 p.m., as one might do, for example, in designing an office building. Table 1 shows the extent to which we can reduce heating and cooling requirements.

As a further refinement of our analysis technique, we looked at the sequence of classifications throughout the day (from midnight to midnight) for each day of the year in various locations. These sequences form diurnal patterns of changing

Table 1. Percent of time in Standard Comfort Zone (SCZ) and Modified Comfort Zone (MCZ)

Location	SCZ	MCZ	MCZ 8am-5pm
Dodge City, KS	0	28	29
Madison, WI	1	20	39
Medford, OR	1	22	42
Miami, FL	1	44	74
Phoenix, AZ	4	35	45
Seattle, WA	0	15	30
Santa Maria, CA	0	25	66
El Paso, TX	1	38	49
Fresno, CA	1	33	53
Albuquerque, NM	0	26	41
Charleston, SC	0	26	54
Bismarck, ND	1	20	36
Blue Hill, MA	1	19	36
New York, NY	1	22	39

architectural response. Figure 4 shows an annual timetable for a generalized year. By cutting a vertical section through this figure, a pattern is defined as the sequence of codes encountered.

For example, in pattern 1 (Figure 4), the day is cold, though midday may exhibit periods of collectible sunlight. In pattern 4, the day starts out cold, then warms up until it is comfortable in full sun, then warms to the point where shading and ventilation are required, until finally, the day is too hot to be cooled by simple shading and venting. As the day progresses, the air temperature drops, and the pattern reverses symmetrically. (This is a generalization: no climate we have studied actually behaves this regularly.)

Each location can be described by the distribution of these diurnal patterns throughout the year. In contrast to conventional

averaging methods of climate description, these patterns allow us to see the dynamics of climate on both a daily and seasonal scale. They help us to comprehend a year with relatively few day types, to anticipate the architectural problems presented by each season, and to predict whether earth-sheltering and passive solar features — among other things — would be appropriate.

For example, one location might be characterized in one season by days that start out cold, become comfortable during midday, and become cold again at night. This pattern is labelled C-MCZ-C. In a warmer season, the pattern might be cold, comfortable, hot, comfortable (C-MCZ-H-MCZ). A day that exhibits both extremes of hot and cold is a prime candidate for earth-sheltering.

One significant finding of our research is that although climates vary tremendously throughout North America, several important patterns are common. Therefore, designing with climate can be simplified by recognizing the similarities rather than the differences among climates.

One pattern, characterized by cold nights but potentially comfortable daytimes (if the sun and wind are appropriately moderated), is common to all locations we have studied; consequently, every structure should be designed to accommodate it. In hot climates, it is a winter pattern; in cold climates, it is a summer pattern, and in temperate climates, it is a spring/fall pattern.

Dodge City: An example

To illustrate this process, we will examine the climate of Dodge City, Kansas. Dodge City exhibits all the extremes —

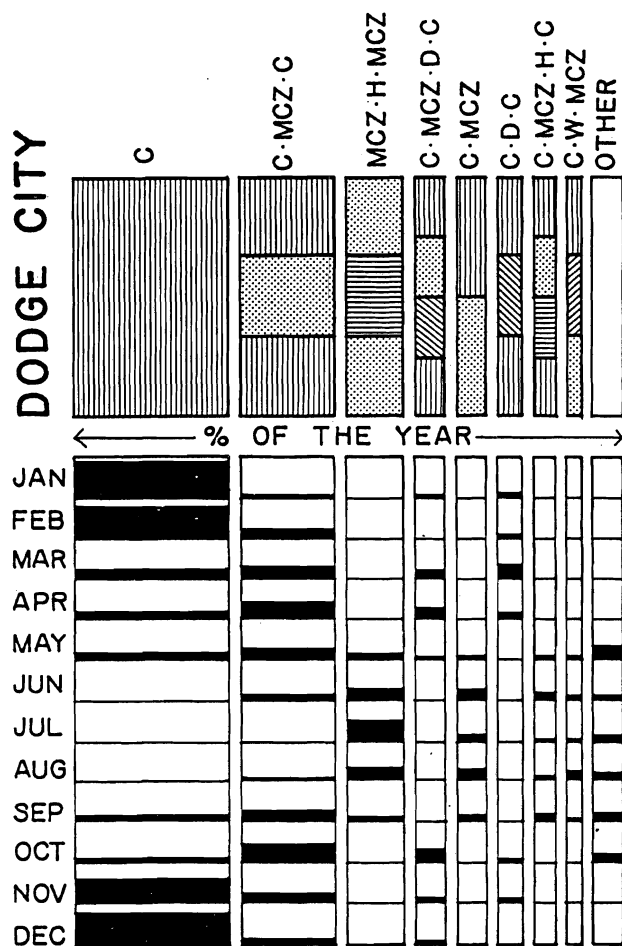


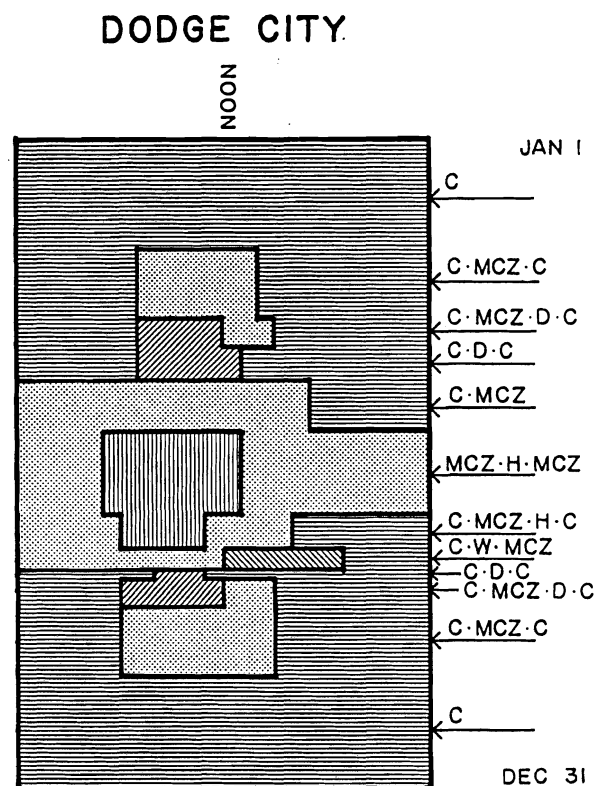
Fig. 5. The Pattern Time Table for Dodge City

Table 2. Description of the Dominant Diurnal Pattern Codes for Dodge City.

C	Cold all day. (winter)
C-MCZ-C	Cold morning and night with outdoor comfort possible during the day. (spring and fall)
MCZ-H-MCZ	Comfortable morning and evening, with overheating mid-day. (summer)
C-MCZ-D-C	Cold morning and night, with periods of outdoor comfort during the day, followed by dry but otherwise comfortable periods. (spring and fall)
C-MCZ	Cold morning followed by comfortable day and evening. (summer)
C-D-C	Cold morning and night with dry but otherwise comfortable daytimes. (winter and spring)
C-MCZ-H-MCZ	Cold early morning, followed by comfortable late morning, with a hot afternoon, followed by a comfortable evening. (summer)
C-W-MCZ	Cold morning, followed by a humid or rainy period, with comfortable evening. (summer and fall)

cold, hot, dry, wet — in addition to extensive periods that fall in the modified comfort zone. A temperate climate such as this one with cold winters and hot summers is an ideal location for earth-sheltering because the stable earth temperatures can be used to minimize the differences between indoor and earth temperatures. We will also show how earth-sheltering can be used to increase comfort where conditions fall in the modified comfort zone.

Figure 5 shows a timetable and annual summary of the dominant climate patterns in Dodge City. Ninety-one percent of the year can be described by only eight day types; the



remaining nine percent exhibit erratic diurnal sequences, many of which may indicate summer storms. (Table 2 describes the pattern codes used in Figure 5.)

To develop architectural design criteria, the next step is to define in more detail the climate classifications shown in Figure 3. For winter, the cold pattern can be defined as cold without sun (nighttime), cold with moderate sun (partly cloudy), and cold with intense sun (clear). These day types can be characterized by the relative importance of direct solar gain (cold, cloudy days), indirect gain (cold, clear days), or heavy insulation (nighttime).

In the summer, when the modified comfort zone predominates, the specific architectural responses will be to block wind and admit sun, or to admit wind and block sun, etc. Taking these climate responses into consideration, earth-sheltered buildings can be designed to effectively meet the specific requirements of each season.

Architectural response of earth-sheltered buildings

Earlier we discussed two generic types of earth-sheltered buildings and their associated outdoor spaces. If we understand and design for the modified comfort zone, we can make these outdoor spaces comfortable for a great deal of the year. Consequently, the designer can justify making the enclosed, more expensive spaces smaller, as the outside area can frequently be used as part of the living space.

Figure 6 shows how each of these types responds to the cold winter conditions with and without sun. The basic premises are that first, when sun is unavailable, heat loss should be minimized. Earth-sheltered buildings, of course, lose less heat than aboveground buildings — and that advantage can be maximized if the windows are protected either by locating them in an atrium, or facing south away from the wind. Heat loss may be further reduced by the use of insulated glazing covers. Second,

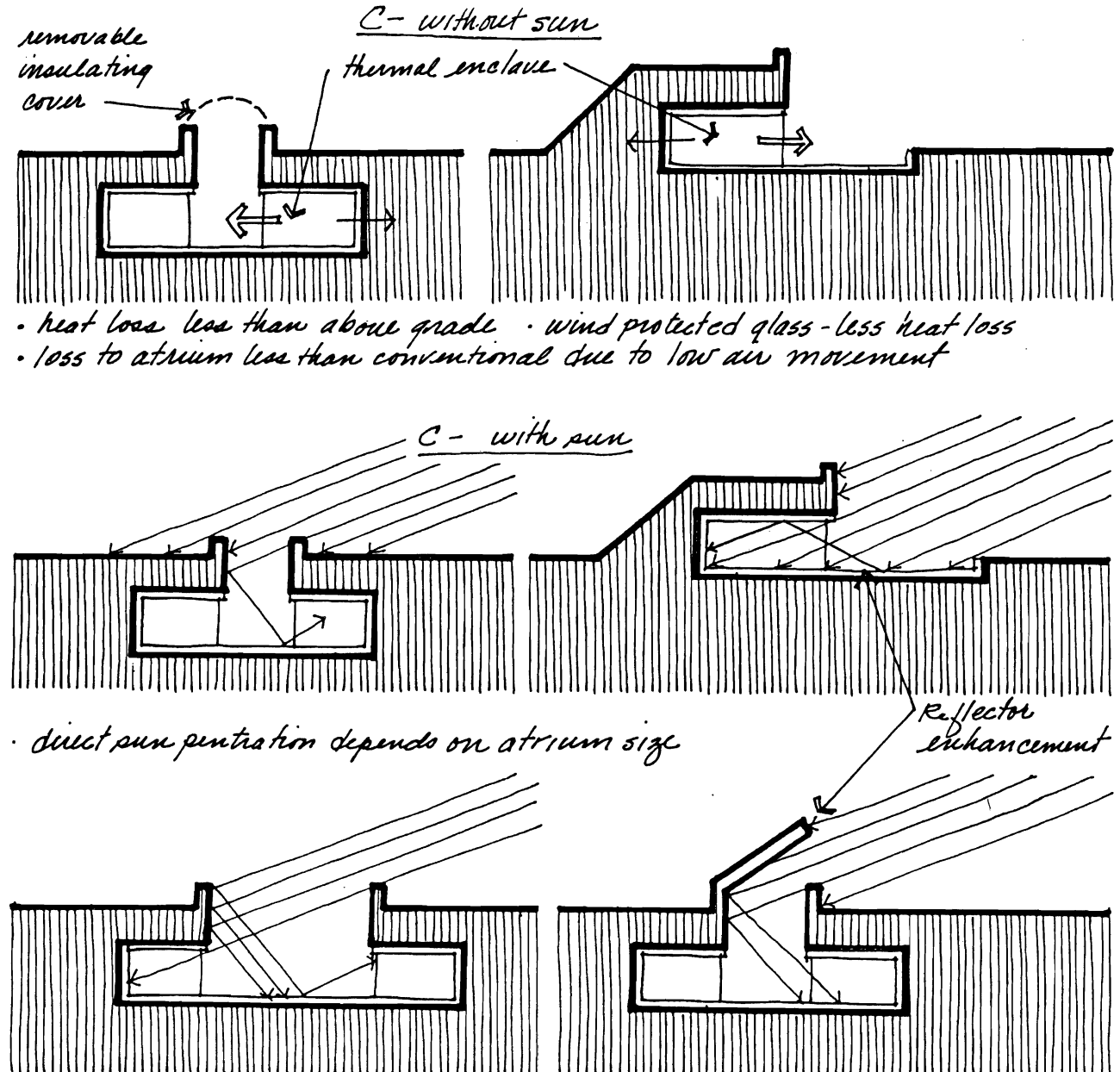
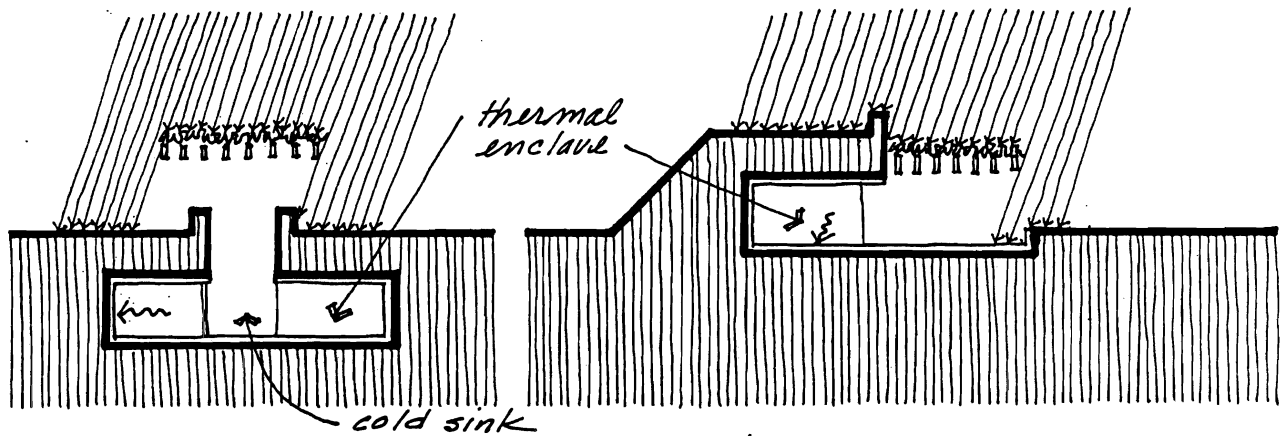


Fig. 6. Earth-Sheltered Responses to the C Pattern



- external shielding from high summer midday sun & low afternoon sun
- desirable heat loss to surrounding earth from thermal enclaves

Fig. 7. Earth-Sheltered Responses to the H Pattern

solar radiation can be enhanced, either by expanding the size of the atrium or by using reflecting surfaces. (The illustrations in Figure 6 are not intended as specific design recommendations for Dodge City.)

Figure 7 shows how each building type responds to hot summer conditions. The sun is blocked, especially at the windows used for winter solar gain, and indoor spaces are cooled by the earth. As in the architectural response to the cold pattern, the enclosed spaces form a thermal enclave that controls the infiltration of uncomfortable outside air.

In Figures 8 and 9, the responses of these two types of buildings to modified comfort patterns are illustrated. Figure 8 diagrams a typical spring/fall condition in temperate climates, with cold nights following moderate days. If the wind is blocked and sun admitted, the outdoor spaces (i.e., the atrium or south courtyard) will be comfortable even in chilly weather. At the site scale, wind can be blocked by trees or by landforms; at the building scale, by the building itself. Sun can be admitted by leafless deciduous trees at the site scale, or by carefully designed overhangs at the building component scale.

Figure 9 diagrams the opposite response, necessary for moderate mornings and evenings with hot middays. Any outdoor space where the wind is admitted and the sun is shaded (i.e., the south courtyard and south of the atrium) would be comfortable in relatively warm weather. Interior spaces would be comfortable

as long as the sun is blocked and natural ventilation provided. In this summer condition, the outside spaces would be shaded by deciduous trees, and the wind, coming from another direction, would not be impeded. At the component level, vents and shades will admit wind and block sun.

Conclusion

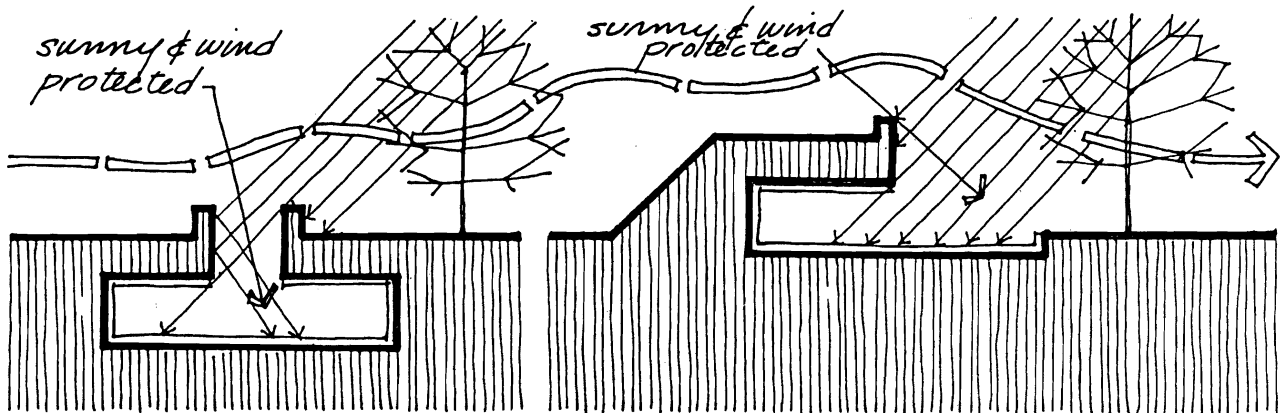
The energy-conservation benefits of earth-sheltering in extreme temperatures is well established; we have demonstrated that these benefits also apply under less extreme conditions. By designing for times when thermal comfort can be achieved through simple architectural means, we can reconsider the thermal environment to include the outside spaces that are always associated with earth-sheltered buildings.

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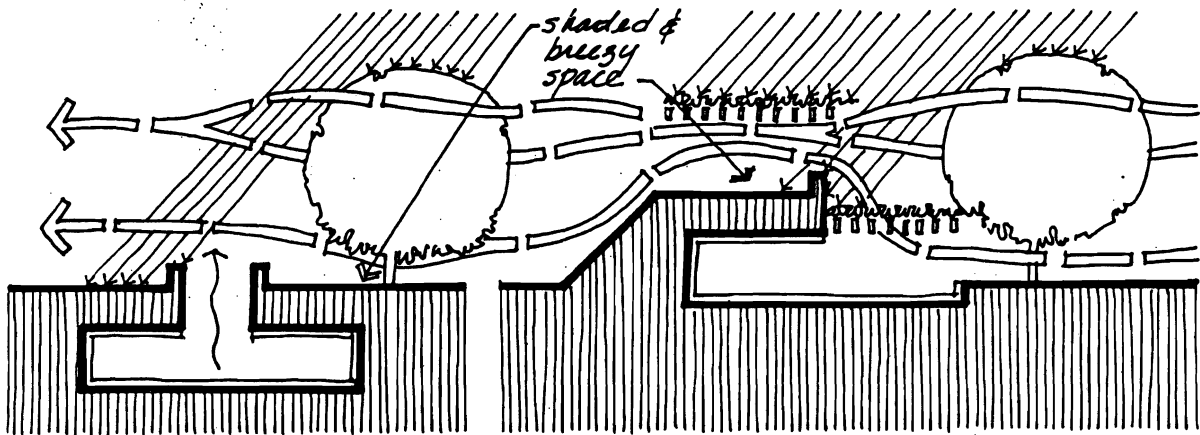
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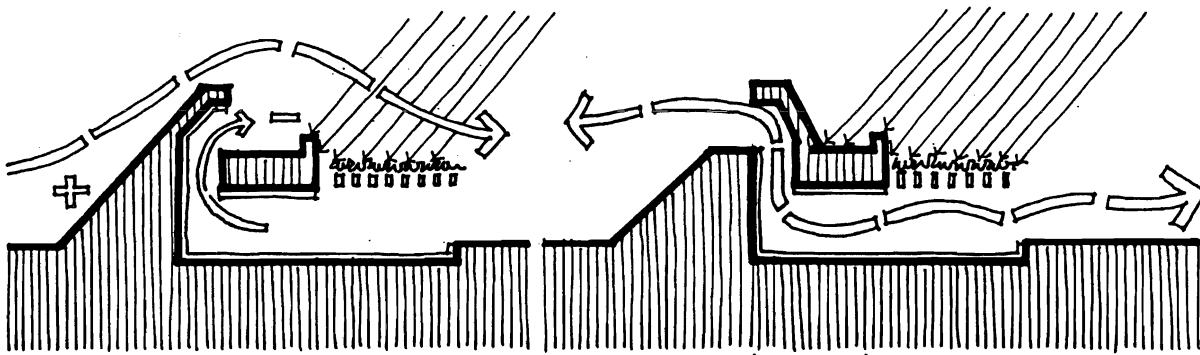


- sun unblocked by leafless deciduous trees
- sun allowed to penetrate indoor space for night time heating

Fig. 8. The Architectural Response, Block Wind-Admit Sun



- outside spaces should be shaded by deciduous trees or vines
- night sky radiation can be used to cool the atrium



- wind scoops can be used to bring the wind into the 'enclosed' space

Fig. 9. The Architectural Response. Admit Wind-Block Sun