AN URBAN RADIATION OBSTRUCTION MODEL

(Research Note)

RANDALL S. FRANK and R. BRUCE GERDING
TRW, Redondo Beach, CA, U.S.A.

and

PATRICIA A. O'ROURKE and WERNER H. TERJUNG
Department of Geography, California State University, Northridge, CA, U.S.A.

(Received in final form 1 August, 1980)

Abstract. An urban street canyon radiation obstruction model has been developed. The model can describe community structure in terms of the type and dimensions of every building, block, road, park, etc. The need for massive data acquisition in regard to obstruction modeling calls for computerized algorithms, relieving the researcher of the needless tedium of hand calculations and the accompanying high degree of error and labor costs. The model program OBSTRUCT was written in FORTRAN IV for use on the IBM 3033. To facilitate changes or modifications, OBSTRUCT was written in modular form.

1. Introduction

The city has an infinite number of microclimates intimately linked to the composition of its surfaces and the relationships among its structures. Microclimates created or drastically altered by the shade effects of tall buildings are one simple example.

An understanding of the microclimates created by buildings should aid in the planning of new urban sites or the redevelopment of old ones. A predictive methodology is needed to deal with the fundamental processes of the varied geometries and compositions of the city's fabric.

A basic problem is to understand the spatial relationships between sunlit surfaces, shaded surfaces, and horizon obstructions. This is determined by the orientation and height of buildings, street width, solar zenith angle, and solar azimuth. Among other things, the heights of the skyline in all directions in regard to a particular surface have to be acquired.

The physical nature of an urban community can be described or modeled in terms of its structural characteristics. The level of description depends on the modeling resolution employed. As a coarse indication of community structure, one might describe land use in terms of the presence or absence of man-made structures. A more refined model might describe community structure in terms of the type and dimensions of every building, road, park, railroad, etc. Studies by Terjung and Louie (1974), Outcalt (1972), Arnfield (1976), Nicholas and Lewis (1980), and Terjung and O'Rouke (1980) have shown the need for such considerations. The need for massive data acquisition in regard to obstructions calls for suitable computerized algorithms, relieving the investigator of the needless tedium of hand manipulations.

Boundary-Layer Meteorology **20** (1981) 259–264. 0006–8314/81/0202–0259$00.90.

In boundary-layer meteorology, the distribution of the changes and budgets of energy and their interrelations with the urban environment can be studied, in part, by modeling the community as a specific number of rectangular blocks where each block represents a building or a surface area such as a parking lot or unused land. By specifying the dimensions and distributions of blocks, one can approximate the physical structure of a city.

The computer program that we have developed examines the solar obstruction shadowing in an ideal city model in which the buildings are uniformly distributed and in an arbitrary city model in which the buildings are randomly arranged. The output can be interfaced with existing models to determine, for example, the heat effects at various sun angles in an urban environment. Obviously, view-factors obtained from these statistics are equally applicable to longwave radiation exchanges in street canyons.

2. Problem Description

The concept of a system has been introduced to relate the shadowing dependencies among blocks. A system consists of a series of seven points located on the line connecting the centers of two particular adjacent blocks. A city model could then conceivably have as many systems as there are adjacent blocks. Each of the seven points serves as a viewing location from which sightings are taken of all blocks which could potentially shadow or obstruct the viewer.

An obstruction system for any adjacent pair of blocks consists of an orderly listing of all potential shadowing obstructions at various incremental angles proceeding clockwise around each of seven viewing points. This listing includes the parameters of distance, height, and angle for each shadowing block from each viewing point.

Figure 1 illustrates the geometric placement of the seven viewing points within an ideal model. The system diagrammed was developed from the centers of adjacent blocks, labeled 1 and 2. The model is termed 'ideal' because all the streets are either parallel or perpendicular and the faces of the adjacent blocks are of equal length. Given two blocks, the northern or eastern block is designated as block number 1. All seven viewing points lie along the center line between blocks 1 and 2.

From each of the seven viewing points, sampling (sighting) vectors are projected. At each of the incremental sampling angles, a swath width is extended. Any intersection with a block of a greater height than the viewing point is recorded. At each angle, intersection searching progresses outward from the viewing point until two intersections with progressively greater heights have been found or the search radius limit has been reached.

The extension of the system concept to a non-ideal or arbitrary model requires several modifications. In an arbitrary model, streets might not be parallel, the faces of adjacent blocks might not be parallel or of equal length, and the centers of blocks 1′ and 2′ might not lie on the system center line (Figure 2).

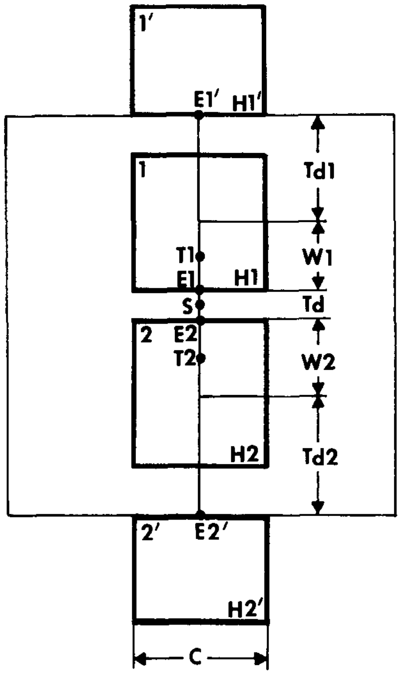

Fig. 1. Geometric placement of viewing points within an ideal system. 1 = the north or east block defining the system, 2 = south or west block defining the system, 1' = the block adjacent to block 1 on the opposite side from block 2, 2' = the block adjacent to block 2 on the opposite side from block 1, $H1$, $H2$, $H1'$, $H2'$ = the heights of the subscripted blocks, C = length of the adjacent faces between blocks 1 and 2, $T1$ = viewing point A, located midway between the center and edge of block 1 at the top of the block, $T2$ = viewing point B, located midway between the center and edge of block 2 at the top of the block, $E1$ = viewing point C, located on the edge of block 1 facing block 2 on the center line at ground level, $E2$ = viewing point D, located on the edge of block 2 facing block 1 on the center line at ground level, $E1'$ = viewing point E, located on the edge of block 1' facing block 1 on the center line at ground level, $E2'$ = viewing point F, located on the edge of block 2' facing block 2 on the center line at ground level, S = viewing point G, located in the middle of the street between block 1 and block 2 at ground level, and $Td1$, $Td2$, $W1$, $W2$, Td = distances between the various viewing points as illustrated.

3. Program Description

OBSTRUCT consists of the main program and several subroutines. The main program reads in the appropriate inputs: performs a series of legality checks on the input data; identifies block centers, neighborhoods and systems; calculates all system points; and scans the neighborhood for obstructions. One subroutine determines the system points; another establishes whether or not two line segments cross. If the two line segments do cross, a routine is used to calculate the point of crossing. Given a directed line segment originating in a system, the nearest block intersection is computed.

To initiate the obstruction model, the following values are inputed into the primary routine:

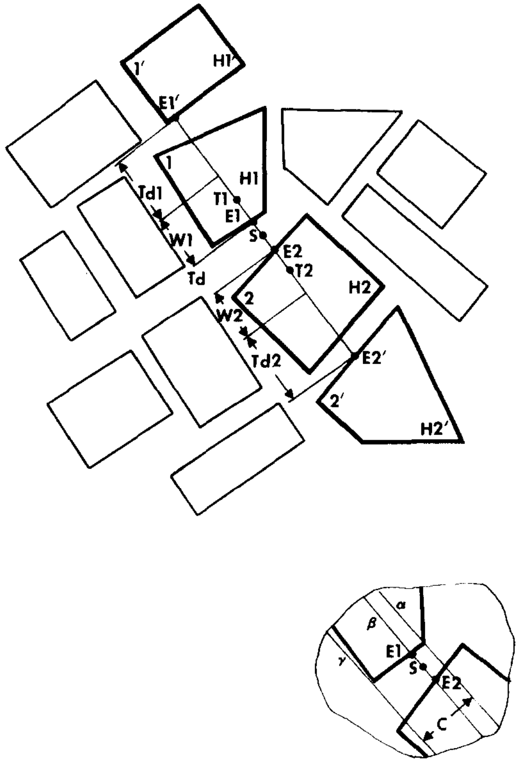

Fig. 2. Geometric placement of viewing points within an arbitrary system. See Figure 1 for symbols.

(a) number of blocks in the city,
(b) length of the scan vector,
(c) maximum distance allowed between system block centers,
(d) block identification numbers,
(e) block heights and,
(f) the X and Y coordinates for the four corners of each block.

Before beginning the analysis, the input is scanned for errors, and the block is checked for convexity.

All error checks involve simple comparison tests, whereas convexity is established by calculating a series of cross products using the side vectors of the block in question. This can be demonstrated with the aid of Figure 3.

$$\begin{aligned}
\mathbf{V1} &= (x2-x1)\mathbf{i}+(y2-y1)\mathbf{j}\\
\mathbf{V2} &= (x3-x2)\mathbf{i}+(y3-y2)\mathbf{j}\\
\mathbf{V3} &= (x4-x3)\mathbf{i}+(y4-y3)\mathbf{j}\\
\mathbf{V4} &= (x1-x4)\mathbf{i}+(y1-y4)\mathbf{j}
\end{aligned} \tag{1}$$

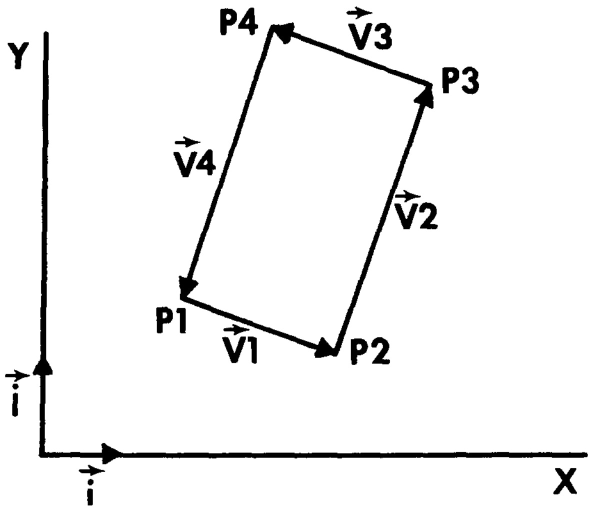

Fig. 3. The geometry used to determine convexity. **i**, **j** = unit vectors, p_k = block corners ($k = 1, 2, 3, 4$), $\mathbf{v}_k$ = side vectors.

The cross product of any two vectors in two-space a and b, is $k|a||b| \sin \theta$, where θ is the angle between the two vectors and k is perpendicular to the vector plane. As long as $\theta < 180$, the cross product is positive. If the cross product of each consecutive pair of side vectors is positive, the angles between them are less than 180 degrees and the block is convex. Because a concave block would make one cross product negative, the convexity of a block can be tested by checking the sign of the product of all four cross products.

One of the subroutines has the task of identifying all systems. This is accomplished by constructing two lines through the center of the block in question and searching for the closest block. The initiating block is assumed to be to the east or north. In the event that there is more than one candidate for the closest block, an arbitrary decision is made to begin the system definition. Once a system is identified, it can be defined in terms of the variables: T_i, T_j, E_i, $E_{i'}$, E_j, $E_{j'}$, H_i, $H_{i'}$, H_j, $H_{j'}$, Td, Td_i, Td_j, W_i, W_j, and two system block ID's, i and j (Figure 1: 2). These parameters are calculated by four subroutines.

To determine solar obstructions, a directional wedge and angular width is stepped around the neighborhood at equally spaced intervals. The incremental sampling angle is arbitrarily set equal to 20 degrees, and the number of stepped scans is either nine or 18 depending on the location of the system viewing point. One of the subroutines examines the possibility of line segment intersection, whereas these intersections are computed in another subroutine.

Given a directional vector of finite length originating at a system point, potential system points as well as possible obstructions resulting from neighborhood blocks are computed. Then two subroutines are used to find all possible obstructions by considering the possibility of an intersection between the directional vector and each side of every block in the neighborhood. Once the obstruction possibilities along the directional vector are determined, they are sorted in ascending order (by heights).

4. Remarks

Prior to the creation of an urban radiation obstruction model, solar shadowing data for a city were commonly computed manually. Inherent in a manual data collection scheme are a high degree of error, a lack of standardization, a large time requirement, and high labor costs. The creation of an automated collection scheme alleviates these difficulties. In order for the model to maximize its utility and minimize the operational cost, OBSTRUCT is written in modular form, containing no trigonometric or logarithmic functions. The program is designed under a FORTRAN H compiler, optimizing the code and minimizing the execution time and cost.

Acknowledgements

This research was funded partially by a grant from the University of California. Use of the computer facilities of the UCLA Office of Academic Computing is appreciated.

References

Arnfield, A. J.: 1976, 'Numerical Modelling of Urban Surface Radiative Parameters', Collection of Research by McMaster University-Trained Climatologists, Dept. of Geog., the Ohio State University, Columbus, Ohio.

Nicholas, F. W. and Lewis, Jr., J. E.: 1980, 'Relationships Between Aerodynamic Roughness and Landuse and Land Cover in Baltimore, Maryland', Geol. Survey Prof. Paper 1099-C, U.S. Govt. Printing Office, Washington, D.C.

Outcalt, S. I.: 1972, 'Reconnaissance Experiment in Mapping and Modeling the effect of Land Use on Urban Thermal Regimes', *J. Appl. Meteorol.* **11**, 1369–1373.

Terjung, W. H. and Louie, S. S-F.: 1974, 'A Climatic Model of Urban Energy Budgets', *Geog. Analysis* **6**, 341–367.

Terjung, W. H. and O'Rourke, P. A.: 1980, 'Simulating the Causal Elements of Urban Heat Islands', *Boundary-Layer Meteorol.* **19**, 93–118.