Robert Samuels 1998

Urban Climate and Thermal Pollution: Sustainability and Habitability in Urban Environments

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Preface

The thermal nature of the urban climate, and its impact on global-climate change is the focus of this paper, one in a series evaluating sustainability and habitability potentials for 21st Century urban environments.[1] A seeking after emergent and generic principles…cross-cultural, inter-climatic - the global in the local…is the aim. A conceptual model - an urban design paradigm - born of this research is proffered here, albeit only a working model. Logically coherent, logistically it is fraught with obstacles – poverty and humidity two great hurdles to transcend; the hi-rise central-city reality another - but suburbia is the surprising saviour, with it's ubiquitous potential to be transformed into old-city/new urban–neighbourhoods. The rationale for the research is the endemic *necessity* to come to terms with contemporary thermo-genic lifestyle and the ubiquitous thermally-polluted city, to mitigate against the destructive climatic consequences already emerging on the warming earth.

Between the Tropics of Cancer and Capricorn, the climate imposes massively on the lives of thousands of millions of people. Few intrinsic elements differ in the *urban thermal experiences* of people from Mexico City to Jakarta, Calcutta and Dhaka: *heat* the invariable given – despite the varying influences of cosmology, culture or colonialism on urban form. The cities of this regional climate-type are the focus of this paper. To this research is brought 20 years of experience of Western European cities, and many forays into the old-city hearts of Paris, Siena, Amsterdam, Copenhagen and Stockholm. Despite their different climatic reality from the tropical and sub-tropical, their streetform and builtform embody *millennium–old notions of habitability and sustainability*, as valid in the 21st Century as the 12th: generic expressions of centuries of human ingenuity, thus capable of enriching the experience of all humans in all urbanised environments.

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[1] Samuels (forthcoming), Millennium Paradigms: Habitability and *fin de siecle* Urban Climate, '20th Century Planning Experience' Conference, July 1998, UNSW.

The goals of the World Meteorological Organisation's 'Tropical Urban Climate Experiment' (TRUCE) includes the study of: 'ways in which physical structures of cities affect urban climate and thermal stress of the inhabitants, the consumption of energy and the dispersion of pollutants'…and the development of.. 'models to better understand the tropical urban climate and improve, through urban and building design, the urban environment'(Jauregui, 1990). These are a few steps in that direction.

Introduction

Underlying the conceptual model advanced here is a recognition of the often conflicting need to ameliorate the low life quality experienced by urban inhabitants of this global region, as well as simultaneously sustain the ecological environment for future generations. Effluence is born of affluence. This is an extreme irony. As Asian cities, for instance, have become more wealthy their air-and-water-pollution has increased - a rising standard of living decreasing quality of life. Delhi, richest city in India, is the fourth most polluted city in the world; and while Thailand's GDP doubled between 1975-89 its atmospheric pollutants increased tenfold (Agarwal, 1997).

Qualifying the entire proposition is the recognition that a combination of poverty and the diversion of national resources into private hands significantly increases the possibility that these ideas will always remain ideals. Contemporary philosophy suggests market-driven approaches: special conditions for investment in sustainable urban facilities, and charging users real costs, including environmental costs. These are necessary but not sufficient. Without an ecological ethic consciously incorporated into the lifestyles of people the very survival of humankind will be in jeopardy.

The starkly evident and over-powering hi-rise reality of cities such as Hong Kong, Singapore and New York ensure, inevitably, that this 20th Century urban model (myth?) will be imposed on all our descendants.

What chance, then, sustainable urbanism? But, then, could the time be more opportune for a 21st Century vision of life quality and environmental quality? In Asia alone burgeoning populations (over 4 billion by 2010) will require the equivalent of *25 new* cities.

Modern cities have not been shaped by a concern for urban climate. The salient issue pursued is to understand the climate-appropriate qualities of ancient and medieval cities, and coherently adapt them for the cooling of hot-humid modern cities (old city-new climates) as a way of mitigating the impact of urban thermal pollution on global climate change - via heat radiated directly to the greenhouse mantle. Global warming via greenhouse gas emissions from energy used for cooling is a complementary issue but is not pursued here.

Radiative forcing from anthropogenic *heat* does not yet seem to be recognised even by the UN Intergovernmental Panel on Climate Change. IPCC (1996) measures for mitigating climate change include reducing urban heat islands by reducing carbon emissions from energy consumption. Heat emission, as a climate-altering agent, is neglected.

Tropics of Cancer to Capricorn via the Equator

Although the climate range of this vast region varies between humid and arid, and coastal and island locations can be cooled by sea breezes, the focus here is on the seemingly intractable problems of the hot and humid city. A principal feature of this climatic type is constancy – high temperatures, high humidity and low wind movement, day and night, season after season.

As distance from the equator increases, so these conditions are modified, but the *ubiquitous impact of contemporary urbanisation* further exacerbates these stressful climatic conditions. Urban thermal pollution can be traced to a few powerful factors, amongst which are: thermal embodiment in the urban mass (the heat island effect), incidental heat emissions (due to thermo-genic urban lifestyles), exclusion of natural evaporative coolers (trees) and heat sinks (water); and, quite simply, poor urban design, born of an ignorance of the ingenious geometry of ancestral urban shadowing and urban ventilation configurations and an addiction to hi-rise corporate-image CBDs in which the ‘canyon’ effect distorts both air circulation patterns and traps solar radiation.

Heat as the Core Concept

> The real limits to energy consumption are imposed by environmental conditions, not our ability to discover and mobilise sources of energy, though this latter is what most people worry about at present. The ultimate limit is set by the amount of *heat* that we can safely release without heating up the world as our use of energy increases…(producing)… unacceptable climatic changes.
>
> We cannot recycle energy, since it is all eventually converted into waste heat. This (creates) thermal pollution…(and)…puts an upper ceiling to the use of energy on the planet. The atmosphere warms up, quite independently of the greenhouse effect.
> Charles Birch, (1976/93), Confronting the Future

This fundamental insight reduces to the simple formula: energy-work-heat-climate.

1997 is almost certain to be the warmest on record. Average temperatures across the world were 0.38^{o}C higher than the average for 1961-90, before the impact of the huge El Nino is accounted for.[2]

International concern with greenhouse gases (GHGs) has focussed the world's attention on the emission of CO_2, CH_4 and N_2O in particular, and their role in climate-change. Resolutions are concerned with energy: reducing fossil fuel emissions, conservation, efficiency in buildings, solar/renewables, and fuel-cell/hydrogen powered vehicles. In themselves, however, $CO_{2\text{-equivalent}}$ emissions are innocuous; it is their heat absorbing and radiative forcing properties which are crucial. Obviously, a move from hot energy to cool energy is vital in this regard yet, whatever its source, when energy become 'work' heat is produced. The urgency of this understanding is multiplied in the knowledge that, all things being equal, the earth's population is likely to double in the next 50 years, concentrated in the already teeming and steaming developing countries. In the race to catch up with Western standards of urban living GHG and heat emissions will relentlessly conspire to disrupt the global climate.

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[2] British Meteorological Office

Embodied Heat and Operational Heat @ the Urban Scale

Operational heat is the heat produced by the functioning of a city, while embodied heat is physically contained in the urban thermal mass (unlike embodied energy which ‘symbolically’ represents the fossil-fuel consumed and carbon emitted during the lifecycle of materials).

Thermal embodiment in urban mass is a fundamental aspect of the urban heat island effect. Passive solar design in cooler climates calls for thermal mass as an essential element – yet this needs to be ‘traded-off’ against the GHG and heat emissions for which concrete is responsible. In hot humid climates mass is to be avoided - a better solution being light-weight and porous buildings raised above the ground, where air can pass and moisture evaporate. But this is no longer straightforward. As climate-change increases winds-storms and cyclones, traditional climate-appropriate buildings become more vulnerable, and climate-rejecting concrete and steel buildings (frequently air-conditioned) replace them. In any event, large commercial buildings in all countries are built from concrete and steel as a general rule, and at the urban scale this thermal mass and its embodied heat becomes seriously problematic.[3]

Urban Heat and Cool Islands

Heat is concentrated in urban agglomerations, for a variety of well-known reasons, and results in well-recognised health effects both directly as heat stress and indirectly by intensifying photochemical smog; and in increased energy use for cooling. The direct impact of heat emissions from the urban climate on global climate-change, however, is still to be evaluated.

The cool island or *oasis* effect derives, first, from the modifying influence that vegetation and water have on thermal pollution in cities, acting as heat transformers and heat sinks (besides their role as carbon sinks). Design for ventilation at the urban scale encompasses and integrates these oases, but is also influenced by the geometry of streets and the massing of buildings.

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[3] Alberti: ‘wherever the sun’s heat is troublesome, a wall of pumice will not absorb so much heat nor retain it for so long’. If only it were that simple…

Obvious sources of urban heat retention in the built environment are thermally massive materials (concrete, brick, steel) and dark-coloured roads and roofs. Waste-heat produced by machinery and motorised vehicles and, less obviously, by the unwitting pumping of hot internal air (warmed by lighting, appliances and humans) via air-conditioners to the urban air-space needs recognition. Simultaneously, because stormwater run-off is maximised in hard-surface cities, the evaporative cooling capacity of rain soaked soil is lost. Los Angeles, for instance, cooled by 5^{o}F between 1880 and 1930 due to intensive irrigation and orchard planting, but then warmed by 6^{o}F to 1980 as asphalt replaced trees (www.LBL.gov). Where trees and buildings provide shade cool spots are created, while hot spots occur where winds wash down the faces of tall buildings, and heat is bounced off the reflective glazing of buildings - intensifying the urban canyon heating effect.

The nature of the street geometry and building massing ultimately generates *thermal islands*. This intricate relationship, if simplistically interpreted, would suggest that orthogonal grids are optimal since they permit prevailing winds to penetrate into cities. However, complex and 'organic-growth' street configurations, a time-proven re-solution, can capture winds from different directions at different times of day and night; and the multitude of intersecting streets and urban places (nodes) can act as thermal vents. Wind-tunnel/canyon effects can also be minimised, particularly where streets are relatively narrow, curved and have varied building heights and setbacks – over and above the inherent shading potential in such configurations. Where green spaces and bodies of water are interspersed in the urban morphology cooler air will flow from them to hot spots where rising hot air changes the pressure gradient. Together these forces can generate thermal circulation, inducing ventilation on an urban scale. These natural phenomena could help cool a city.

Heat as a catalyst, increasing the reactivity in sunlight of pollutants such as nitrogen oxides and hydrocarbons, and the probability of ozone smog, is discussed elsewhere.[4]

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[4] Samuels, 1998, *op. cit*

Hot Energy and Cool Energy

Contemporary energy production is pyrotechnic *ie* wood, peat, biomass, coal, oil, gas, petrol and diesel are burnt…and uranium generates nuclear heat. Hot energy is used to construct the built environment (cement and ceramic kilns, aluminium and iron smelters…). Industrial and chemical processes are hot, transportation systems are hot, and all operational energy releases waste-heat.

Renewable energies, derived from wind, water and light (photovoltaics) are cool sources. Even co-generation is a cool energy in the sense that it re-uses waste heat; and a passively-cooled building could also be considered a form of cool energy use. Nonetheless, hot energy is still used to make cool energy - and will be for some time to come.

Heat from Fires

Carbon emissions during combustion in forest fires are not taken into account in IPCC calculations of GHGs, on the assumption that over a number of years forest regrowth will replenish carbon lost.[5] Besides the many other factors to consider (such as loss of nitrogen and phosphorus, which hampers reforestation) the heat emitted in 1994 during, for example, the prescribed burning of 668,000 hectares plus wildfires across 519,000 ha in Australia (Kirschbaum, 1997)…is nowhere considered. Like all deforestation, fires remove both natural evaporative coolers and carbon sinks from the planetary store. If the Kyoto protocol is ratified and Australia is permitted to increase its GHG emissions by 8% on 1990 levels by 2010, much of the rationale is based on reducing carbon-sink losses due to the land-clearing and deforestation that accounts for some 25% of CO_2 and CH_4 emissions. Heat sink and heat exchange capacity, similarly, should be recognised.

[5] The Indonesian forest and peat fires during the (probably global-warming induced) El Nino repetition of 1997 were estimated to capable of releasing more carbon dioxide than all the power stations and car engines of Western Europe in a year (Pearce, 1997).

Heat Tax

Carbon taxes; tradeable carbon levies; carbon budgets. To this, a *Heat Tax* needs to be added, calculated according to a National Heat Inventory. This could be based, first, on the cumulative or national 'urban temperature excess over the temperature of surrounding rural areas'(WMO, 1997) where urban heat sinks (cool islands) would automatically be taken into account. Agricultural deforestation alters the rural benchmark; a formula for this calculation needs to be established. Recognition would also have to be given to the percentage of hot to cool energy produced and consumed.

The greater the urbanised population, the greater the impact on the heat inventory (rural towns to be included in the heat index). Negative radiative forcing or *artificial* cooling from sulphate and other reflective aerosols would need to be accounted for but not discounted against the urban heat gain index, since they are produced from the *combustion* of fossil fuels. In due course, an equitable calorific contribution for all nations could be calculated. Given that urban form, housing density and transportation strategies can modify this thermal pollution equation, there should be a natural incentive to design cool cities - and adopt cool lifestyles.

Old-City Models

Grid City

The street *grid* is a millennium urban paradigm. Grids are the basic urban morphology seen in all cities, ancient to modern. Besides having an inherent, rational, 'syntactic logic'(Behling & Behling, 1996), the early urban grids accommodated defensibility requirements, were often shaped by the surrounding fortified walls and the location of gates in them, and sometimes reflected a concern for solar orientation or cosmological beliefs. Further, a desire for an ordered community, where social stratification can find a ready spatial solution, is also abetted by grid-logic, today as historically.

Irrespective of the *organic-cellular* form it might take, so evident in Medieval and Islamic Europe and North Africa, some form of lattice is inevitably present. The extent to which it is *orthogonal or organic* is a matter of degree. Erbil (ancient Arbela) in Iraq, permanently inhabited during the past 6 millennia, illustrates this close-knit cellular urban morphology (Morris,1972/94) - a timeless quality that modern designers of the urban village would do well to emulate.

Erbil, Iraq (ancient Arbella, Mespotamia): *cellular urban morphology*

Source: Morris (1972/94)

Organic Grid Cities: Climate-Appropriateness

The climatic advantages of organic street form cities have been attested to by major urban theorists over the centuries.

Even where cities have an austere grid form, lanes and alleys behind these formal streets are often the narrow, winding form of organic growth cities. In Mesopotamia, for instance, 'streets were arranged so that back lanes where inhabitants socialised and sat outside were curved and narrow ensuring protection from dusty winds (Golany, 1995). Vitruvius (30BC) suggested directing streets away from prevailing winds, to avoid their violent force (see Rykwert, 1976).

Alberti, in the fifth century AD, claimed advantages for winding narrow streets, since these minimise the effects of climatic extremes. He also noted the observation of Cornelius: that Nero enlarged the streets of Rome and it became hotter. Similarly, Palladio (1570) recommended that streets be made ample and broad in cities with cool climates, but that for cities with hot climates streets should be narrow, with high houses for shade.

The old-city of Dhaka, founded in the 10th Century, and seeking shade not sun, has closely-packed, mostly 3-storey high houses with distinctive narrow street frontages (often only one metre wide) facing onto narrow streets (and disproportionately long shaded extensions running back to depths of 15 metres). At the heart of the old-city of Delhi were the religious, political and commercial foci, while the rest was made up of organic, narrow twisting lanes and mixed land-uses – not dissimilar to Mediterranean European cities of the time. Colonial Governor–Generals in the Indian sub-continent during the early 1800s believed they could improve the salubrity of the cities they inherited by increasing urban ventilation, simply by overlaying radial routes onto the narrow streets. Whether this cooled cities or had the opposite effect is unknown. One of the governors of Dhaka mentioned: ‘this populous quarter which was sometimes scarcely passable for the throng is now sufficiently open to admit the unobstructed passage of vehicles’ (Ahmed, 1980). This would *not* be interpreted as a sustainable solution in contemporary urban ideology. Burckhardt, in his *Travels Through Asia* (1829), also mentioned the narrowness of the street as contributing to coolness.

Recognition of the organic grid of European medieval cities as a climate-appropriate strategy, consciously planned or not, finds expression in Lewis Mumford’s words:

> Not by accident did the medieval townsmen, seeking protection against winter winds, avoid creating such cruel wind-tunnels as the broad, straight street. Likewise, in the south, the narrow street with broad overhangs protected pedestrians against both rain and the sun’s direct glare. Frequently the street would be edged by an arcade which formed the open end of a shop, giving better shelter than even the narrow open street (glass a seventeenth century invention) (Mumford, 1961/91: 355)

Furthermore, there was a tendency during the later Middle Ages for the upper floors of houses to project out over the street, thus also shading the public realm.

In his 10 Books on Architecture, Alberti provides us with yet another rationale for the shaded, arcaded, narrow streetform:

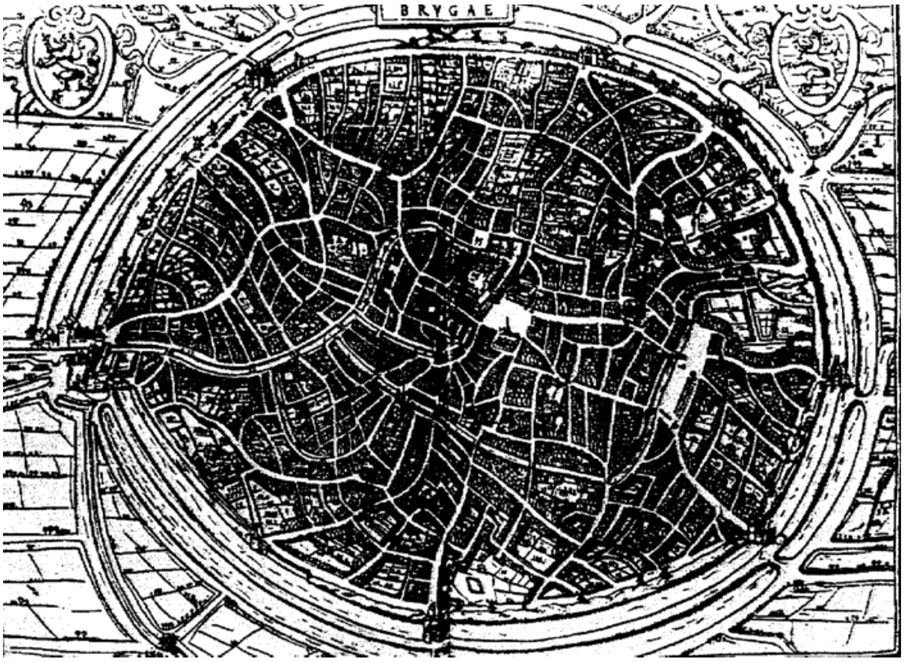
> We notice that when we gape open our mouths, the air we breathe out is warm; but when we blow with our lips tight, our breath comes out cool. So also…when air reaches an open

> space, especially one exposed to the sun, it becomes warm; but if it passes through a more constrained and shady passage, it comes out quicker and cooler

Given that organic street grids have multiple intersecting nodes (voids) where thermal-venting can occur due to pressure gradient differentials, there is an enhanced likelihood of urban cross-ventilation and convected air movement. Where courtyards and urban squares are shaded and have fountains, the micro-climate is cooled - a natural air conditioning system employed since earliest times, notably in cities of Arabia and Persia, and other hot-arid climates - which can also induce air movement .

Organic-cellular cities *are* climatically coherent. The rigidly *axial* solar orientation of a city such as Priene, in Greece (400BC) denies it the wealth of experience and interaction naturally emergent in the intricate web of medieval cities like Siena, Bruges, Avignon, Paris. Moreover, the organic old-city form could accommodate both solar access (buildings tended to face both front and back lanes[6]) and solar control, where 3 to 6 storey buildings on narrow winding streets shade the city in warm climates. Further, the distribution of prevailing winds can be maximised amidst lattice streets, being channelled and broken-up by the urban form embedded in the curving streetform, rather than funnelled down grid-iron urban canyon/wind tunnels, or swirling turbulently around wide-open wind-swept places like the *Place de l'Etoile* in post-Haussman Paris or *La Defense* in post-Mitterand Paris today.

[6] small window openings were predominant, and lighting technology was primitive - interior daylight and exterior night-light were thus minimal; not necessarily so.

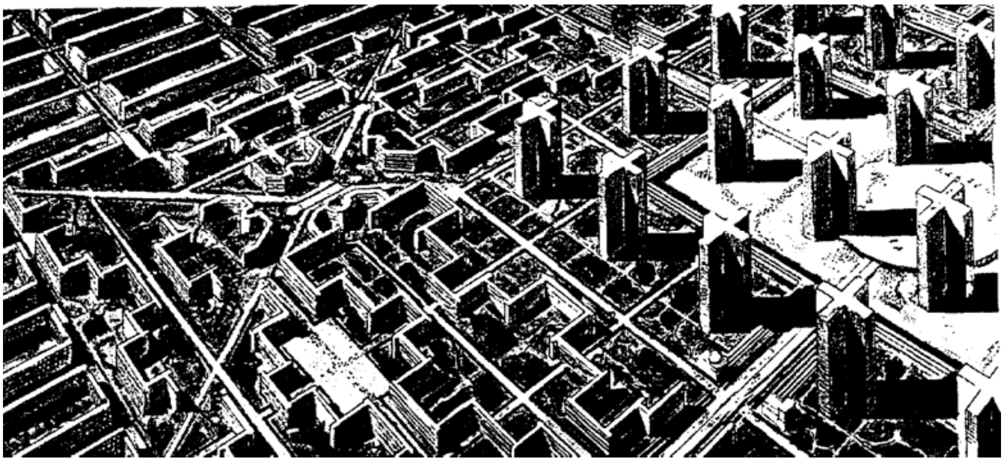


Bruges, Belgium (Flanders): *medieval urban form*
Engraving by Guicciardini, in *Descrizione di tutti I Paesi Bassi*, 1567

Siena, Italy: *organic street geometry*
(line-drawing: author)

Grids and Cars

The orthogonal grid favours the car, thus inadvertently encouraging the street to become the road (where the objective is to get somewhere not to experience the journey, or the place itself). Consequences (over and above GHG emissions) are air-pollution, noise-pollution and heat-pollution. The grid-iron inevitably leads to grid-lock. Corbusier (1924), the most *mis*guided but unfortunately influential of urban planners, had the following to say: ‘a modern city lives by the straight line…the curve is ruinous…we must de-congest the centres of cities to provide for the demands of traffic…a city made for speed is made for success’.



Corbusier’s *Contemporary City*
Source: Corbusier (1929/71)

The organic grid, however, inherently favours the walking citizen, bringing people out onto the streets, creating the living street, the café street, the safe street (animated and naturally policed). Here housing is integrated with the street, becomes the streetscape, rather than cowering back from the road.

These realisations in themselves should be sufficient reason to re-instate the pedestrian city, yet another millennium paradigm lost in the unconscious pursuit of technological advance, besides the ecological argument of curbing GHG and heat emissions.

Climate Appropriate Urban Design: *Old City - New Climates*

From an evaluation of thermal design principles built-in to old cities, and from vernacular climate-appropriate architecture, two over-arching factors emerge with the potential for cooling hot-humid cities: *insolation and ventilation*. Street grid geometry and building massing are common influences on both (inseparable from urban morphology) affecting solar control (and insulation) in the former, while canyons and nodes affect thermal exchange in the latter. Thermal mass is related to insolation; while the tempered landscape of trees and water are elements of evaporative ventilation.

In a nutshell, the issue is heat gain and heat loss at the urban scale.

Generic Old-City Urban Form

Old-city ingenuity, emergent over centuries, can be further categorised into several repeated and elemental notions which seem readily applicable today in the design of sustainable and climate-appropriate cities and urban neighbourhoods: contiguity, compactness, containment and co-incidence.

Contiguity refers to the moulding of the urban form by attached buildings (frequently street-long) interspersed with nodes (the voids amongst the form), forming the streetscape. Insolation and ventilation are both significantly influenced by this morphology. *Containment* refers to the constrained building heights (enclosure by city walls) and to the human scale of the cities - naturally pedestrian-oriented. *Compactness* is indicative of the substantial density of these agglomerations[7], and *Coincidence* is a reflection of their mixed-land-uses, a wide range of activities coinciding in space, thus accommodating a low movement society.

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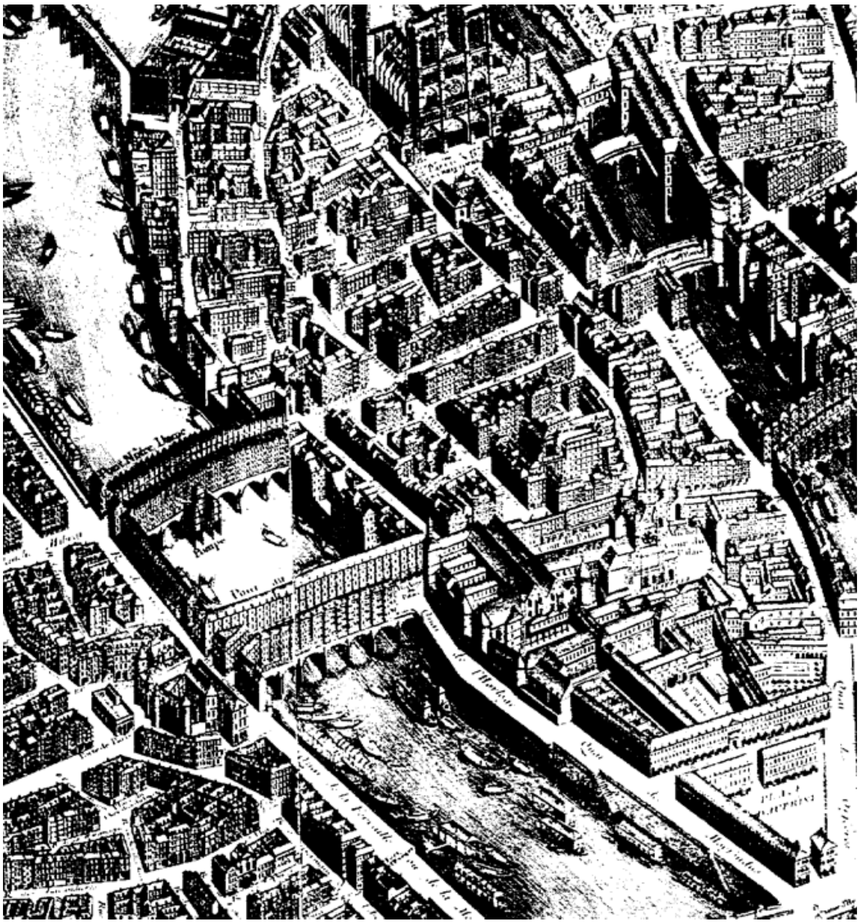
[7] American *new urbanism* is pitched at suburban densities of about 20-30 people per hectare while European and Asian cities average about 50-150pph (Calthorpe 1993, *The Next American Metropolis*; Newman, 1994)



Paris: *Old-City, New-City – Millennium Paradigms (sustainability and habitability)*
Source: Rudofsky (1969) *Streets for People*

Insolation

Urban Thermal Mass

Street geometry (street width to building height ratios) influences the spatial-temporal distribution of the urban heat. Emmanuel (1993) cites research showing how urban heat *excess* could not be attributed solely to thermal inertia in urban mass, street surface and rooftop characteristics but is also related to the *vertical* surface configurations of walls and facades. The *urban canyon* influences both insolation and air movement.

Design for low thermal absorption involves a few basic approaches:-

- light-weight structures: also congruent with ventilation demands, but efficacy is affected by a climate-change induced structural dilemma: concrete and steel structures are better at surviving cyclones. Energy embodiment, energy use (air-conditioning to overcome thermal discomfort) and heat embodiment are all thus compromised. In principle, timber is the perennial answer (although mono-cultural forest plantations are not sustainable), bamboo has remarkable structural strength, and thatch roofs are not only low thermal absorbers but are also evaporative coolers after rains.

- earth-cooled mass *or geospace*: where the earth acts as an insulator against heat gain (and loss), and subterranean buildings and infrastructure are thus removed from the urban heat island equation (see Golany, 1989; and Baggs' 1990 geo-spatial plan for Sydney). Downtown Toronto has an underground urban domain, connected to an underground subway, and although the climatic incentive is different there, the principle is proven.

- light coloured streets, buildings and roofs are heat reflecting, and reflective coatings are even more effective.

- heat sinks and exchangers: wherever heat can be absorbed and/or cooled, hot air rising to the greenhouse mantle is diminished.

A congruent and simple re-solution involves the use of local stone in shaded, cobbled streets, which are also pedestrian rather than vehicle friendly.

Urban Shading

In equatorial cities the sun is always close to the vertical, diminishing progressively as distance towards the two Tropics increases. Entire cities need to be shaded[8]; to reduce *radiant temperature.*

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[8] Emmanuel (1993) suggests a 'shadow umbrella' at the neighbourhood scale, based on shadow angles, using 'Upfront' simulation software.

- Embedded in the vernacular streets of old are colonnades, arcades, porticos[9] and shaded market-places.

- Buildings incorporate loggias and other shaded porches or verandahs, roof overhangs, canopies and pergolas (see also pergodas), and *brise soleils*, deep-set windows and screened walls; but modern solar control *glass* (the sheath for almost all hi-rise buildings today) reflects heat back to the street, reinforcing the urban canyon heat trap and its impact on global climate.

- As a consequence of street geometry and urban massing, buildings can shade each other. In cold climates this is to be avoided, in hot climates, built-in. Building height and setback from street, and narrowness and curve of street are all important variables.

- Trees shading buildings can reduce cooling energy by 35%, and summer temperatures in a shady neighbourhood can be 5°C cooler (www.LBL.gov). The palm trees of traditional oases are ideal, with their wide canopies and high trunks (allowing ventilation at ground level); and where solar access in winter is also desirable, deciduous trees are the solution.

Ventilation

Urban Cooling

> urban climate can be improved by appropriate city design such as opening urban corridors and utilisation of night-time breezes
> WMO (1997:18)

Geography, geometry and greening are the core issues in ventilation at the urban scale; heat exchange and air movement via both pressure-gradients and thermal-gradients the objective.

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[9] In Bologna a 20 mile long portico stretches from the centre of town to the mountain, protecting the

- geography

Urban geography is both fortuitous and chosen. European medieval planners, for instance, chose high sites (for both defence and hill breezes), valley slopes (cool night air descends), and sites along rivers or straddling rivers (cooling breezes) and also often diverted rivers around their cities or used moats for defensive purposes – with incidental cooling effects. Belts of trees can also channel winds and breezes, or provide shelter from them.

- geometry

Rigid axial street layouts (on N-S & E-W axes) do not necessarily optimise air movement. Many other salient aspects, such as: diurnal temperature variation and sky-view, heat-sinks, ground cover, thermal mass and urban massing can be overlooked if a reductionist ‘solar orientation’ is adhered to at the urban scale. Where streets are exclusively aligned to prevailing winds, winter and summer winds (which often come from opposite directions) can create canyon and tunnel effects due to the rigid grid geometry.

Streets oblique to the wind (30^0 to 60^0) facilitate the penetration of wind (Givoni 1991). In organic grids multiple variations on this theme occur naturally, and at the urban scale this is an overall advantage.
Where urban mass is surrounded by countryside city-heat can move to the cooler spaces, via the thermal gradient effect, and be dissipated (cooled) by vegetation. A similar, profound understanding is evident in Germany where:

> after the war Stuttgart arranged its open space to increase air circulation. Whereas the terrain formerly trapped hot air, parks now are placed on spurs running into the city’s basin. Air is cooled over the vegetation, drops into certain prescribed channels (where zoning regulations prohibit building) and passes down the slopes into the city as cooling winds. (Tandy, 1978:26).

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inhabitants from both sun and snow…as well as providing a place for community activities

Urban Massing and Urban Voids (Streets and Squares) as Ventilators

Night-sky radiation is a vital cooling mechanism functioning at the urban scale. High buildings, and narrow and contiguous street configurations minimise direct solar irradiation of streets and building facades during the day but could diminish nocturnal *sky-sink cooling*. Consequently, buildings varied in height, in setback from street and in slope of facade, and embedded within an organically varied streetform - could maintain sufficient sky-view for night-time heat loss, whilst protecting a city against daytime heat gain.

Voids can function as thermal vents or chimneys, where pressure gradients due to rising hot air induce air movement. Where feasible, shaded fountains and waterfalls and green foliage associated with such voids could aid further by pre-cooling the air. Even on hot humid days, the shade of a tree is cooler than the hot facades of buildings and hot roads, thus generating heat exchange, with consequent movement of air.

Hi-rise *clusters* of buildings, already endemic in all cities and inevitably here to say, arranged around a central open space (even if demanding the demolition of a building) could also function as thermal chimneys.

- greening

Since cities experience less humidity than the surrounding countryside (Nieuwolt, 1966, reported a 20% reduction in Singapore) some urban evaporative cooling capacity should, theoretically, be available even in hot-humid equatorial climates.

A 100-year old beech tree can transpire and evaporate about 100 gallons (450 litres) of water into the air on a summer's day, a mature orchard about 600 tons per acre per day (Robinette, 1972). Green plants not only sequester carbon (from CO_2), but are natural urban coolers, reducing air temperature *and* radiant temperature – since latent heat, drawn from the urban mass and transformed into energy to facilitate the transformation, also cools the mass.

Urban reforestation (irrigated with urban run-off), greening of both streets and buildings (internal corridors as green streets; roof gardens) and integrated parks multiply urban heat (and carbon) sinks. Theoretically, integrated urban lakes fed by urban run-off should be ideal as heat sinks, but in practice mosquito-borne diseases already affect up to 500-million people (State of the World, 1996, Brown *et al*), most living in the zones between the Tropics. Water must move.

Even large parks have only a limited climatic effect in built-up areas, but vegetation does alter conditions in the microclimate around buildings: influencing solar exposure, wind speed and air and radiant temperatures. On an average sunny summer day the average temperature of walls shaded by trees and/or shrubs can be reduced by 15^{o}C; and the surface temperature of grass turf at noon, similarly, has been measured as 15^{o}C lower than that of surrounding rocks (Givoni, 1991). Thus, a large number of small parks spread over the whole urban area, will be more effective than a few large parks.

The canopy of trees restricts heat from being re-radiated from the ground at night…the time when global warming is most apparent. From the canopy itself, however, heat is transferred at night, and the air can thus be cooled at the urban scale. Also, air passing below the foliage of trees increases in velocity (Tandy, 1978) - an advantage in hot humid climates. Thus, in principle, urban trees should be well spaced, have high trunks and high canopies.

Vines and trellises on walls of buildings cool by evaporation and shading. Given the intractable hi-rise phenomenon of all cities, perhaps the oldest solution of all might be useful: Babylonian hanging gardens…

Recent simulation research at the Institute of Terrestrial Ecology at Edinburgh University suggests that after 2050 tropical vegetation could suffer a die-off due to a warming of up to 8^{o}C in parts, leading to higher evaporation rates, lower rainfall and the eventual collapse of the tropical ecosystem.[10] This would result in billions of tonnes of carbon stored by these rainforests being ejected into the atmosphere, as well

[10] New Scientist, Dec., 1997

as methane from the rotting forests, accelerating global warming. Simultaneously, the cooling effect of the rainforests would be lost.

Urban Transportation as Heat Source

Thermal pollution is exacerbated by hot cars, trucks, buses and motorbikes. Mass transit systems integrated within medium density urban residential domains not only reduces GHGs but also heat emissions.[11] The earth absorbs the heat produced by the subterranean mass transit system, which is thus not pumped to the atmosphere.

Subterranean infrastructure has the added expense of excavation, and water-proofing but less structural strength is required, and it is sheltered from cyclones.

Given the cost of public transit systems, especially if underground, again a market-based approach could be effective, for instance: removal of subsidies for road transport, user pays-pricing mechanisms that reflect the full social and environmental cost of private transportation, and private corporation incentives (discounted purchase of land around stations, which inevitably increases in value). A high proportion of cities are devoured by roads; this space could become available for private purchase as market gardens ('edible landscapes') as well as reconstruction as public realm.

Singapore, the island city-state, has an extensive mass transit system. Calcutta has an underground metro (and tram network)…so, why not elsewhere?

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[11] Earth cooled air…from earth tubes - could enter the city from the cool subterran-transit system

Stockholm, Sweden, 1997: *Light-rail and shaded cycle-path integrated in urban domain*
Photo: author

Bangkok, Thailand, 1997: *we hold these truths to be self-evident?*
Source: Time Magazine

Besides subterranean mass transit, other systems that do not add heat to the urban climate are bicycles (a time-proven solution in many countries, from Holland to China) and Light Rail – a Western European strategy at present. Light rail systems are integrated into central urban areas in Germany (Munich, Frankfurt, Berlin); Spain (Barcelona); Holland (Amsterdam) and Sweden (Stockholm). Hong Kong opened theirs in 1988, Sydney in 1997.

Climate-*Change* Appropriate Design (Urban Climate Warming)

Core issues for re-solution in climate-warmed cities derive from the same basic problems of insolation and ventilation, shading and cooling, especially adaptation to hotter nights and enhanced humidity (the unsung GHG!) and shade/rain protection for pedestrians in the public realm. There are also new structural questions related to wind-storm and cyclone/hurricane intensity and frequency to be resolved, and resolution of excessive urban storm-water run-off and drainage problems consequent on enhanced precipitation, Further, complex design and planning dilemmas relate to anticipated rises in sea-level and river-level, due to the thermal expansion of water and ice melt-down.

Renewable Energy in the 21st Century City

Climate appropriate and passive solar efficient buildings have been with us from earliest times, as have some early solar cities, and wind and water power are as old as humankind. Today we can add solar power stations, energy-efficiency rated building design, materials and appliances, ‘smart’ building technology (heat, light and movement sensors) and energy management, and *fin de siecle* photo-electric or photovoltaic (PV) cells and wind-turbines (see: Richard Roger’s Turbine Tower in Tokyo) integrated into the building fabric itself - all cool energy sources. PV cells on rooftops and facades, and both PV and *photosynthesis*-simulating cells laminated into glazing are distinct possibilities when economies-of-scale and technological innovation eventually make this a feasible (affordable) cool-energy alternative. Photo-electric cells built-in to the urban shading infrastructure would automatically have maximum exposure to the sun’s rays. Renewable power thus generated throughout a city can be stored on the electricity-grid. There will be no need for huge battery storage. Indeed, the power station itself will ultimately *be the battery*, no longer required to generate power itself.

A possibly novel application for renewable energy as an urban ventilator and cooler - particularly useful in hot-humid climates – was formulated during this research. *Photo-electric powered wind turbines* could function as ventilators – moving air through a city. If strategically located - in urban places and at street intersections, and especially at the edge of bodies of water and in parks where air is naturally cooled – air flow could be *induced* in a city. (Solar pumps raising water to run down the facades of buildings have already been trialed: see Grimshaw's 1992 Expo Pavilion in Seville).

Low air movement, humid cities would surely be the beneficiaries of such an innovation.

Simultaneously, these solar wind-turbines would themselves generate power… renewable-renewable energy.

Ecological Fallacy

Renewable energy: cool, clean, cheap and inexhaustible…what more could we ask? Embodied in this green-scenario, unfortunately, is an unwitting ecological fallacy. One the one hand, irrespective of the coolness of the source of this energy, use of it still produces waste-heat, and the more that is used, the more thermal pollution is enhanced. The heat-absorbing capacity of the atmosphere is anything but infinite. And, will not human nature ensure that we use as much as we possibly can, thus inadvertently consuming ourselves into extinction. Planetary resources are anything but infinite even if energy is.

Efficiency and Sufficiency

Energy efficiency is necessary but not sufficient in itself as a sustainable solution. As a means to reduce GHG emissions, energy-efficiency can be enhanced via design, technology, enterprise and government: through legislation, penalty, subsidy, and incentive.

Sufficiency, an ecological ethic, involves changes in lifestyle. Without awareness of ourselves as part of the environment and not apart from it, design and technology remain as *in-built* potential. For this potential to become manifest, certain *sine qua non* ideological changes will be imperative: voluntary simplicity at the individual level, environmental consciousness and environmental literacy amongst the public, and environmental responsibility at professional and management levels. Short-term myopia, born of political expediency, will forever hamstring governments.

Perhaps more critical than anything is the importance of understanding the symbiotic roles of energy and heat in climate-change. Urban climate involves an endless thermal exchange: sun to city, city to sky.

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