CITY FORM:
THE CREATION OF COMFORTABLE URBAN MICROCLIMATES

G.Z. Brown
B. Novitski
H. Kleczynski
Department of Architecture
University of Oregon
Eugene, OR 97403

ABSTRACT

This paper describes a method for analyzing the climate of exterior spaces in terms of human thermal comfort. Hypothetical city configurations are compared in two U.S. climate zones.

1. INTRODUCTION

Exterior spaces in urban settings -- plazas, sidewalks, streets, and parks -- constitute a majority of a city's land use. They form important meeting places, and their character largely determines the "image" of the city. Using natural energy to produce thermally comfortable conditions extends still more the usefulness of these spaces. Designing for sun and wind access results in the need for less built area per inhabitant annd therefore less non-renewable energy consumption. An energy-conscious city provides the most livable area for the least energy cost.

Although the importance of building form and spacing in the determination of microclimates has been discussed by several authors (Robinette[11], Chandler[5], and Miess[9]), their work does not include specific design recommendations based on human comfort. However, specific relationships between climate elements, architecture, and human comfort have been studied by Olgyay[10], Fanger[6], Arens[1], and Brown and Novitski[3]. Separately, the effect of building form on sun penetration (Knowles[8]) and wind speed (Beranek and van Koten[2], Gandemer[7], and Cermak[4]) has been determined for some building configurations. However, the impact of specific city configurations on human comfort has, to our knowledge, never been systematically quantified.

2. METHODOLOGY

Our work is predicated on the "Modified Comfort Zone", or MCZ, a range of temperature and humidity in which comfort is achievable with the appropriate moderation of the sun and wind. An outdoor space can be comfortable in chilly weather if the wind is blocked and the sun is available for warming (MLO), or in hot weather if the sun is blocked and the wind is available for cooling (MHI).

We define the Standard Comfort Zone, or SCZ, as that temperature range (varying with humidity) in which comfort results from the balanced interaction of the sun and wind. The cold code C is broken into three levels of insolation to indicate which solar gain heating systems may be appropriate. The hot code H is broken into three levels of relative humidity to indicate which passsive cooling systems may be appropriate.

In this paper, we concentrate on outdoor spaces at the urban scale. The generalized model we use is shown in Fig. 1. The streets are analyzed by how often they perform well thermally. For each hour in the year which falls within the MCZ, each street is evaluated according to whether it a) admits the sun and blocks the wind, when it is chilly (MLO), or b) blocks the sun and admits the wind when it is warm (MHI). All blocking and admitting are a function of the actual patterns of the wind and sun around the blocks, as determined by wind tunnel studies and conventional sun angle calculations. Selected points throughout the grid are given a score between 0 and 100%: the percent of time they perform well thermally relative to the maximum number of potential MCZ hours.

The result of the analysis is a "contour map" of the city's thermal performance. A designer can use this information in determining the appropriate location for various outdoor functions. Similar monthly evaluations are also available, so that seasonally variable functions can also be located appropriately.

City	MLO(%)	SZC(%)	MHI(%)	Total MCZ
Charleston	24	16	10	50
Dodge City	20	6	8	34
Madison	13	7	5	24
Phoenix	17	16	14	47

Table I

Table I shows the distribution of the various climate codes for several locations and helps to describe the character of each climate. The percentage given for each code is relative to the total number of hours in a year.

3. GENERIC PATTERNS

Using a model of a generic city grid with the block width twice the street width and the block height equal to the street width, (see Fig. 1) we evaluated the amount of time that specific street locations were comfortable. The streets were divided into a grid system, with 8 cells per block (see Fig. 2) so that climatic conditions could be observed for specific street locations.

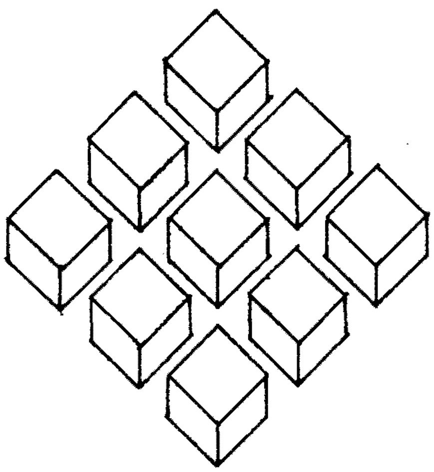


Fig. 1 Model of generic city

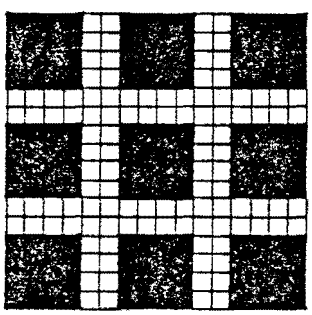


Fig. 2 Cell division of city grid

Using climate data from Madison and Phoenix, the interaction of the sun and the wind was studied for each hour of one day for every month to determine how often each cell was comfortable, compared to the total time of potential comfort. Each hour was analyzed with a solar heliodon to determine which cells were sunny and using hourly wind directions and windflow patterns to determine which cells were windy. During MLO hours, the wind must be blocked and the sun admitted in order for a cell to be comfortable; while during MHI hours, the wind must be admitted and the sun blocked in order to achieve comfort. During SCZ hours, comfort is achievable if both sun and wind are blocked or both are admitted. For hours before sunrise and after sunset, comfort can be achieved by blocking the wind for MLO hours, admitting the wind for MHI hours or doing nothing for SCZ hours.

After all the cells in the city grid were analyzed for each month, the results were combined into seasonal and yearly percentages for Madison and Phoenix climates.

By studying the percentage of comfort actually achieved for each cell in the city grid, we discovered eight generic patterns comparing the relative percentage of comfort between different positions within the city grid. (See Figs. 3-10) Each of these patterns, although derived from specific wind and sun data, occurs more frequently in specific comfort conditions (MLO, MHI, or MCZ), with some consistency between each climate location. In addition, some patterns are highly dependent on wind direction, resulting from a consistent wind direction or many nighttime MCZ hours (such as in Phoenix summers); and some patterns are highly dependent on sun conditions, resulting from a variable wind direction or many daytime MCZ hours (such as in Madison spring and fall).

City Grid Patterns:

In pattern #1, the north-south streets are more comfortable than the east-west streets (see Fig. 3). This pattern occurs during MHI hours, caused by winds from the north or south to cool the streets and shade during the afternoon hours when MHI usually occurs.

In pattern #2, the north-south running (N/S) streets, except intersections, are more comfortable than the east-west running (E/W) streets (see Fig 4). Comfort, occurring during MLO or MCZ hours, is caused by winds from the east or west, which are blocked in these streets. Many MLO hours occur at night when comfort can be achieved just by blocking the wind; therefore this pattern is highly dependent on the wind direction. Both orthogonal and diagonal wind directions produce windy intersections, so an MLO pattern will never have comfortable intersections. During MHI hours, the intersections will be comfortable as long as the sun is blocked.

In pattern #3, the E/W streets are more comfortable than the N/S streets (see Fig. 5). Comfort, occuring during MHI hours, is caused by winds that came most often from the east or west to cool these streets, combined with shade around noon.

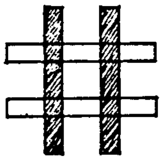


Fig. 3

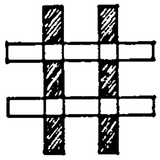


Fig. 4

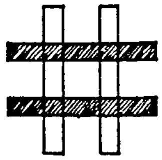


Fig. 5

In pattern #4, the E/W streets, except intersections, are more comfortable than the N/S streets (see Fig. 6). Comfort, occurring during MLO hours, is caused by winds that came most often from the north or south, which are blocked in these streets. Many MLO hours occur at night, so this pattern is highly dependent on the wind direction during MLO hours. Comfort, during MHI hours, results from a diagonal wind direction and shade around noon. The intersections are less comfortable than the E/W streets because they are sunnier than the middle of the block. The diagonal wind does not produce a strong orthogonal comfort pattern, so this pattern is more dependent on the sun during MHI hours.

In pattern #5, comfort is fairly uniform throughout the city grid (see Fig. 7). This MCZ pattern occurs when comfortable spots during MHI and MLO hours are in opposite locations, thus cancelling each other out and producing a uniform pattern.

In pattern #6, comfort is fairly uniform throughout, except the intersections are less comfortable (see Fig. 8). This pattern, during MLO hours, is caused by a mixed wind direction with many night hours. This pattern occurs as an MCZ pattern, when MHI and MLO patterns are opposite, but the intersections are less comfortable due to many MLO hours.

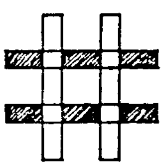


Fig. 6

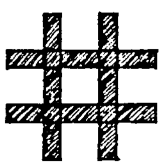


Fig. 7

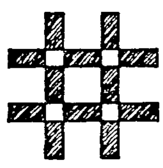


Fig. 8

In pattern #7, comfort is not achieved anywhere on the city grid (see Fig. 9). This occurs either during MLO hours, when the streets are not sunny enough to be comfortable, or during months when it is either too hot or too cold for comfort to be achieved under any sun or wind conditions.

In pattern #8, comfort is only achieved at the intersections (see Fig. 10). This could occur during MHI hours when a constantly changing wind direction would keep the intersections the coolest, as long as they were shaded.

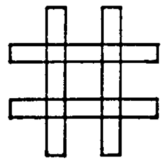


Fig. 9

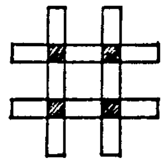
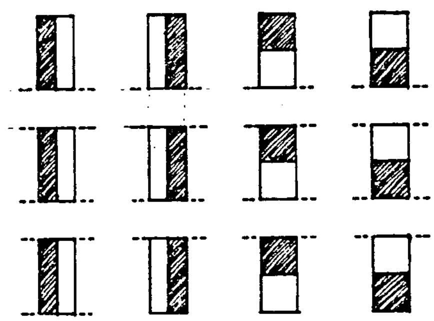
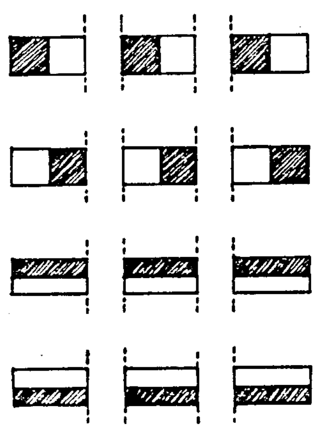


Fig. 10

In addition to these eight city grid patterns, eight patterns for variations of comfort within the street were also observed (see Fig. 11). These patterns are also specific to climatic conditions (MHI, MLO), and are usually more dependent on sun than on wind (because the wind patterns are usually more constant within a given street). These patterns, when combined with the generic city grid patterns, create more specific level of detail to describe the city microclimates.



North/South Streets



East/West Streets

Fig. 11: Street Patterns

It should be remembered that the city grid patterns indicate comfort relative to other positions in the city grid, but do not show actual percentages of comfort.

4. RESULTS

These observations are based on city blocks 98 meters square (320 feet square) of a uniform 18 m. (60') height. The street width is constant at 24 m. (80'). Data points in the center of cells along the edge of each block are evaluated. The cells are arranged similarly to those in Fig. 2 with four in each intersection but with sixteen rather than eight in each street. A hot arid climate based on Phoenix weather data and a cold climate based on Madison weather data have been analyzed for two grid orientations, one orthogonal and one diagonal to cardinal compass points.

The orthogonal grid achieves about a 10% larger portion of the total possible MCZ hours in the Phoenix climate than in the Madison climate. The total annual MCZ ranges from 25 to 38% of the possible MCZ for the Phoenix climate and 17 to 24% for the Madison climate. In terms of total MCZ, the E/W streets perform somewhat better than the N/S streets in the Madison climate; while in the Phoenix climate, the N/S streets perform better than the E/W streets.

Just looking at the MLO condition, the orthogonal grid performs poorly in both climates achieving comfort just 5 to 20% of the hours possible. The E/W streets, especially on the north side, perform best in the Madison climate, as would be expected because of their superior access to sun. In the Phoenix climate, however, the N/S streets perform the best because many MLO's occur at night when the wind must be blocked, but sun access is not necessary.

The orthogonal grid performs best in the Phoenix climate during the SCZ condition, when sun and wind are in balance, achieving 61 to 78% of its potential as compared to 31 to 74% of its potential in the Madison climate. In both cases the intersections performs better than the streets.

The N/S streets perform best in both climates during the MHI conditions because they offer the most shade when the sun is high during the warm months of the year. The west side of the N/S street performs best in the Madison climate because the MHI is usually an afternoon condition, and the sun is most completely blocked on the west side. In the Phoenix climate on the other hand, both sides of the N/S streets perform equally well because the MHI is both an afternoon and morning condition.

Comparing a diagonally and an orthogonally oriented grid in the same climate, Madison, the total performance score achieved is in the 17 to 24% range regardless of orientation. With the diagonal orientation both streets perform about the same; however with the orthogonal orientation, the E/W streets perform about 4% better than the N/S streets. Just considering the MLO condition, the north side of the E/W streets is the most comfortable although the northwest side of the northeast/southwest running (NE/SW) streets is almost as comfortable. The total MLO performance, the predominant condition in the Madison climate, is poor, ranging from 5 to 16% for both orientations.

During SCZ conditions, where any building influence disrupts the balance of sun and wind, the intersections are the most comfortable, and the N/S and northwest/southeast running (NW/SE) streets are the least comfortable.

Under MHI conditions the SW/NE streets of the diagonal grid perform about 10% better than the E/W streets of the orthogonal grid. However, the N/S and NW/SE streets, particularly their west sides, perform the best.

Comparing diagonal and orthogonal grid orientations in the Phoenix climate, for annual MCZ conditions, the N/S streets of the orthogonal grid perform 2 to 4% better than the more uniform NW/SE and SW/NE streets of the diagonal grid.

5. CONCLUSIONS

In both climates studied the streets within the diagonal grid orientation were more nearly equal in performance to each other than the streets within the orthogonally oriented grid. In the orthogonal grid either the N/S streets or the E/W streets performed best depending on climate.

Studies which are currently underway include varying building heights, city squares and two additional climate types.

6. ACKNOWLEDGMENTS

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