Sustainable urban design and outdoor space analysis using MRT®, and photography of scale models: A case study of the Rio Nuevo project in Tucson, Arizona, USA.

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Abstract

A methodology for assessing thermal comfort conditions in outdoor spaces is described. Utilizing fish-eye lens photography of scale models view factors of radiating objects relevant to a location are calculated. The MRT® computer program is then used to manipulate the data, including the microclimate, and to predict the PMV comfort index. The method allows designers improve the thermal conditions by retesting the models. Recently, an agreement was made between the University of Arizona and the Rio Nuevo Facility of the City of Tucson to perform on a project entitled “Sustainable Urban Design and Outdoor Space Analysis of Rio Nuevo”; a major revitalization project for downtown Tucson. A team of faculty and graduate students collaborated on the design and assessment of major outdoor plazas within the Master Plan proposed by the “Rio Nuevo” authorities. The method provided a mean to efficiently design thermally comfortable outdoor spaces and provided opportunity to contribute in minimizing the urban heat island phenomenon in urban spaces.

Conference topic: education and transfer of technology
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INTRODUCTION AND DESCRIPTION OF THE RIO-NUEVO MASTER PLAN PROJECT

Like many cities throughout the world, the downtown core of Tucson, Arizona was dying through activity exodus to suburban areas. Simultaneously, the adjacent Santa Cruz River basin, once a fertile riparian area, upon which Tucson was founded, dried up and became a repository for trash. Following other fragmented initiatives to reverse these trends and re-establish the birthplace and civic core of Tucson, the Rio Nuevo Multipurpose Facilities District was established in November 1999 by passage of proposition 400 in the general public election. This authorized the raising and use of 360 million USD of tax increment funding to seed long-range development. In 2000, a multidisciplinary planning team, following an interactive process, that elicited needs and visions from thousands of citizens, prepared a comprehensive new Rio Nuevo Master Plan. The plan outlined a design vision to: “Create a vital city heart that expresses and nurtures Tucson’s unique natural landscape, cultural heritage, rich history, and community values.”

On January 17, 2001 an agreement was made between the Arizona Board of Regents (ABOR) for the University of Arizona and the Rio Nuevo Multi-Purpose Facility District of the State of Arizona for the City of Tucson to perform certain services for a project entitled “Sustainable Urban Design and Outdoor Space Analysis: Critical Regionalism, Energy Conservation, Passive Solar Systems – Rio Nuevo.” A team consisting of two faculty and five graduate students from the School of Architecture collaborated with City managers and Hunters Corporation on the design and evaluation of two plazas; the west “Cultural Plaza” and the east “Civic Plaza,” and a connecting pedestrian bridge as proposed in the Draft Master Plan and Conceptual Building Program by Hunter Interests Incorporated for the Rio Nuevo Project.

Figure 1. The proposed Rio Nuevo Master Plan and the three selected outdoor spaces.

METHODOLOGY

The sustainable urban design methodology provides a mean of efficiently predict and evaluate thermal conditions of outdoor spaces. It has three main steps; 1) evaluation of the geometry of a location by calculating the view factors of all surrounding radiating fields, 2) collection of major microclimate data, and 3) prediction of thermal conditions utilizing a computer program named MRT®[1,2]. MRT
manipulates the view factors and the natural elements of temperature, moisture, solar radiation, reflectivity, as well as absorptivity and radiant emissivity of surrounding natural landscape materials and man-made surfaces to predict the Mean Radiant Temperature (MRT), the Predicted Mean Vote (PMV) thermal index and the percent of people dissatisfaction (PPD). These indices represent the thermal comfort condition of the location. Recent development of the method[8] allowed designers to test scale models of outdoor spaces, assess view factors through fish-eye lens photography of the models. This development expands the use of the method to non-built projects while it was previously limited to investigation of existing outdoor spaces. Designers can easily change the models and re-test different design strategies for improvement.

Procedures of the evaluation process adopted for the Rio Nuevo project

During the semester, the students first used an existing plaza as a case study to apply and learn the methodology. The second module of the semester was to design the three different outdoor urban spaces as proposed by the Rio Nuevo Master Plan. During this phase, students built the large-scale models. The last module focused on the thermal prediction and evaluation of the different outdoor spaces and the re-design and evaluation process for thermal comfort improvement.

THE MUSIC HALL PLAZA CASE STUDY

The “Music Hall Plaza”, in downtown Tucson, was selected as a case study because it has a variety of unique spaces that can be evaluated for their thermal characteristics. Five major locations were selected; location 1: a basecase condition with no shade, no adjacent buildings and no vegetation, location 2: a seating and circulation area under a bosque of mesquite trees, location 3: a north facing mound of grass, shaded by the Music Building, location 4: a seating area close to a pool of water shaded by deciduous trees, and location 5: an elevated point shaded from the west by buildings and opened to local wind.

Assessment of geometry and view-factors

Fish-eye lens photography technique is used to represent the hemispheric radiating environment in studies of radiation exchange in urban environments. They allow accurate calculation of view factors of radiating surfaces as a means of determining the receipt of long wave radiation by the human body in complex radiating environments (Figure 3). A person’s view-factor is defined as the fraction of the radiant flux that strikes a person from a particular surface to that which would be received from the entire environment radiating uniformly.

The fish-eye lens technique was adapted from I.D. Watson and G.T. Johnson of Macquarie University, New south Wales, Australia [7]. The circular photographs are overlaid with a polar graph whose annuli and radii correspond to a specific fraction of a person’s view factor. Since a person’s radiating environment is represented as a sphere, photos were taken for both hemispheres once by looking down to the ground and another looking up towards the sky. The height of the tip of the lens is set at a level of 1M above the ground, representing a standing person, and is adjusted perfectly horizontal with the help of spirit levels. A tripod stand is needed to hold the camera in the desired position.

Microclimate data collection and construction of climate stations

In order to collect microclimate data specific to the Music Hall Plaza faculty and students, with funding from the City, purchased instruments and designed and assembled five climate stations (Figure 6). Data collected are: wind speeds, solar radiation, globe temperature, dry-bulb and wet-bulb temperatures, relative humidity and surface temperature. Infrared thermal guns were used to collect
Surface temperatures. Special forms were also designed and used on site by students to record the collected data as well as students’ personal response to the thermal condition of the different locations between the hours 8:00 A.M. to 5:00 P.M. Data collection was performed on the day of March 21, 2001, which is the Equinox day.

Figure 5. Students building the climate stations in preparation of site visit

Computer modelling and prediction of thermal conditions

In order to calculate the thermal conditions at each location and to predict human thermal comfort, the MRT© computer programs was used. In addition to the prediction of the mean radiant temperature (MRT), ASHRAE New Effective Temperature (ET*) and the Predicted Mean Vote index (PMV) which represents human thermal comfort on a scale from -5 to +5 were also predicted for each of the five locations on the Music Hall Plaza.

Figure 6. PMV index predicted for locations 1 and 2 on March 21, 2001. Location 1 experience thermal stress almost all day while location 2 is overheated only when the sun is overhead and penetrates through the tress.

DESIGN AND ANALYSIS OF THE SELECTED OUTDOOR PLAZAS WITHIN THE PROPOSED RIO NUEVO MASTER PLAN

To apply the methodology that was previously tested in the case study of the Music Hall Plaza, students studied and designed the proposed sites for the Rio Nuevo project. After spending three weeks in the design process they began application of the thermal evaluation method. Since students are now evaluating designed (versus built) projects it was necessary to use the newly developed method of the fish-eye lens photography technique of large scale models to capture the geometry and predict the view factors.

Construction and testing of scale Models

Theoretically, physical models of buildings and urban open spaces provide a means of accurately predicting daylight illumination but they are 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 reliable way to compute view factors of the various radiant surfaces at a reference point which otherwise would involve complex, often unmanageable, equations.

For long-wave infrared radiation, where radiation from all surfaces must be considered, methods of calculation based on the 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 the human body. By using a spherical target, whose diameter includes a 6-foot human figure, computation of the view factors is greatly simplified. Because the MRT program uses fish-eye lens photography to represent the hemispheric radiating environment acting on a 6 foot average human figure, we can then assume that the real environment can be reduced in scale down 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'-0".

Figure 7. Scale of models is based on the diameter of the fish eye lens in use

Photography technique of the models

Since a person’s radiating environment is represented as a sphere, and the fish-eye lens photograph represents only a hemisphere, therefore, the process of estimating view factor at each target point requires taking two photographs; one with the lens facing up at 3 feet high above the ground level, and the other looking down, also at a 3 feet height above ground. Because the selected scale is 1" = 6 feet, when photographing the model the camera lens needs to be at ½" from the plane of the model base. For photos looking down, a mini tripod could be used. Photos looking up require cutting a 3" hole at each selected location.

Figure 8. Students applying photography technique of their scale models

FINAL DESIGNS AND RESULTS
As mentioned above, students selected three different sites. The first is the west “Culture” plaza. Two students projects were developed. The second site is the east “Civic” plaza. One student project was developed. The third project was the development of a pedestrian link and a bridge between the “Culture” and the “Civic” plazas. The last student designed a courtyard house to the south side of the “Civic” plaza and studied both the indoor and outdoor spaces. The five different projects are illustrated in figures 9 through 13 below. Explanation of each geometry, strategies and thermal condition are given in the captions.

Figure 9 a. The proposed design for the west “Culture” plaza showing a stepped central space shaded with a grid of palm trees, an outdoor dining area shaded with tensile structure, and a surrounding shaded two level pedestrian walkway

Figure 9.b. Illustration of the shaded dining area associated with the water pool feature, which in the dry and hot climate of Tucson, added evaporation to the air and contributed to restoring thermal comfort. The elevated sidewalks are all designed to be in the shade, yet provide upper level interaction with the plaza.

Figure 10 a. Alternative design for the “Culture” plaza

Figure 10.b. In this proposal, an enclosed centre space formed the core of the plaza and was circled by multilevel walkways and upper roof gardens which shaded the lower level pedestrian activities. Additional lower level dining areas near the Santa Cruz river were proposed.

Figure 11.a. The east “Civic” plaza is designed to include shaded areas, outdoor restaurants, central multiuse stepped space, climate control features such as sunken walkways, Bosque, tensile structure, water walls and cool towers.

Figure 11.b. Demonstration of the central area shaded by tensile lightweight structure. A bosque area is also shown in the background.

Figure 12. The area between the west “Culture” plaza and the east “Civic” plaza has been developed to provide a pedestrian link through a bridge over interstate 10. While the highway presented an obstacle between the two plazas this project proposes proper way of linking while demonstrating thermal comfort strategies.
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Figure 13. This project demonstrates proper climate responsive strategies to achieve thermal comfort conditions within and around the proposed courtyard housing units. Examples used are shading lightweight tensile structures, sunken areas associated with cool towers technology, shaded pedestrian walkways, landscape walls with vegetated areas and low emissivity paving materials.

Prediction of thermal condition

To demonstrate the application of the method, thermal analysis of one of the selected location from the courtyard project is presented. This location has been designed to include a cool tower, a shading fabric and low emissivity ground paving material composed of a combination between concrete blocks and grass between the large joints (sometimes referred to as grasscrete). An opening in the model base allowed for photography of the sky hemisphere using the fish eye lens, while a tripod allowed photography of the ground hemisphere. The two circular photographs are illustrated in Figure 14 below. When the circular images are overlaid with a polar grid, the view factors are calculated and the program MRT is then used to predict the PMV index as illustrated in figure 15 below.

Figure 14. Circular images of location 6 at the courtyard housing project shows the cool tower, shading structures and ground low emissivity paving material.

It is obvious from the plotted results illustrated in figure 15 that comfort condition was maintained in that location throughout the typical summer day of June 21. The shading structure blocked much of the direct solar radiation, the low emissivity ground paving material minimized the radiant heat and the cool tower provided cooling by evaporation. The PMV index did not exceed +1 even during the hottest time of the day.

DISSEMINATION OF THE RESULTS

The final step of the procedure was to meet with City officials and the Rio Nuevo authorities to present the final projects and share the thermal analysis results. It was concluded that the work of this comprehensive studio provided a venue for faculty, students, City officials and practitioners to efficiently collaborate for the benefit of the community.

Figure 16. Students presenting their projects to City of Tucson officials, Rio Nuevo authorities and faculty.

CONCLUSION

Man-made built environment of urban development in large cities has altered the natural biological order of heat balance. The lack of evapotranspiration, the sealing off of natural evaporative surfaces, and the use of materials of permanence, like concrete, asphalt, and glass has contributed to increasing local warming. In the climatic extreme of arid regions this “heat island” phenomenon reduces the hospitality of a community by causing thermal discomfort in outdoor spaces as well as increasing the energy needed for cooling indoor spaces. The presented methodology provides a tool to designers to identify and analyze the major elements that most contribute to the thermal condition of an urban outdoor space. The MRT analytical tool facilitates the process of making proper decisions about the space geometry and surrounding buildings, the landscape materials and building material and colors, the shading condition and the control of direct short wave radiation, to achieve human thermal comfort.

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REFERENCES


