

Energy design strategies for city-centres: an evaluation

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ABSTRACT: *City-centres* are replica of high energy intensity with growing building services as a consequence of rapid urbanization and ever-increasing urban densities. Energy for building services is increased owing to '*urban heat island*'. These higher heat sinks also elevate energy demand profile for downtown areas. Low energy system considerations for urban buildings in city centre require consideration of a wide range of factors including Urban Square design, geometry & orientation in context of micro-planning needs. Present paper evaluates city-centres enlisting existing shortcomings and proposes simultaneously design criteria's citing examples from existing city centres across globe. This will help designers, micro-planners, architects in redefining building design criteria's that correlates to city-centres & downtowns for energy efficiency.

Keywords: Energy, urban square, design, micro-planning.

1. INTRODUCTION

Global urban population is forecasted to increase from 47 % of 6.1 billion in 2000 to reach 60% of 8.1 billion by 2030 [1]. Major increase will be in Asia & developing nations and that more than 90% of the increase in the world's population during this period (2 billion persons) would unevenly concentrate in urban regions [1] & [2]. City centre as part of urban agglomeration infact are bustling with mixed land usage and in particular cases are major source of nation economy as highlighted by Immanuel [3].

Energy consumption of buildings in city-centre is very high due to increasing commercial usage. Energy demand for city centre is function of solar loads, wind flow patterns and external air temperature. Improvements delineated in city-centre will have direct consequences on energy savings. The thermo-physical properties of the various urban

elements, surface characteristics in terms of texture & colour, canyon geometry, and anthropogenic activity are important factors that determine the radiant surface temperature in the urban environment.

2. CITY-CENTRE CHARACTERISTICS

2.1 Urban Square

This is defined as volume contained in city centre and characterized by multitude of high rise buildings with mixed land usage. Infact urban squares contain higher building density, higher UHI (Urban heat island) influences and deep street patterns. Urban square is marked by high energy concentration not only in terms of elevated UHI effect but subsequent exploded energy demands for building services. Building height, proportion and orientation delineate Urban Square properties. Evaluation criteria for urban square are shown in Figure '1'.

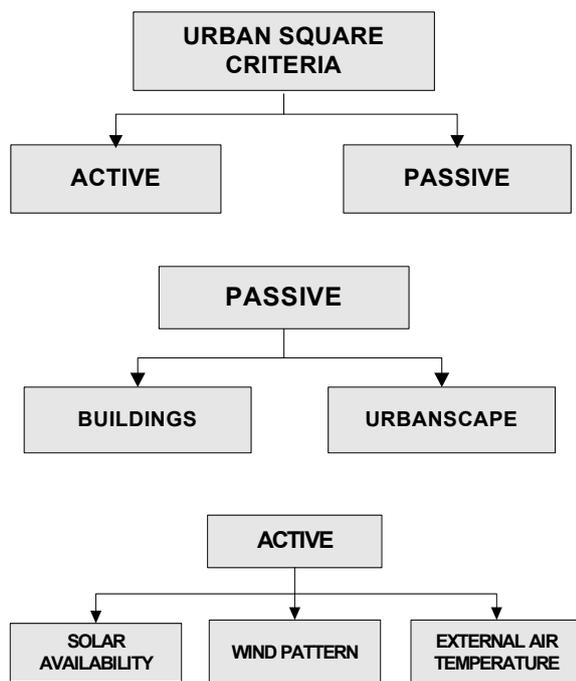


Figure 1: Urban Square evaluation criteria



Figure 2: An Urban Square for Kansas City, USA

A typical urban square as shown in Figure '2' is marked by higher energy demands with higher building densities.

2.2 Urban Canopy

This is characterized by width 'W', length 'L' and height of building blocks. This also delimits the boundary layer for consideration of wind effects. It is seen that thermal environment changes abruptly when crossing urban canopy. Thus urban canopy is dividing line for wind flow & configuration patterns.

2.3 Street Canyon

These are differentiated on the basis of 'H/W' ratio of building block where 'H' is height of building and 'W' is width of adjoining street. *Deep canyon* exist when ratio is greater than '2', otherwise we have *shallow canyons*.

3. URBAN SURFACE ENERGY INDEX

Writing the urban square energy budget formulation:

$$Q_R^* + Q_A + Q_G + Q_S + Q_L = 0$$

Where

Q_R^* : net radiation

Q_A : anthropogenic heat flux

Q_G : ground heat flux

Q_S : sensible heat flux

Q_L : latent heat flux

Net radiative fluxes consider both shortwave and long-wave components for a diurnal cycle. Here we define urban surface energy index in terms of radiative heat flux parameter as it dominates and govern surface energy exchanges. *Anthropogenic* heat & *latent* heat is site specific and for index formulation is held negligible.

Thus urban surface energy index (USEI) is

$$USEI = \frac{Q_R^*}{Q_R^* + Q_G + Q_S}$$

Since most of city centres are burgeoning commercial hubs, it substantiates need for energy demand profiles of individual buildings leading to energy intensity profiles. Aim is to minimize energy intensity for urban square in time domain meeting contrary demands of increased surface area and decreased energy intensity profiles for individual building. We have urban building energy intensity (UBEI) defined by combination of maximization and minimization functions.

$$UBEI = \min \left\{ \sum_{i=1}^n \frac{E_i}{r_i * w_i * A_i} \right\}$$

$$A_i = \max \left\{ 1 + 2 \left(\frac{H_i}{L_i} \right) + 2 \left(\frac{H_i}{W_i} \right) \right\}$$

Where

i=1 to n refers to number of building units.

E = Energy load

r = no. of floors

A = wall to floor area ratio

w = Wall area

and H, L, W defines height, length and width respectively.

4. URBAN SQUARE ANALOGIES

We present analogies under 'ACTIVE' part of urban square design criteria. This is explained under following analogies: source/sink for *solar availability*, least resistance for *wind* and thermal capacitance counting on prevailing *air temperatures* in urban square as direct result of thermal capacity.

4.1 Source & sink analogy

City centre are acting both as *source and sink* in a diurnal cycle and this cycle is alternated once every day. Main idea behind this analogy is to make it *perfect sink* during day and *perfect source* at night for interiors contrasted to generation of intense UHI in exteriors. Proposed Source/Sink analogy is thermal analogy and draws from solar energy haulage for community storage. Here city centre will take the role of community thermal storage system. It is manifestation of renewable energy technologies to urban systems. Extension of it is integration of multitude of new technologies in Urban Squares.



Figure 3: Sink analogy applied to Urban Square in Montreal

Figure '3' show imperfect sink for solar insolation whereby urban square is dotted by multitude of odd shaped buildings. Above figure highlights two such categories: bi-axial foliated and longitudinal U-shaped profiled buildings.

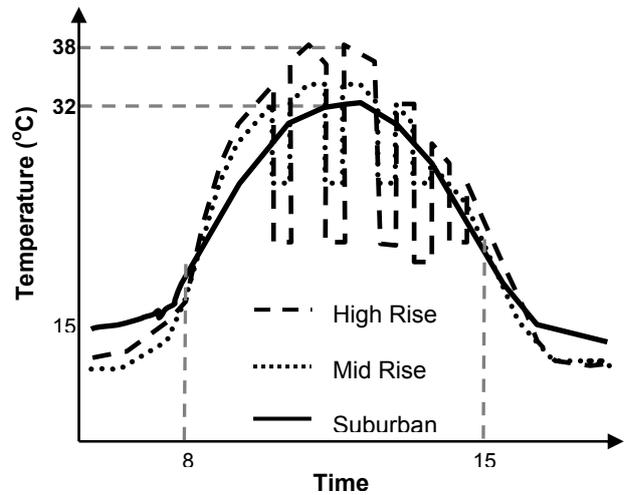
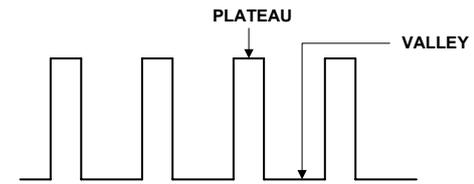
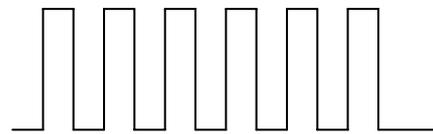


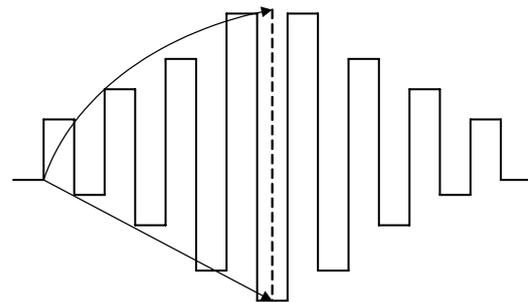
Figure 4: Diurnal Temperature profile for Urban Square



(a) Low pitched even height



(b) High pitched even height



(c) Low pitched uneven height

Figure 5: Energy profiling for urban square buildings for source/sink analogy

High rise buildings in urban square provide cool interiors. This is evident from Figure '4' where temperature differences between *valley* and *plateau* are far greater than the low rise settlements in urban square. Further there is pronounced UHI effect at solar noon. Intermingling plateau and valley in urban square provides a very uneven energy profile with conditions worsening in case of high pitched even height of buildings in the urban square. Although a low pitched mid to low rise urban square form is well suited but it does not cater to growing demand of population density concentrated in such city centres.

Figure '5' present comparison for profiling of buildings in urban square. High pitched even height of buildings present flat histogram leading to increased energy demands for the buildings. Low pitched uneven height of buildings is more suitable generating convex energy profile.

4.2 Least resistance analogy

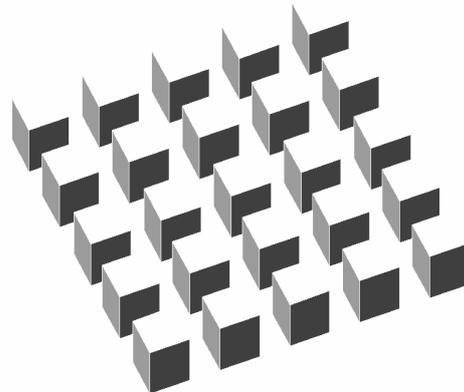
We present here *second* analogy which is manifestation of '*wind criteria*' and we call it least resistive so as to provide best alternatives for single sided and cross ventilation strategies in urban square. Here we have to meet dualistic goal, firstly, to reduce wind speeds around buildings at pedestrian level, which is often reduced due to resistance offered by buildings and utilizing it at impinging corners at elevated heights. City centres, which are marked by clustering of high rise buildings there is increased scenario for application. Here we need to have 'diffuser type' or 'ducted' buildings. This is easy for designers to incorporate seeing the scope of harnessable renewable energy for urban squares. For such diffuser shaped high rise buildings, length of diffuser need to be larger. Seeing the 'dimensions & multitude' for community based high rise city-centres building units, this is feasible.

Air flow analysis inside the canyon is not driven by the wind flow above the canyon. And for both cases of single side and cross ventilation there are very little differences for deep or shallow canyons as has been shown by Santamouris & Georgakis [4]. Under a buoyancy-driven scenario, the temperatures in each building room space increases with height due to the outside thermal plume. Wind and stack forces do not always reinforce but they oppose each other.

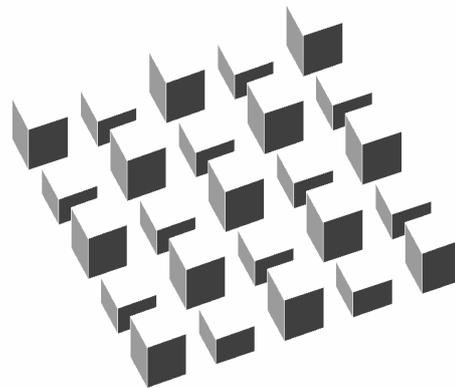
For case of urban squares under consideration buoyancy predominates due to dead winds scene in deep canyons. Here we want to highlight importance of *temperature inversion* effect for valley based urban squares which are left unaccounted in earlier researches. Valley winds overcome stack influences considerably in valley based urban squares for suppression of nocturnal UHI as can be seen in case of San- Francisco & Montreal.

Wind drafts could be confined through *block massing* and *looped clusters*. But this has to be envisaged in context of above mentioned analogy whereby a perfect sink during day discourages design

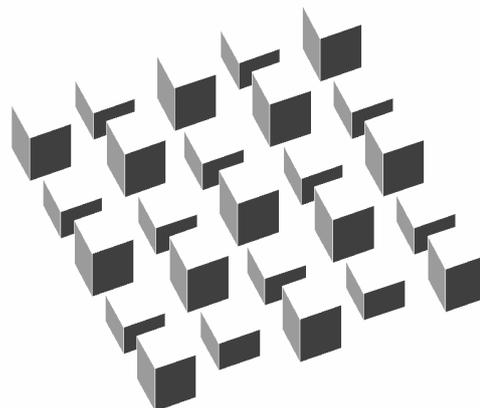
that loses heat flux. Wind speeds are directly linked to characteristics of street canyons, their H/W ratio.



(a) Symmetrical and Even height



(b) Symmetrical and Uneven height



(c) Staggered and Uneven height

Figure 6: Urban Square configurations for Least Resistance analogy

Vortex formation takes place at building edges and there is occurrence of dissipative zones. No vortex formation exists for deep canyons as they are

marked by stabilized speeds. Higher resistance to wind speeds vitiate city cores without availability of ventilation as thermal effects are more prominent at low speeds. Main considerations for the block arrangement in urban square are shown in Figure '6'. These are:

- Symmetrical: this will generate increased wind drafts for enhanced ventilation.
- Staggered: Here vortex formation will develop at the edges of buildings and we get reduced speed. Most of the wind speeds are MASSED.

Staggered and Uneven height of buildings in urban square provides best ventilation. Guiding criteria's for least resistance analogy:

- Orientation in direction of prevailing major wind direction or that guided by wind –roses. Again this orientation is not useful for deeper canyons.
- Larger diffuser lengths for high rise agglomeration of buildings for side walls.

A ventilation strategy for the urban squares is reflected in the orientation, profiling and clustering of buildings and is governed by prevailing winds. Urban squares are marked by interplay of induced winds and stack phenomena simultaneously.

4.3 Thermal capacitance analogy

Our third presented analogy rests in urban square '*thermal capacity*'. An urban square is marked by higher building density. High rise buildings in clusters provide higher thermal capacitance and are more useful under clear sky conditions contrary to notion of increased obstruction as has been shown by Mwaniki Wa-Gichia [5]. Further a higher building density demands higher ventilation at night as higher thermal capacitance adds to nocturnal UHI as highlighted by Hui [6]. High rise building fulfils the need of higher population density desired in urban square and dilutes away need of building orientation.

5. URBAN SQUARE PLANNING

We present urban square 'PASSIVE' evaluation criteria which rest in details pertaining to design of buildings and remedial measures for existing *urbanscape*. 'Buildings' are evaluated in terms of size, proportion and thermal mass while 'Urbanscape' is evaluated for urban square absorptivity and bio-climate.

5.1 Building

Building features for urban squares are investigated in terms of thermal mass, glazing, and building proportions.

5.1.1 Height to width ratio

Although an 'H/W' ratio of '2' or smaller presents with even temperature distribution but it does not cater for high population demand for urban square. Again higher 'H/W' ratio bring forth reduced sky view factor which when provided with higher thermal capacity of building envelopes vitiate external environment for commuters in summers of high latitude based cities. Humidity has very small influence for summers and winters when comparing *deep canyons* to *shallow canyons*. A higher ratio with isolated buildings dotting the urban square with uneven height is desired.

5.1.2 Glazing ratio

Although a number of researches highlight optimized glazing ratio for individual building but considering building envelope to be active part of building we do not propose any constraint on it. Again importance of glazing is not in its limitation in terms of area but reflectance delineating excess albedo in urban canopy. Secondly north glazing area should be justified. Most of urban squares reviewed like Tokyo, Fukuoka, New York provide unvarying proportions of glazing in each orientation.

5.1.3 Thermal mass

Depending upon climate, thermal mass of the building envelope can be varied. Urban squares in cities which are marked by high diurnal variation in temperature need to have higher thermal mass for reducing annual energy demands. This is further true as UHI effect increases air temperature for prolonged period in urban squares. To prevent massive buildings, a thermal attenuation or delay of 3-4 hr. is appropriate. Further insulation reduces considerably energy demands as compared to non-insulated thin or massive envelopes.

5.2 Urbans cape

This is evaluated in terms of bioclimatic changes in the urban square that is attributed to surface cover. City centre is marked by extended '*hard cover*' and there is little scope for absorption of solar energy by soft cover. UHI is decreased with increased foliage and tree cover in vicinity of city-centres as a result of *coupling effect*. This is clearly seen in case of Tokyo city urban square shown in Figure '7'. Conjugate heat flux influences micro-climate and urban square UHI is perfectly moderated.

Higher surface temperatures vitiate environment at pedestrian level through intensified radiation exchanges. A comparison for different surfaces in city-centre by Sakakibara [7] shows that streets are most vulnerable followed by buildings roof for surface temperatures. Design considerations for roof-tops should cater for reflective finishes or provisions of 'green-roofs' should exist for areas extending 5000 sq. m.

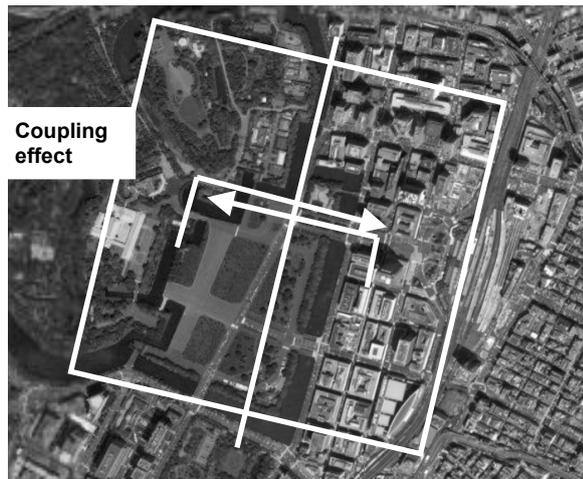


Figure 7: Urban square of Tokyo city moderates UHI effect

Site specific Urban Square features moderate UHI effect like in case of Manhattan Island Urban Square as shown in Figure '8'. Here higher FAR for strip buildings are massing winds. There is need for stepped / cascaded high rise buildings for strip development.



Figure 8: Waterfront Urban square of Manhattan Island, New York moderates UHI effect

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6. CONCLUSION

This paper has delineated a *dual approach* for energy design strategies for Urban Squares by developing simple analogies rooted in active and passive form. Further paper has shown important design & planning considerations for micro-planning needs in urban squares in context of energy exploitative strategies citing and comparing major urban squares around the globe.