ABSTRACT: For the last ten years the MRT program has been under-development by the author, at the University of Arizona. The program provides a numerical analysis tool to be used by designers to evaluate human thermal condition in outdoor urban spaces by predicting the impact of the radiant elements and the microclimate elements that contribute the most to the "urban heat island" phenomenon. Due to the complex geometry of urban outdoor spaces, recently, the MRT method adopted the fish-eye lens photography technique to accurately estimates a person’s view-factors which represent the spherical radiating environment acting on a 6’ average human figure in a specific location. This method is more precise than the previous hand calculation. While originally the method is used for existing open spaces, this paper describes a new approach by the author for the evaluation of person’s view factors in designed (non-built) urban spaces through fish-eye lens photography of scale models. The method assumes that the actual environment can be reduced in scale up to the limit of the sphere whose diameter is the size of the fish-eye lens in use. A case study of the “Arts Oasis”—a plaza on the campus of the University of Arizona—is used to demonstrate the new method. Comparison between results obtained from the real plaza to that obtained from a 1”=6’ scale model showed close similarity with only ±10% overall margin of error. When assigning surface temperatures and microclimate data to the scale model, the method provides a design tool for thermal comfort evaluation of non-built open spaces.

1. INTRODUCTION

Urban development continues to replace natural biological communities with the human necessities of habitation, commerce and transportation. The physical results of these human needs are the built elements of a city. This man-made urban form has a direct impact on the local microclimate. In the climatic extreme of arid regions this "heat island" phenomenon reduces the hospitality of a community by increasing the energy needed for cooling indoor spaces as well as by causing thermal discomfort in outdoor spaces.

Since 1989, the MRT program has been developed by the author, at the University of Arizona [1] [2] [3] [4]. The program provides a numerical analysis tool to be used by designers to evaluate human thermal condition in outdoor urban spaces. Relative to a given outdoor location, the impact of three major elements is analyzed: 1) long-wave radiation from surrounding buildings, 2) microclimate elements, such as sun, wind, temperatures, etc., and 3) man-made features, such as paving materials, landscape, water features, etc.

In 1998, the MRT program was used to evaluate the thermal condition of the El-Presidio urban plaza in downtown Tucson, Arizona, and the results were published in the proceedings of PLEA’98, Lisbon [5]. In the extreme climate of the southwest region, this evaluation was necessary to preserve the plaza as an important cultural space. The study of one location on the plaza revealed that in a summer day (June 21) an average mean radiant temperature of 182°F in the shade was observed. This is about 60 to 75°F higher than the average dry-bulb temperature. Thermal condition of the location was affected by long-wave exchange from ground cover (concrete paving) and near-by-buildings at 45% and 32% view factors respectively. A person’s view-factor is defined as the fraction of the radiant flux which strikes a person from a particular surface to that which would be received from the entire environment radiating uniformly [6].

Figure 1: Person’s view factors in radiating field.
When evaluating existing urban spaces, MRT method of estimating a person’s view-factor is by using fish-eye lens photography to represent the spherical radiating environment acting on a 6 feet average human figure. This method calculates the exact percentages of the different radiating entities affecting the thermal environment at a given location.

2. PHYSICAL MODELS

Since the fish-eye lens photography technique utilized to predict person’s view factors, used by the MRT program, applied only to existing urban spaces, it was necessary to further develop this technique to account for designed (non-built) urban spaces. This is necessary for designers and students to evaluate their projects by estimating view factors which, from the author perspective, could practically be determined from scale models.

2.1 The Approach

Theoretically, physical models of buildings and urban open spaces provide a means of accurately predicting daylight illumination while not suitable where the phenomenon does not scale down properly such as in the case of the thermal environment. However, in complex building geometry, physical models, when combined with fish-eye lens photography, can provide a quick, easy, and reliable way to compute the area and orientation of the various surfaces (view-factors) contributing to the radiant field at a reference point which otherwise would involve complex, often unmanageable, equations.

2.2 Determining of the Scale

For long-wave infrared radiation, where radiation from all surfaces must be considered, methods based on actual human figure model are too laborious to be practical. In practice, the long-wave mean radiant temperature is measured using a globe thermometer which is considered a close approximation to that for the human body [7]. By using a spherical target, whose diameter includes a 6 feet human figure, computation of the view factors is greatly simplified.

Because MRT uses fish-eye lens photography to represent the hemispheric radiating environment acting on a 6 feet average human figure, we can then assume that the real environment can be reduced in scale up to the limit of the sphere whose diameter is the size of the fish-eye lens in use. If the lens diameter is 1” (22.5 mm) then the scale is 1” = 6’.

3. THE “ARTS OASIS” CASE STUDY

The University of Arizona “Arts Oasis” site is a 1.8 acre central open space surrounded by the Colleges of Fine Arts from the west and south, the College of Architecture, Planning and Landscape Architecture (CAPLA), and the Center for Creative Photography (CCP) from the east and Speedway Boulevard from the north (Fig. 4).
At present, the Arts Oasis does not live up to the creative potential implied by its location. The site was excavated in 1987-88 to accommodate a pedestrian and bicycle underpass. Subsequent development of the College of Fine Arts expansion project helped to further define the site as an important campus open space. Without integrated site improvements, however, these projects were achieved at a detriment to building visibility and access and to site’s usefulness (Fig. 5).

Visually and functionally, the area is considered by many to be an embarrassment to the University, with steep, eroded slopes, virtually invisible and/or inaccessible buildings, minimal lighting, few walkways and almost no plantings. While it was never intended that the Arts Oasis remain undeveloped, unforeseen budgetary problems have conspired to leave the site in a state of neglect. University efforts have been in progress since 1992 to reserve this trend by attempting to define a program for the site and identify funding sources for its improvement. A study was done for a concept design and implementation strategy for the Arts Oasis[8].

3.1 Scope of Work
A collaborative research work through the Masters thesis of Mr. Girish Kripalany [9], a graduate student at the College of Architecture, Planning, and Landscape Architecture, and the author, as committee chair, is conducted to predict and analyze the thermal conditions of the plaza using the newly developed model photography method.

The process involved four major steps: 1) Estimating a person’s view factor by using fish-eye lens photographs at eight different selected locations on the actual plaza. 2) Collecting microclimate data on a typical summer day. Data includes dry-bulb and wet-bulb temperatures, wind speed, solar radiation and shading conditions. 3) calculating the MRT longwave which determines the thermal condition as a result of the radiating objects on the plaza. And 4) Constructing a scale model of the plaza and repeat the fish-eye lens photography process at the same exact location as in the real plaza, and determine the view factors. Finally, a graphical comparison between view factors determined from actual site and that from the model is made to verify the accuracy of the process of using scale models.

3.2 Construction of the Model
The model was constructed at a scale of 1”=6’-0” taking into account that the 1” camera lens = 6’-0” average human height as explained above. For calibration purposes, all materials used in the model represented the actual materials on site by the same color. Also, all trees were constructed to actual scale (Fig.6).

3.3 Photography of the Model
The model was placed on a four legged stand outdoors to provide underneath access to its base. It was oriented exactly the same direction as on site. Care must be taken to keep the model perfectly
horizontal to the ground with the help of a level. Starting with location 1, a picture was taken with the camera placed on a tripod with its lens facing downwards, parallel to the floor, and ½” above the floor. The camera is then inverted to get the picture of the sky. A circular opening in the base of the model at the particular location 1, being the same diameter as the lens of the camera, had to be cut. The camera is then placed on a tripod underneath the model and raised up through the circular opening at the base. A picture is then taken with the camera lens elevated ½” above the floor surface and is parallel to the plane of the model floor at location 1. The process is then repeated for all eight locations. Figure 7, below demonstrates the site and the model fish-eye lens photography technique while Figure 8 shows the fish-eye photographs taken for the same location 1.

3.4 Calculation and Calibration of View Factors

After the photography session, the circular images produced by the fish-eye lens are overlaid with a polar grid with 25 annuli and 40 radii dividing the circle into 1000 parts. Each cell in this polar grid represents 0.1 percent of the radiating environment on half of the radiating hemisphere. Therefore, combining both the looking upwards and the looking downwards photographs, each cell in the polar grid will represent 0.05% of the total radiating environment at that location [10].

The circular images looking upward show the surrounding buildings, foliage and other objects, whereas the images taken by pointing the lens toward the ground show ground cover, grass and other landscaping elements as well as the lower portions of the surrounding buildings. To calculate each of these areas simply count the number of cells occupied by the materials or objects and multiply it by 0.05. Table 1 below shows the view factors obtained from site photography compared to those obtained from model photography for location 1. It also shows the margin of errors calculated individually for each material as well as the percentage weighted margin of errors.

<table>
<thead>
<tr>
<th>Surface Material</th>
<th>Site %</th>
<th>Model %</th>
<th>Margin of Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sky</td>
<td>8.2</td>
<td>7.8</td>
<td>-4.9%</td>
</tr>
<tr>
<td>Concrete</td>
<td>45.5</td>
<td>47.8</td>
<td>+5.1%</td>
</tr>
<tr>
<td>Building</td>
<td>42.0</td>
<td>39.6</td>
<td>-5.7%</td>
</tr>
<tr>
<td>Foliage</td>
<td>0.2</td>
<td>0.2</td>
<td>0.0%</td>
</tr>
<tr>
<td>Asphalt</td>
<td>3.1</td>
<td>3.5</td>
<td>+12.9%</td>
</tr>
<tr>
<td>Rocks</td>
<td>1.0</td>
<td>1.1</td>
<td>+15.0%</td>
</tr>
<tr>
<td><strong>100 %</strong></td>
<td><strong>100</strong></td>
<td><strong>±5.7 %</strong></td>
<td></td>
</tr>
</tbody>
</table>

From the above table, it is obvious that even the margin of error of some materials is above 10%, the overall percentage weighted error is about ± 5.7 %. Results for the other 7 locations yielded similar overall margin of errors; around ± 10 %.

3.5 Thermal Comfort Assessment

As described above, using fish-eye lens photography we have established the person view-factors for each location. The result of the estimation method gives us the exact percentage of radiating surfaces at each location, affecting thermal conditions. These values are then used to calculate the longwave MRT\(_{LW}\) (Mean Radiant Temperature), i.e. the collective thermal effect of surrounding building and landscaping materials on microclimatic changes. This is achieved by assigning surface temperatures and emissivity values relevant to each material. For a given time and date, MRT\(_{LW}\) is calculated from the following equation:

\[
MRT_{LW} = \left(\frac{\sum VF_i E_i T_i^4}{\sum VF_i E_i T_i^4}\right)^{1/4}
\]

Where VF is the view factor, E is the emissivity, and T is the absolute temperature of the material.

The following graphs (Fig. 9) demonstrates similarities of MRT\(_{LW}\) results for the eight selected location at the Arts Oasis plaza.
Although not demonstrated in this paper, the process should continue by inputting human figure parameters, such as clothing factors and metabolism activity, and microclimate parameters into the MRT program to predict the PMV index of thermal comfort at each location. This process is explained in previous publications by the author [1, 2, 3, 4 and 5].

4. CONCURRENT WORK

Currently, the author is co-teaching, with Professor Fred Matter, a graduate design studio—Arc502; “Sustainable Urban Design”—where students are utilizing the fish-eye lens photography of scale models to analyze the thermal conditions of two main plazas in downtown Tucson. Both plazas are not yet built but they are part of the overall master plan of the “Rio Nuevo” a major revitalization project currently undertaken by the City of Tucson. After building the scale models for the two plazas, the students will evaluate the thermal conditions at different locations, apply design strategies for improvement, and finally conclude design guidelines to be reported to the City of Tucson and the project’s master planners. Figure 10 below shows students using fish-eye lens photography of a near-by plaza for the purpose of validating the process, and for a later installation of five climate stations to collect microclimate data.

5. CONCLUSION

Fish-eye lens photography, can provide a quick, easy, and reliable way to compute the area and orientation (called view factors) of the various surfaces contributing to the radiant field at a reference point in outdoor spaces which otherwise would involve complex, often unmanageable, equations. In this paper, the author provided a new method by which in complex building geometry, physical models are combined with fish-eye lens photography to provide an accurate tool for the prediction of thermal conditions in designed (non-built) urban spaces. As demonstrated by the Arts Oasis case study, the accuracy of predicting view factors from scale models was proven to be within ±10% from that predicted from the existing spaces. This method, added a new capability to the author’s MRT computer program, in providing a flexible design tool with which designers can investigate scale models, have the freedom to change the geometry of the space, replace landscaping and hardscape materials at a particular location and test the results again to optimize the climate condition and achieve human thermal comfort.

ACKNOWLEDGMENT

The author would like to acknowledge engineer Lew Thompson for his help in the development of the algorithms used in the MRT program and graduate student Girish Kripalani for undertaking the process as a major part of his masters thesis.

REFERENCES


