THE MICROCLIMATES AROUND FREE-STANDING BUILDINGS

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ABSTRACT

This paper describes the methodology and results of a project to study the behavior of the sun and wind in creating more or less favorable microclimates around two suburban building types in two U.S. locations.

1. INTRODUCTION

Although the importance of building form and spacing in the determination of microclimates has been discussed by several authors (Robinette, Chandler, and Miess), 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, Fanger, Arens, and Brown and Novitski. Separately, the effect of building form on sun penetration (Knowles) and wind speed (Bernek and van Koten, Gander, and Cermak) has been determined for some building configurations. However, the impact of specific architectural 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).

The Standard Comfort Zone (SCZ) occurs when the unobstructed wind, sun, ambient air temperature, and relative humidity balance to produce thermally comfortable conditions. Below the MLO is it too cold for simple radiation to provide sufficient warmth, and above the MHI it is too hot for the wind to provide sufficient cooling. These cold and hot periods, when enclosure and other measures are required for heating and cooling, have been excluded from this analysis of outdoor spaces. All data are relative to potential MCZ hours.

We have developed a computer model which describes a building or a cluster of buildings. Shading patterns throughout the year are calculated for the surrounding field. Similarly, a physical model is built and subjected to wind tunnel tests. Selected points in the field are evaluated for every potentially comfortable hour in the year. For each hour, resultant wind and sun intensities are calculated, based on real hourly weather data and modified by the adjacent building configuration. The final computer printout gives a "score" for each point analyzed indicating the percentage of time that the point, by virtue of its orientation around the building, is thermally comfortable. Results are also available for each month separately so that seasonal variations can be detected.

3. RESULTS

The studies included in this paper are for free standing, suburban, residential-scale buildings with two generic shapes: an ell and a courtyard house. See Figure 1. In each case the outside space created by the building geometry was divided up into a four-by-four grid. The ell was analyzed for four orientations and the courtyard for two orientations for every hour in a year for the climates of Madison, Wisconsin and Phoenix, Arizona.

The percentages shown for each MCZ condition are relative to the total possible hours for that condition under ideal conditions. For example, if a point on the grid is in the shade only half of the MHI hours, (block sun, admit wind) it will receive a score of 50.

3.1 Comparing Four Orientations of the Ell

The ell-shaped building was analyzed for four

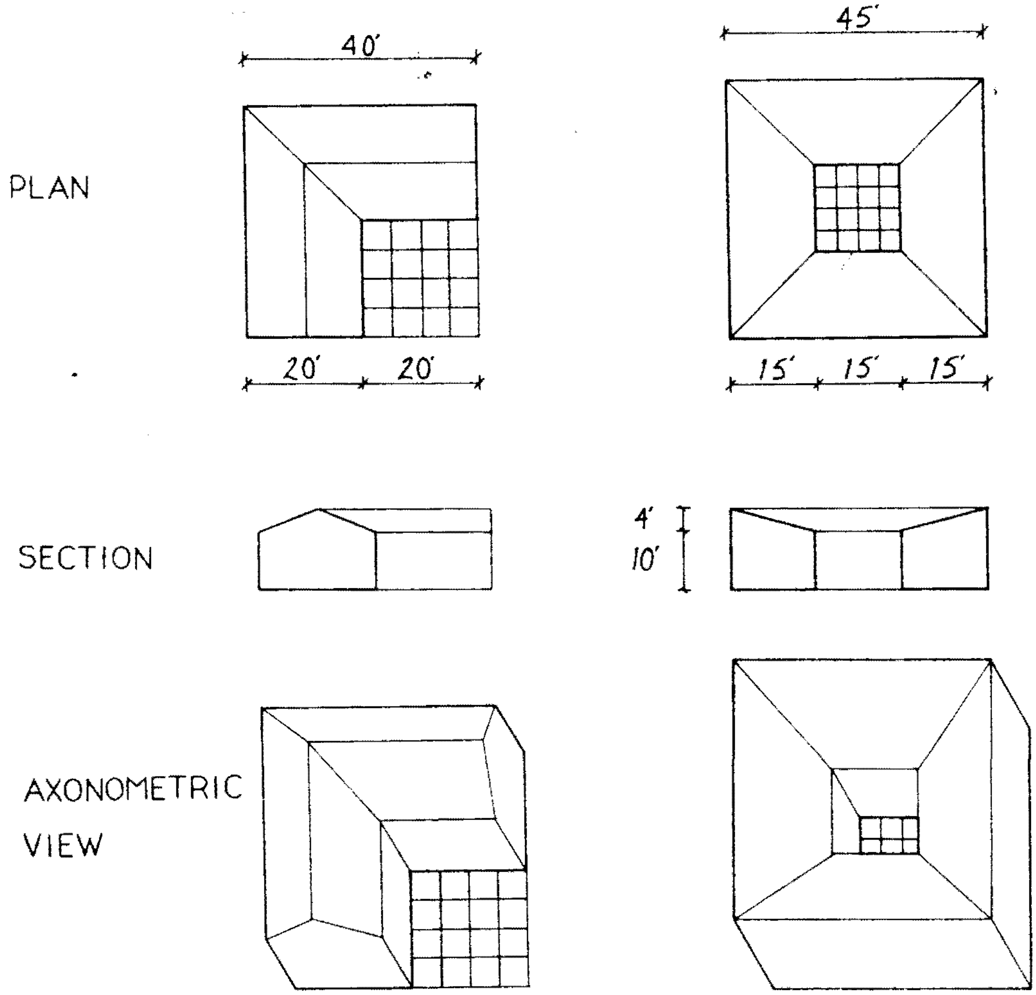

Fig. 1 Ell and Courtyard Configurations

orientations in Phoenix, a hot, dry climate. MHI in Phoenix is a morning condition, MLO when you need to block the wind but the sun is not necesary (or available) for warming, is primarily a nighttime condition.

The grid scores for the Phoenix ell are shown in Figures 2 and 3. The heavy lines repreaent the sides of the grid formed by the building. North is to the top of the page.

Because MLO is frequently a night condition, the best performing areas for all orientations are in or near the corners, where there is the best protection from the wind. The south-facing orientations are somewhat better due to the times when solar radiation is needed and available for heating. Since this happens usually in the morning, the southeast facing courtyard performs the best. For all orientations, the unprotected corner performs the worst.

26	31	36	38
26	28	34	39
32	32	36	38
34	35	35	39

44	36	29	20
44	39	31	22
44	44	39	31
43	39	40	41

45	47	47	47
37	42	48	44
28	35	44	45
20	26	37	48

53	50	49	45
48	49	43	39
49	43	36	30
47	38	30	24

Fig. 2 MLO Scores for the Ell in Phoenix

During MHI periods in Phoenix when shade is critical, occur in the late morning and early afternoon throughout most of the year and during the late afternoon only during the cooler months. Therefore, the best performing locations face north and, because of the relatively high solar altitude, are close to the building. Although more wind is available farther from the building, shade is not, and this is the controlling factor.

1	5	9	16
2	6	10	17
5	12	16	20
14	21	27	27

18	13	8	4
17	14	13	9
19	16	17	13
27	29	25	19

2	5	10	19
2	6	10	16
2	6	9	16
1	3	5	10

18	12	9	6
17	13	11	8
16	12	11	7
10	9	9	6

Fig. 3 MHI Scores for the Ell in Phoenix

Since the best MHI spaces face north and the best MLO spaces face south, this suggests a design solution with two outdoor spaces, one for each orientation.

3.2 Comparing Madison and Phoenix Performance of a Northeast Facing Ell

Madison has cold winters and cool nights throughout the year, so most MCZ occurs during the day, spring through fall, with occasional overheating periods in summer afternoons. Unlike Phoenix, its MLO usually occurs in the morning, and the MHI in the afternoon.

32	27	19	15
29	28	23	19
27	28	28	26
21	22	23	29

44	36	29	20
44	39	31	22
44	44	39	31
43	39	40	41

Fig. 4 MLO Scores for Madison and Phoenix

During MLO periods, both locations demonstrate diagonal regions in the northeast facing yard which vary in performance as a function of their proximity to the corner. In Phoenix, as previously described, the best performing area is nearest the corner, where the wind protection is best. In Madison, where sun is more important for MLO warming, the corner is too shady, so the best region is away from the corner. The exposed corner offers too little wind protection, so the performance drops back down.

28	36	53	65
26	30	37	51
26	26	30	35
29	28	26	26

36	48	60	72
32	36	48	59
28	29	34	47
25	27	29	32

Fig. 5 SCZ Scores in Madison and Phoenix

The standard comfort zone, or SCZ, occurs when the sun and wind naturally balance to produce a comfortable effective temperature. Since any architecture will upset this balance, the times of SCZ always perform best away from the building regardless of climate region or yard orientation.

43	27	15	4
47	35	21	12
48	39	27	18
65	64	60	49

18	13	8	4
17	14	13	9
19	16	17	13
27	29	25	19

Fig. 6 MHI Scores for Madison and Phoenix

Since MHI is an afternoon condition in Madison, the northeast facing yard performs very well near the building, where the shade is the most consistent. However, in Phoenix, MHI occurs during the late morning to early afternoon when the sun is too high to be effectively shaded by the building.

33	29	28	26
32	30	27	26
31	29	28	27
32	33	32	32

31	30	30	29
30	28	29	28
30	29	29	29
32	31	31	30

Fig. 7 Total MCZ Scores for Madison and Phoenix

Considering the clear differences between the climates and the performances for the various conditions, it is surprising that the scores for the total MCZ are so uniform between climates and within the grids. Since the best locations for one condition are usually the worst locations for another condition, their scores cancel each other, yielding an average score which is uniformly mediocre.

3.3 Seasonal Variation in Phoenix

The northeast facing ell shaped building was analyzed for Phoenix in January, May, July, and October, representative months of winter,

WINTER

25	29	31	18
6	4	7	9
6	6	5	15
6	6	6	13

SPRING

63	47	32	25
71	62	43	34
72	67	58	47
73	65	63	60

SUMMER

59	46	33	23
72	65	50	27
82	82	68	45
89	86	81	71

FALL

52	32	18	13
55	47	29	17
58	58	47	31
53	47	53	49

Fig. 8 MLO Scores for Phoenix

12	16	42	44
0	1	7	11
0	0	1	9
0	0	0	7

40	59	73	86
34	44	59	81
30	33	44	59
27	34	39	44

49	65	77	85
46	53	68	77
44	44	53	64
39	43	44	47

46	56	62	72
43	46	53	69
34	32	39	59
28	28	32	38

Fig. 9 SCZ Scores for Phoenix

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	3

18	14	6	0
16	18	19	16
15	14	16	14
23	26	25	14

0	0	0	0
0	0	0	1
0	0	0	0
0	1	1	0

30	28	22	15
29	22	22	15
49	48	52	45
47	50	51	42

Fig. 10 MHI Scores for Phoenix

19	22	30	22
4	3	6	8
4	4	4	12
4	4	4	10

35	31	24	20
35	35	33	32
34	33	33	31
39	39	38	33

32	37	39	41
32	34	39	39
33	33	35	36
32	34	33	33

40	34	28	24
40	34	30	25
49	48	48	43
46	45	49	44

Fig. 11 Total MCZ Scores for Phoenix

spring, summer, and fall. Figures 8-11 illustrate the scores for the four conditions for these four months.

For reasons discussed earlier, MLO performs best in the wind protected corner except in the winter, when the sun is the controlling factor. The SCZ condition performs best, as always, away from thė building. The MHI is virtually nonexistent in the winter, and performs best in the spring and fall in the shady places near the building. Because it is a morning condition in the summer, the east facing yard receives no protection from the high sun, so the performance is very poor.

Because the various conditions perform so differently there is also a difference between optimum locations from season to season. The northeast corner is best in the winter and summer and the southwest corner is best in the spring and fall.

3.4 The Courtyard Building in Two Climates

The building with a totally enclosed courtyard was analyzed for Madison and Phoenix. Because the geometry of the court is deep relative to its area, it tends to be well protected from both sun and wind. The wind reduction is 84-88% of normal throughout the courtyard, and it is shady except when the sun altitude is very high.

As a result, the MLO performs poorly in Madison where sun access is important. The sunniest north edge performs least poorly. In Phoenix where sun access is better and where MLO is frequently a night condition, the good wind protection in the courtyard is the controlling factor and overall performance is very good.

27	24	22	24
24	23	21	21
20	19	18	18
17	14	13	16

46	45	43	44
44	45	43	41
41	42	42	40
43	41	41	43

Fig. 12 MLO Scores for Courtyards in Madison and Phoenix

The MHI situation is just the reverse. In Madison the court performs very well during MHI hours because these occur during the mid to late afternoon when the sun is too low to penetrate. During these periods, the wind velocity is high enough so that it is sufficient for cooling even when it's reduced. In Phoenix, on the other hand, MHI frequently occurs around midday when the sun is too high to be blocked by this geometry.

53	47	43	41
53	50	45	41
58	56	52	47
73	72	71	71

22	21	23	26
25	24	26	29
28	27	29	32
33	34	35	35

Fig. 13 MHI Scores for Courtyards in Madison and Phoenix

The SCZ condition performs badly in both climates since the large wind speed reduction adversely affects the otherwise comfortable balance of sun and wind.

25	24	24	24
24	24	22	23
25	25	24	25
31	28	28	30

22	26	26	22
26	26	26	27
26	26	26	27
22	26	27	22

Fig. 14 SCZ Scores for Courtyards in Madison and Phoenix

The total MCZ exhibits an averaging effect because the various conditions perform differently in different places in the courtyard, they tend to balance each other out and yield a uniform performance total for both locations.

3.5 Comparing a Courtyard and an Ell in Phoenix

A courtyard configuration was compared to four orientations of an ell-shaped building for Phoenix. The supporting data have already been shown in figures 2, 3 and 12-15.

32	29	27	28
30	29	27	26
30	29	27	26
33	30	30	32

29	30	30	31
31	31	31	32
32	31	32	33
33	34	35	34

Fig. 15 Total MCZ Scores for Courtyards in Madison and Phoenix

For the MLO condition, the courtyard has a more even distribution than any of the ells. It's highest score is lower than the high score in the southeast- and southwest-facing ells but higher than the high score of the northeast and northwest facing ells.

With the MHI, the courtyard again exhibits the evenest distribution and, overall, much higher scores. The courtyard scores resemble a summary of the best scores from the ells.

Because the ells provide less obstruction from the wind, the SCZ performs far better than in the courtyard. When you look at the total MCZ, all of the strong tendencies cancel each other, and no single location within the yard is a clearly preferable place for outdoor activities.

4. CONCLUSIONS

Several outdoor space configurations were analyzed for their effects on microclimates in Madison, Wisconsin and Phoenix, Arizona. Each configuration was found to behave differently for each of several climatic conditions, but on average, every configuration was found to have a uniform and mediocre performance score. It appears that, to maximize comfortable outdoor spaces, it is necesary to have at least two different spaces with different orientations -- one for cooler times and one for warmer periods. This suggests a Z-shaped building. with two yards facing opposite directions. The particular directions depend on local climatic conditions and can be surmised from the data tables.

Improved performance for both building types can probably also be realized by adding changable elements like canvas covers which provide shade for the MHI condition but are removed to permit sun penitration during the MLO condition, or by modifying the wind flow through the open area using windbreaks to create areas of higher or or lower velocity in appropriate areas.

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