A HYPOTHETICAL "SHADOW UMBRELLA" FOR THERMAL COMFORT ENHANCEMENT IN THE EQUATORIAL URBAN OUTDOORS

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The primary characteristic of the equatorial climate is its almost unchanging weather patterns. Unlike other climates, daily weather patterns dominate over seasonal weather. It is said that in this region, all seasons occur within a single day. There are cool mornings, warm early day, hot and humid daytime and almost unbearably damp afternoons, all within the day, repeating perpetually. While no single climatic parameter is excessively high, the combination and the time of occurrence make equatorial climates unbearable. Thus, a combination of air temperature at 3031oC (86-88oF) coupled with a relative humidity of 80% or more, occurring with 0.1 m/s (3.3 ft/s) or less air movement, is extremely oppressive from a thermal comfort point of view, even though theses parameters in and by themselves are not thermally oppressive.

Urbanization, due to its increased thermal capacity, lack of water for evapotranspiration, and above all due to the "canyon effect", tends to aggravate an already stressful climate. Although the equatorial climate's heat islands are not extensively researched, the few studies that do exist, tend to confirm this view (Refs.1,2,3,4). What seems to happen in urban equatorial climate is not so much a positive thermal stress (thermal discomfort due to overheated conditions) during daytime, but at night (Refs.1,5) when thermal stress is already positive.

This problem acquires greater importance when one considers that the nighttime rate of air movement is low or nil in the equatorial tropics. Furthermore, being in the "Doldrums" twice a year for extensive periods, the equatorial tropics do not have high wind velocities at the macrolevel. Most daily wind flows are local in nature (like the sealand breeze). A nocturnal urban heatisland tends to keep the air temperature over land almost as high as that over sea, thus weakening any nighttime land breeze (Fig. 1).

The "problem" of climateconscious equatorial urban design is therefore twofold: Prevention of heat buildup as the day unfolds (so as to reduce nighttime cooling loads) and, encouraging convective cooling at night.

Viewed in this manner, the urban design goals would be a) Radiation reduction during day and, b) Ventilative cooling at night. The nature of the climatic problem is such that neither of these goals can be achieved by separate strategies.

However, tropical living is a part indoors and part outdoors activity, though one suspects mostly the latter. For living in the equatorial outdoors is relatively pleasant for most of the year. Correa quantifies this aspect of flexibility of outdoor use by a factor called the "usability co-efficient." (Ref.6) Thermal comfort design goals therefore have to be different for the outdoors and the indoors. While people spend longer time at any given time in the indoors, outdoor occupants are typically there for shorter periods at a given time. As such, shading to reduce the thermal stress and perceivable air movement to enhance the cooling effect are necessary in the outdoors.

This paper hypothetically develops a "shadow umbrella" for radiationreduction in the outdoors during the day. The primary tool in achieving shading is urban massing, though the potential of vegetation in enhancing shading and reducing urban heat island is also considered. The use of water in achieving/enhancing nighttime ventilative cooling is a secondary consideration. In doing so, it addresses three issues: establishing the basic characteristics of urban equatorial climate; a tentative "shadow umbrella" (a shadow canopy that would shade an entire neighborhood outdoor area by its urban massing a concept exactly opposite to what Knowles called a "solar envelope" [Ref.7]); and, determining the location(s) for bodies of water (lakes, pools or fountains) within this overall "Shadow Umbrella."

The primary hypothesis here is that contrary to popular belief, solar radiation control is the main climatecontrol option. The use of other options like ventilation is not so much as to solve the problem, but to enhance the solar radiation reduction option. Thus, the use of water for example, is to be understood as a tempering agent to the "Shadow Umbrella" and cannot be employed by itself. In fact , the presence of large waterbodies, in the absence of shade, will actually aggravate the thermal comfort problem in the equatorial regions where the relative humidity is already high.

It must also be mentioned that the "shadow umbrella" developed here is preliminary only, developed mainly to determine the urban massing and the location(s) of bodies of water and vegetation. More finetuning of the urban massing than that suggested here is necessary before a concrete form of the order of Knowles' "solar envelope" could be developed. However, as a rough firstcut, this paper offers a framework for the consideration of other climateenhancing options, like the use of vegetation.

Characteristics of Urban HeatIslands in Equatorial Areas

Heat balance at earth's surface is given thus:

- Q* = QH + QE + QS, where
- Q* = Total heat received at the surface (Heat Flux),
- QH = Sensible turbulent heat transfer,
- QE = Evaporative turbulent heat transfer, and
- QS = Net heat storage (Ref.8).

The primary difference in urban and rural thermal processes, as identified by Oke is in the partitioning of heat between QH and QE. In rural areas, more turbulent heat is lost by evaporative cooling than sensible means. (Ref.8) In the cities where impervious surfaces abound, most turbulent heat transfer is by sensible means. Sensible heat transfer, being what it is ("Sensible" i.e. perceivable by humans) causes thermal stress to those who live in the zone (the Urban Boundary Layer, where most people live).

What matters the most about ^QS is the quantity stored. As night progresses, the only heat that is available at surface level is the stored heat and the amount obviously will determine how much will eventually be lost by evaporative or sensible means. Urban surface materials usually have higher thermal capacities and therefore their nighttime temperature increasing abilities are greater.

As Oke points out, the impact of urbanization is "to favor partitioning more energy into sensible rather than latent heat and increase the importance of heat storage by the system" (p 16). As such, he points out that any system of urban classification in terms of benevolent/malevolent systems as related to the urban heatisland should take into account its water storage capacity and surface moisture availability.

Water provides a buffering or modifying influence, because gradual moisture depletion allows for evaporative cooling to extend over a period of days or more. On the other hand, impervious elements in urban landscape experience an almost dichotomous wet/dry behavior. (p 8)

Summary of Early Studies on Equatorial Urban HeatIslands

One of the earliest equatorial urban microclimatic studies was conducted by Nieuwolt in Singapore. (Ref.1) Taking air temperature and relative humidity measurements at various points in the cityand suburban areas, and comparing them with the readings from the Singapore Airport (representing a "rural" setting), he found that the city was appreciably warmer (33.5oC or 5.46.3oF) and drier (relative humidity up to 20% lower) than the airport. The narrow streets in the central parts of the city had the worst microclimate. During the day, the sea front was wetter and cooler than the rest of the city, but the effect was found only on a very narrow strip of land around the sea (due to tall buildings blocking the benevolent effects of wind). Interestingly, the effect of wind was found to increase the differences between the city and airport. Nieuwolt attributed the climatic differences to the increased absorption of solar radiation by the city and its lack of evapotranspiration with a greater emphasis on the latter. (In a typical tropical rural region, evaporation accounts for 85% of the heat loss [Ref.9].)

Interestingly, he also found that with the onset of a thunderstorm (which occurs very frequently in the equatorial tropics), air temperature dropped by more than 7oC. In an equatorial city where the daily temperature swing is only about 5oC, this drop is very significant.

Another study of interest was conducted by Sani in Kuala Lumpur. (Ref. 3) His findings agreed with those of Nieuwolt's. However, he also found that the CityCountry Temperature Difference (CCTD) was related to the cloud cover. On clear days the CCTD was 4.45oC (89oF), but on cloudy days, it was only about 22.2oC (3.54oF). He attributed the CCTD to surface characteristics of the city (more dark color surfaces) and the lack of vertical air mixing that keeps hot air trapped at bodylevel.

A third study was conducted by Adebayo in Ibadan, Nigeria. (Ref.4) Observing a higher air temperature in the citycenter than in the rural area, he cited the following as causes for the city-country temperature difference: a) reduction in albedo (thermal reflection) which causes more heat to flow to and from earth's surface, b) presence of a pollution veil and, c) urban canyons, which trap the net radiation.

Urban Geometry & Heat Island Effects

Although the surface characteristics have been traditionally cited as the cause of urban heat islands, an increasing number of authors are beginning to suggest that the geometry of urban canyons, namely, the streettobuilding height and width relationships are important, if not the primary, contributors to the problem.

Goward shows that the daytime urban heat excess cannot be attributed solely to the higher thermal inertia of urban surfaces relative to rural interface thermal inertia. (Ref.10) Terjung & Louie on the other hand hypothesize that the urbanrural daytime temperature anomaly is solely attributable to the aspect of vertical surfaces to the sun. (Ref.11)

In Lawrence, Kansas (a small town 25 miles east of Topeka), Henry and Dicks found that the temperature difference between a highly developed part of town and a representative rural area to be actually 1.9oC (3.4oF) higher in the rural case. (Ref.12) This anomaly was attributed to the almost urbanlike street geometry of that particular rural setting.

Oke, et al. shows that although many types of surfaces abound in urban areas, only two matter in terms of the heat island: natural and manmade. (Ref.13) Within the manmade surfaces they found little corelation between types of surfaces and heat island effect.

Noting that the urban geometry factors have not received as much consideration in explaining the spatialtemporal distribution of urban heatislands as have surface materials, Todhunter takes the position that at a microscale, explicit considerations of urban geometry are more important. (Ref.14) At the mesoscale, however, he argues that both the geometry and surface thermal characteristics play an equal role.

It seems clear that street geometry as an urban design tool is more important in urban climate amelioration than other factors: at least in the smalltomedium scale. Mention must however be made of other climatic urban design issues like wind movement and surface material characteristics. The difficulty with wind movement as a climatic urban design option is its unpredictability. This is especially so in the equatorial tropics where typical wind movement is lower than 1 m/s (3.3 ft/s). Nieuwolt shows that at such low speeds, even smaller obstacles like trees could significantly alter wind flow. (Ref.15) Furthermore, the cooling effect of wind movement which is proportional to the difference between skin temperature and air temperature, is of little value in the equatorial tropics, since both these temperatures are almost equal: 35oC (95oF). (Ref.15) To complicate matters even more, the equatorial wind patterns keep shifting at the onslaught of one or the other monsoon.

As for the surface characteristics of urban areas, it can be said that it is not an urban design "problem". Simple guidelines could be incorporated into urban ordinances that encourage/prevent certain building materials in particular land uses. As Todhunter points out, the effectiveness of such a guideline would perhaps be enhanced if they are applied over a larger area (say, an entire city).

The current paper takes the position that, from an urban design pointofview, urban geometry is far more crucial than the surface characteristics of urban areas in comfort enhancement. In other words, shading potential of the urban mass. It may be noted that sun control of individual buildings in the equatorial tropics where the sun iscloser to the azimuth most of the year, is relatively easier. It is therefore necessary to enhance the comfort potentials of the urban outdoors in the tropics where considerable living occurs. In keeping with the research findings summarized above, this paper therefore deals essentially with the design of outdoor environment at a neighborhood scale (so as to keep the scale at a mediumlevel), that utilizes its urban geometry (massing) to reduce the heat island effect and, "tempered" by the use of natural elements. This tempering is particularly necessary in the equatorial tropics (as opposed to Knowles' "Solar Envelope" where solar design by itself was deemed sufficient) where the sun is always close to the vertical. As such, shading alone is not an economical solution to the problem of urban climate (shading massing in certain orientations would have to be unusually tall). A more thorough analysis of both geometrical and surface characteristic issues and the development of a thorough set of design strategies however, will be attempted later.

Determining a "Shadow Umbrella" For a Neighborhood Outdoor Area in an Equatorial City

The issue that matters most in terms of climatic design and urban geometry is the "ViewFactor". (i.e. the proportion of the total spherical field of view from a subject taken up by surfaces.) Another determinant is the temperature difference between the surfaces and the subject: If surfaces are cooler, the subject looses heat to them; if warmer, the subject receives heat. If urban surfaces could be kept "cool", people passing by would loose heat to them, and, in the equatorial region, would be comfortable. In keeping with this principle, the following steps were taken to establish an urban massing in a neighborhood that would keep its surfaces "cooler" in the equatorial region.

The fundamental step in arriving at such a "shadow umbrella" is to establish the shadow angles. These angles vary by location (latitudes), time of day, and orientation. Since the purpose is to shade a particular surface at all times, the lowest angles must first be established.

The immediate problem was to establish the timelimit within which shading is to be provided. It was assumed that in a commercial neighborhood, the time period would be from 0800 hrs sunset and in a residential neighborhood, 0900 hrs sunset. It must be remembered that in the equatorial regions, temperature rises sharply in the early morning hours. Therefore the outdoors in commercial zones where much activity occur in the morning should be kept cool, at least a little while before people congregate. In the case of residential zones, a later time limit could be set as internal migration of activities within houses is quite easily achieved. Shading till sunset however is needed in the equatorial tropics since the high thermal stress achieved in early afternoon lingers on even after sunset.

Tables 1 and 2 are the result of extensive use of "Lotus 123" and "Upfront" software in determining shadow angles that would shade a given orientation at all times. The columns are latitudes (0o12o which is roughly the region of the equatorial tropics) and the rows are orientation (from North) of the surfaces to be shaded. Orientations not shown are excluded since they demand too low angles that would require unwieldy shading devices. The preferable orientations in the equatorial tropics are graphically represented in Fig. 2.

With the shadow angles and preferred orientations thus established, the next step was to determine the plan dimension of a neighborhood block, using the shading principles graphically shown in Fig. 3. Assuming the east/west facing side to be 30.48 m (100 ft), it was found that the north/south facing side should be 75.44 m (247.5 ft) (Fig. 4). The shadow angle used was that of the western orientation.

Assuming that an urban outdoor volume with a height equivalent to a twostoreyed building is to be shaded, the next step was to find out the surrounding massing needed to shade the selected block in its entirety. Figs. 5-9 show the development of constructions of such massing. The angles denoted are the shadow angles for orientations north (0o), east (90o) and so on.

Similarly, a "Shadow Umbrella" for a residential neighborhood could also be developed, this time using shadow angles that had a time limit of 0900 hrs to sunset (as opposed to 0800 hrs sunset in the case of commercial areas). (see Figs. 10-13).

The following design strategies could be gleaned from the above examples:

1. The most preferred orientations are 0o80o (i.e. within the northeastern quadrant;
2. The urban density should be one that slopes towards the northeast (i.e. smaller buildings in the northeast and taller ones towards west);
3. Northeastern and southwestern corners of a development could be left open.

Within this overall shadow massing, it is now possible to determine location/s of natural elements that would enhance the thermal comfort aspects of the outdoor areas in the whole neighborhood.

Use of natural Elements as "Tempering Agents"

Figs. 9 & 13 show the overall urban shadow configurations for commercial and residential blocks respectively, in an equatorial city. As mentioned earlier, there are vast open spaces in both these cases, offering ample opportunity to fine tune the "shadow umbrella".

The most peculiar climatic event in the tropics is the monsoon season, particularly so in the equatorial tropics where two such monsoons differentiate the "seasons": northeast monsoon and southwest monsoon. As can be seen from Fig. 13, shadow massing developed so far shows compatibility with the general wind patterns in the area.

Carmona suggested that outdoor spaces in the tropics be so designed that the air stream passing through them to windward of each building is not unnecessarily overheated, thus nullifying wind's beneficial effect. (Ref.16) Noting that the equatorial winds are primarily northeasterly or southwesterly origin and the shadow massing so far developed has open spaces at these sides, a case for locating waterbodies in the northeastern / southwestern quarters of the site can be made. Such a location would help cool the incoming air sufficiently as to "temper" it and enhance its cooling potential (For, air's cooling effect depends on its temperature difference from that of the skin).

Fig. 14 shows the location of two ponds closer to the neighborhood (residential) block under consideration. Note also the veranda/arcade arrangements on the northern and eastern edges of the block. Thus a cool promenade encircling the lake is created which seems to reinforce the traditional notion of a lake as the center in some of the equatorial cities (for example, the historical hill capital of Sri Lanka, Kandy, and the ancient SouthIndian temple cities like Madurai and Trichchirappalli).

Water alone will not be sufficient as a tempering agent, since the southern edge of the northwestern block in Fig. 14 will be under sun for some of the time. Trees could be planted as a buffer on this side. (Fig. 15)

One of the characteristics of equatorial tropics is the weak temperature variation, both diurnal and seasonal. Larger climatemodifying elements like lakes, are therefore of little use to particular outdoor stretches, if microlevel enhancements are not provided. In terms of thermal comfort in the equatorial tropics, it is necessary to provide smaller comfortenhancing elements in each urban block. Thus, rather than a large park, many smaller but climatically viable parks will ameliorate the micro climate over a wider area and so on.

Working from the overall concept thus derived, a larger urban area could be designed in a climaticallyappropriate way. Fig. 16 shows one such attempt on an approximately 220 m by 100 m area. It keeps all the principles thus far developed (smaller buildings on the northeast, taller buildings on west, etc.) and leaves the center open for climateameliorating land uses. The pathways are so designed as to pick up the cool air from the centrally located pond and spread it along a northeast/southwest axis (which is the main air movement path). Trees are used to reduce the heat radiation from large open areas where built mass is of lower height. The primary criterion in the whole block is shading.

Conclusion

This exercise then, is an attempt to make the equatorial urban outdoors thermally comfortable. The primary response was to the malevolent effects of urbanization on micro-climate. The paper argued that although life in the equatorial tropics is largely an outdoor phenomenon, modern urban development has by and large failed to facilitate such living in a climatically pleasant manner. The "shadow umbrella" is therefore a design initiative towards rectifying such an anomaly.

Before concluding, it is important to re-emphasize the need for care in employing natural elements in the "shadow umbrella." The use of water and vegetation for example, will only exacerbate the thermal comfort problem if used by themselves. Instead, they should be utilized within the context of a shading strategy. The purpose of natural elements is not so much to ameliorate negative aspects of tropical climate but to enhance the cooling potentials of shading. Indiscriminate use of water will humidify the already humid tropical air: careless placing of trees will inhibit air movement.

Within the context of a shadow mask however, the use of natural elements can greatly facilitate outdoor tropical living. Once comfort enhancement is achieved in the outdoors, individual buildings can easily be shaded by proper orientation. The outdoor block design detailed above dictates a northerly or easterly orientation for most buildings. As discussed earlier, shading on these orientations is easily achieved.

The main drawback in the "Shadow Umbrella" developed here is the time slot selected for shading. More literature surveys are necessary to correctly determine the most crucial time period in terms of shading. It is also necessary to develop shadow massing for orientations other than north, south, east or west. At least all the cardinal points must be taken care of. The possibilities of street layouts other than northsouth must also be studied.

Furthermore, the role of vegetation needs careful attention. It is not just in providing shade that trees are important assets to climatic urban design, but in ameliorating the urban heatisland. The role of trees and other forms of vegetation needs to be studied separately for their shading potential as well as ecological functions.

As a preliminary survey, this paper attempts to set the agenda for these and other issues in the often neglected area of equatorial urban design. More fine tuning of the "shadow umbrella" would make it applicable to a wider range of design problems.

References

1. NIEUWOLT, S: "The Urban Microclimate of Singapore." J.Tropical Geography, 22: 30-37, Jun 1966.

2. OGUNTOYINBO, J.S: "Reflection Coefficient of Natural Vegetation, Crops and Urban Surfaces in Nigeria."

Quart. J. Royal Meteorological Society, 96: 430-441, 1970.

3. SANI, SHAM: "Observations on the Effect of a City's Form and Functions on Temperature Patterns." J. Tropical Geography, 36: 60-65, Jun 1973.

4. ADEBAYO, YINKA R: "Aspects of the Variation in Some Characteristics of Radiation Budget Within the Urban Canopy of Ibadan." Atmospheric Environment, 24B(1): 9-17, 1990

5. GREENWOOD, PETER G. and R.D.Hill: "Building and Climate in Singapore." J. Tropical Geography, 26: 37-43, June 1968.

6. CORREA, CHARLES: The New Landscape, Singapore: Mimar, 1989.

7. KNOWLES, RALPH: Sun Rhythm Form. Cambridge, MA: MIT Press, 1981

8. OKE, T.R: "The Energetic Basis of the Urban Heat Island." Quart. J. Royal Meteorological Society, 108(455): 1-25, 1982.

9. JEN HU CHANG: "On the Study of Evapotranspiration and Water Balance." Erdkunde, p 144 (quoted by Nieuwolt, S., op. cit.)

10. GOWARD, S.N: "Thermal Behavior of Urban Landscapes and the Urban Heat Island." Physical Geography, 2:19-33, 1981.

11. TERJUNG, W.H., and S. LOUIE: "Solar Radiation and Urban Heat Islands." Annals of Association of American Geographers, 63: 181-207, 1973.

12. HENRY, JAMES A., and STEVEN E. DICKS: "Association of Urban Temperatures with Land Use and Surface Materials." Landscape & Urban Planning, 14(1): 21-29, Jan. 1987.

13. OKE, T.R., B.D. KALANDA and D.G. STEYN, (1981). "Parameterization of Heat Storage in Urban Areas." Urban Ecology, 5(1): 45-54. Apr. 1981.

14. TODHUNTER, PAUL E: "Microclimatic Variations Attributable to UrbanCanyon Asymmetry and Orientation." Physical Geography, 11(2): 131-141, 1990

15. NIEUWOLT, S: "Design for Climate in Hot, Humid Cities." In, WMO, (1986). Urban Climatology and its Applications with Special Regard to Tropical Areas. Proc. Conf. organized by WMO/World Health Organization, held at Mexico City, Nov. 2630, 1984. Geneva: WMO, pp 514-534.

16. CARMONA, L.S. de: "Human Comfort in the Urban Tropics." In, WMO, (1986). Urban Climatology and its Applications with Special Regard to Tropical Areas. Proc. Conf. organized by WMO/World Health Organization, held at Mexico City, Nov. 2630, 1984. Geneva: WMO. pp 354-404.

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