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# Progress toward sustainable settlements: a role for urban climatology

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With 2 Figures

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**Summary**

Sustainable development can be defined as that which meets the needs of the current generation while leaving sufficient resources for the needs of future generations. A central objective is to decouple conventional resource use (and its corollary, waste generation) from economic development through technological innovation, improved efficiency and changes in individual practices. As the global population becomes urbanized and human activity is concentrated in urban areas, settlement planning is a key aspect of sustainability. The widespread inclusion of environmental objectives in urban plans at all scales provides an opportunity for the incorporation of urban climate knowledge into the planning process on a routine basis. Many of the stated objectives have both direct and indirect connections to climate. However, for this to happen, climate research and results must be linked more explicitly to the objectives of the sustainable settlement. In this paper, the relevance of sustainability to urban design and climate is discussed and the potential contribution of current urban climatology is assessed, identifying areas of special consideration for transfer to achieve sustainable urban planning and design.

## 1. Introduction

There is a lengthy history of idealised urban plans that link the physical form of the city to desirable social, religious, cultural or environmental outcomes. The newest urban ideal is the sustainable settlement. It is derived from the concept of sustainable development, which has been broadly defined as that which meets the needs of the present generation while ensuring sufficient resources for future generations. It is characterised by an explicit recognition that 'development' (as conventionally defined) is intimately tied to the quality and quantity of environmental resources that underpin it. One of its major objectives is to decouple economic growth from resource consumption and its corollary, the generation of waste. In particular, the reliance of conventional economic development on energy derived from non-renewable fossil fuels has focussed attention on their rates of depletion and uneven access. Coupled to this is the concern for air pollution at all scales and the general acceptance that human activities are of sufficient intensity to cause global climate change. While there is no clear path to achieving sustainability, planning strategies are based on a combination of technological innovation (e.g. zero emission vehicles), changes in behaviour (e.g. increased use of mass transit) and improvements in design (e.g. mixed land-use that minimizes travel).

The concept of sustainability has a particular relevance for urban areas as urbanisation is correlated with both economic growth and increased resource consumption (Table 1; U.N., 2001). In addition, the highest rates of urbanisation are

**Table 1.** Global statistics on urbanisation, energy and resource use compiled from tables published by the World Resource Institute and available at www.wri.org

| | Developed countries | Developing countries | World |
|---|---|---|---|
| Urban population 2000 (millions) | 903 | 1986 | 2890 |
| Percent urban, 2000 | 76 | 41 | 47 |
| Urban growth rate, 2000–2025 | 0.5 | 2.9 | 2.2 |
| Passenger cars, 1996 (per 1000 persons) | 326 | 15 | 84 |
| Gasoline consumption, 1997 (litres per person) | 626 | 55 | 182 |
| $CO_2$ emission, 1999 (tonnes per person) | 10.8 | 1.8 | 3.9 |

occurring in poorer parts of the world where the potential for economic growth and resource use is great. Thus, any positive changes in the 'developed' countries are likely to be overwhelmed by increased resource use in 'developing' countries if they follow a conventional route to development. Even now, much urban growth in the developing world is concentrated in 'megacities' where the degraded environment poses severe health risks and basic management, such as the provision of clean water, is absent. Thus, there is an imperative to outline an alternative path to economic development. An additional impetus is provided by global warming scenarios, which include a global sea level rise. This will pose a particular threat to urban areas, as coastal zones are preferred areas of settlement (Small, 2001).

The rhetoric of sustainability has been rapidly incorporated into urban planning and design guidelines across the world (e.g. The Urban Task Force, 1999). The model for sustainable planning places a concern for environmental issues on an equal footing with its traditional economic and social objectives (Campbell, 1996). The former seeks an economically efficient unit while the latter hopes to create liveable places and ensure the equitable distribution of the costs and benefits of urban living. However, there is no agreement on what the sustainable settlement should be (Haughton, 1997). Currently, most settlements are considered inefficient, profligate in the use of energy and materials, excessive in their generation of wastes and excessively reliant on non-local ecosystem services. In fact, the conventional urban area that has little or no ecologically productive land cannot be sustainable, as it must be supported by a larger area – it is estimated of the ecological footprint of the city of London equates to 90% of the ecologically productive area of Britain (Girardet, 1999). Strict ecological sustainability requires that a settlement be linked to an appropriate, local, ecological unit (such as a watershed) from which it would draw resources. However, this is not seen as a practical model for existing cities that are already linked together in urban networks that draw upon resources globally. A more common approach is to focus attention on strategies that make the settlement more 'efficient' in its use of materials and energy. An important aspect of this newer city management is the inclusion of environmental indicators related to its consumption and waste alongside conventional economic and social measures in its evaluation of settlement performance. Thus, while making settlements sustainable may not be possible, making them more efficient is a key part in achieving global sustainability (Rees and Wackernagel, 1996).

There are clear links between the climate of a settlement and its potential sustainability. Its opportunities for gathering energy, its need for energy conservation and its ability to dispose of airborne wastes are largely controlled by the climate it experiences. Moreover, urban design decisions will create microclimates that either accentuate or moderate the properties of the background climate. Thus, there is a clear role for an applied urban climatology in the planning of sustainable settlements. In this paper, I will summarize sustainability in relation to urban design and climate and assess the current state of, and potential role for, applied urban climatology in this arena.

## 2. Urban design, climate and sustainability

A useful distinction can be made between the varying scales at which urban decisions are

**Table 2.** A summary of the tools (gray diagonal) employed at the building, building group and settlement scales to achieve climatic objectives at those scales. The application of tools at each scale has a climate impact, shown below the diagonal cells, and places limits on decisions made at other scales, shown above the diagonal cells

| Objective | Impacts | Limits | | |
|---|---|---|---|---|
| | | Buildings | Building groups | Settlement |
| Indoor comfort | Buildings | Location<br>Materials<br>Design (e.g. shape, orientation, etc.) | Access to sunlight and wind<br>Air quality | Building codes |
| Outdoor comfort and health | Building Groups | Local climate change<br>Emissions<br>Materials/surfaces<br>Building dimensions – flow interference & shadow areas | Building placement<br>Outdoor landscaping, materials and surfaces<br>Street dimensions & orientation | Guidelines on:<br>Densities;<br>Heights;<br>Land uses; and<br>Green-spaces |
| Energy use<br>Air quality<br>Protection from extremes | Settlement | Energy efficiency<br>Air quality<br>Urban climate effect | Mode and intensity of traffic flows<br>Energy efficiency<br>Air quality<br>Urban climate effect | Zoning<br>Overall extent and shape<br>Transport Policy |

implemented (Table 2) and the achievable climatic objectives at each scale. The sustainable settlement will require a coherent strategy that applies planning/design tools at the appropriate scale (e.g. Rosenfeld et al., 1995) and ensures that actions at one scale are not counteracted at another scale. Thus, while the achievement of settlement scale objectives is dependent on actions at lower scales, these actions themselves are limited by decisions implemented at higher scales. This scale hierarchy does not necessarily correspond with that of decision-making – in fact, many of the critical decisions on transportation, housing and energy may not fall within the remit of settlement-scale administration.

From the perspective of the individual building, the desired outcome is clearest – that of creating an interior climate suitable for its purpose. The unsustainable building seeks to replace the outdoor climate with one that can be tightly managed, often with considerable energy input. The internal climate is specified with few variables, exhibits minimal variation and is occupied by passive subjects. An alternative view employs a variety of techniques to control indoor climate by focussing on design and materials and managed exchanges with the environment. Within this view are approaches that rely on modern technology and materials to actively gather and conserve energy and those that employ passive techniques that rely on design and non-manufactured, local materials. The distinction between the latter two is essentially one of evaluating the balance between embodied energy (that used in the manufacture, transport and assembly of materials) and that used to operate the building (e.g. Thormark, 2002). In either case, the occupant is an active part of the environmental system, adapting to varying environmental conditions. At this scale, there is a substantial body of architectural exemplars to draw upon (e.g. Cook, 1996).

At the settlement scale, the measures of sustainability focus on the efficiency of the urban system of which a key aspect is the movement of materials and people. Settlements that are low density, reliant on private car transport and characterised by strong zoning practices that separate employment, housing and services are regarded as unsustainable. By contrast, the proposed sustainable city is ‘compact’, high density and managed by a transportation network that emphasizes connectivity via mass transit systems. At critical nodes where transport routes intersect, higher population and building densities and mixed-use developments are encouraged (Rogers, 1997). The emphasis is on access to services and employment without recourse to the private vehicle. An element of this vision hopes that the transformation of economies to ones that are based on flows of information rather than people, will obviate much of the transport needs and costs. Other aspects of the sustainable settlement stress a 'design-with-nature' approach where important natural services, like floodplains, are protected. While there are no real-world examples of sustainable cities, individual settlement actions are highlighted as representing 'best practices' that may be copied by other cities. For example, the city of Curitiba, Brazil is presented as an example of a settlement in a developing country that has followed sustainability principles in its managing its growth (Rabinovitch and Leitman, 1996).

At the scale of building groups, the broad settlement objectives intersect with specific building requirements. Guidelines on dwelling density, outdoor landscaping, street properties, etc. are given physical expression at this scale. The climatic objectives include ensuring that the needs of individual buildings are not compromised while outdoor stresses are moderated. In many respects, decisions at this scale are critical to the achievement of objectives at higher and lower scales yet our knowledge and information of climate-design links at this scale are weakest. The higher population and building densities advocated by sustainable planning guidelines requires that greater consideration be given to urban design so that the interactions between buildings are mutually beneficial. Higher population densities can be achieved through different physical designs, each of which will have a distinctive impact on both building climates and the outdoor micro-scale climate. For example, considering access to daylight and significant sunshine for buildings in the in the U.K., Steemers (2003) estimates that densities of 200 dwellings per hectare (that is, eight times the current average) can be achieved by allowing obstructions of up to 30° for south-facing building facades. These types of guidelines need to be broadened to include the outdoor effects. Moreover, similar types of design guidelines are required for other climates where the requirements for solar access (or shade) and wind shelter (or ventilation), for example, are different (e.g. Emmanuel, 1995).

Although there is now considerable impetus to sustainable design and planning there exists considerable difficulties in its achievement. Among these, is that of ensuring guidelines with regard to one property (such as solar access) are compatible with those for another (such as high-density) and that decisions are consistent across all scales. Inevitably, the best overall urban design will have to consider the often contradictory effects of implementing a set of best practices to achieve a given set of outcomes (e.g. Zrudlo, 1988). For example, guidelines on building height, density and use established at the settlement scale will limit the freedom to design the building-group. In addition it is worth stating the obvious, that most settlements are already in place and the most important of all design decisions (site choice) is no longer available. Thus, all future decisions will be made within an existing urban context.

## 3. Urban climatology

Oke (1984) outlined a prescription for the employment of climate principles into planning practice that consisted of two elements. The first was the development of a science based on agreed concepts and a search for general relationships on the causative basis for urban climates. This science would provide a foundation for the development of applied urban climatology that could aid in the planning process. One aspect of the latter would be the creation of manuals that would encapsulate climate principles and provide real world examples.

In the intervening period, the science of urban climatology has advanced greatly. There is now a broadly accepted framework (including the division between the urban canopy and boundary layers) for conducting research and greatly expanded international co-operation. One of the best examples of this is the adoption of the urban canyon as a model of the city street (a key design element of cities), which has yielded a great deal of comparative information (e.g. Oke, 1988). While our understanding of urban climates has greatly improved, this has not yet generated an applied climatology where clear links between design decisions and climate outcomes. Some of the potential and the limits of our knowledge are best illustrated with an example.

An accepted relationship in urban sustainability is that between urban form and transportation energy. Information on gasoline consumption and urban population density for a range of settlements (Fig. 1) provides a clear imperative for densely occupied cities, which are characterised by lower transportation costs and consequent

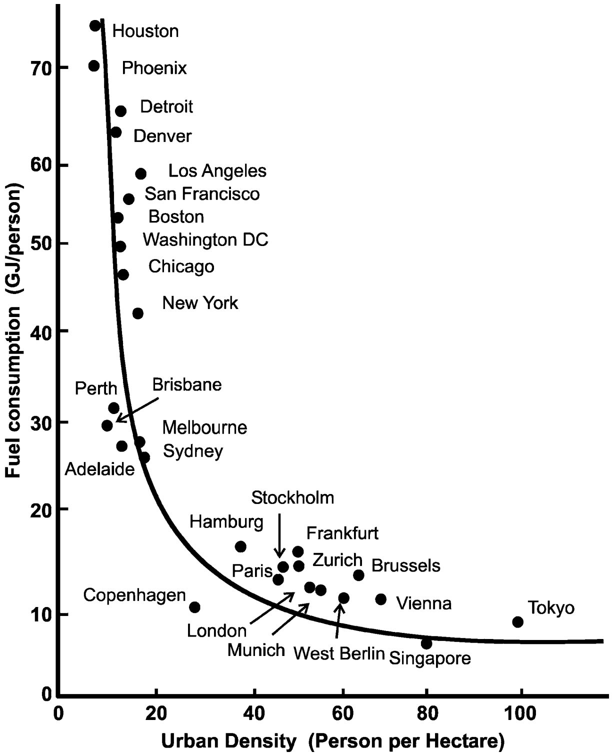


**Fig. 1.** One of the strongest arguments for compact, high-density cities is based upon evidence on per capita energy use in different settlements. This graph illustrates the relationship between urban population density and per capita gasoline consumption (in GJ) based on data compiled for 30 cities in 1980. Redrawn from Newman (1999)

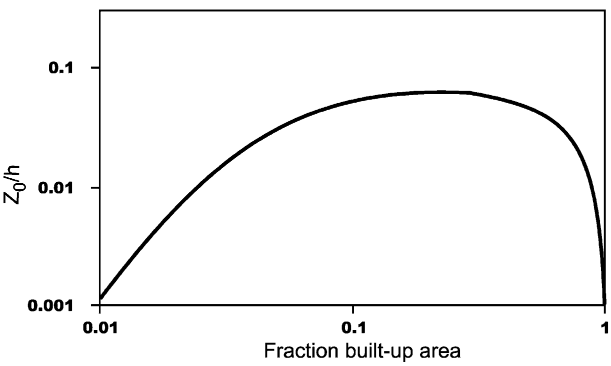


**Fig. 2.** The physical design of cities will affect surface-air exchanges. This graph illustrates the affect of building spacing (fraction of built-up area) on the momentum flux as shown by the roughness length ($z_0$). The graph is for a set of cube-shaped buildings (with a characteristic dimension, h) in a grid arrangement (redrawn from Bottema, 1999)

pollution emission (Lyons et al., 2003). On the other hand, Fig. 2 indicates that the exchange of air between the urban canopy and boundary layers is a function of the spacing between the building elements. As built density increases there is an initial increase in roughness (reflecting greater canopy ventilation) but, as density continues to increase, the canopy layer becomes increasingly separated from the overlying air. As higher population densities are generally linked with greater massing of buildings, together these relationships suggest that although high density cities reduce transport emissions their concentration in the urban canopy layer (the layer of human exposure), may increase. Thus, an important caveat to the conclusion drawn from Fig. 1 is that the three-dimensional design of high-density compact cities should ensure adequate ventilation of the urban canopy layer.

The above example illustrates that there are areas of urban climate knowledge that are relevant to the sustainability field. The distinctive nature of urban canopy and boundary layer climates is well understood in urban climatology. However, the perspective of planning at the settlement scale is often two-dimensional and does not recognise the importance of the vertical dimension of the city – in fact, information on building height is often unobtainable from planning sources. This difference is noticeable in the different use of 'density' as the explanatory variable. At this scale, planning's major preoccupation is with the functioning of the settlement and population density is a key variable but, the canopy layer climate can only be understood by reference to its physical character. A potentially useful exploration would be of the relationship between the three-dimensional form and the functions of settlements.

These graphs also illustrate a distinction between the nature of research and the information available on the urban system. Figure 1 is based on data collected from cities across the world representing a range of climates and cultures. On the other hand, Fig. 2 is based on the results of physical modelling in wind tunnels where arrays of regular blocks are arranged in set patterns. The results confirm and extend observations made in a number of field experiments (e.g. de Paul and Sheih, 1986) but we cannot produce an equivalent graph based on real city information. There are few relationships (the urban heat island is an exception (Oke, 1987)) between design elements and the urban effect that been developed from measurement studies. Moreover, the vast majority of field research on urban climates has been conducted on settlements in the middle latitudes – most are either European or North American urban areas. There is little work on settlements in Africa or Asia or on informal and traditional settlements in the largely less-developed parts of the world. A significant area of research that has emerged in recent years is the application of digital elevation model techniques to urban areas (e.g. Steemers et al., 1997). These techniques offer a relatively simple means for assessing the potential urban effect that could be readily incorporated into urban environmental assessments. However, the absence of information on the climatically-relevant characteristics of cities greatly limits our ability to apply our understanding to settlements generally.

A comprehensive applied urban climatology that consists of clear guidelines for prospective designs that is supported by real-life examples does not yet exist. While there are some guidelines (e.g. de Schiller and Evans, 1998), tools (e.g. Knowles, 2002) and case-studies (e.g. Lazar and Podesser, 1999) these are largely disconnected. There is no framework into which these studies fit, which illustrates the advantages of accounting for urban climate on a routine basis in design decisions.

## 4. Discussion

In general, the field of applied urban climatology is underdeveloped and much of the knowledge is not in a form that be integrated into sustainable settlement planning. One reason for this is an artificial division between those fields studying aspects of the urban climate and the lack of awareness of research in related areas. For example, there is a clear distinction between research on building interior climates and that on outdoor climates between buildings. Whereas the former examines the enclosed (strongly managed), the latter examines the 'open' (often unmanaged) urban canopy layer. While the former is concerned chiefly with daytime conditions and human comfort, the latter is often focussed on detecting an urban effect, often the night-time urban heat island. The physical barrier that separates these two areas of study is the building envelope. As sustainable architecture emphasizes the role of design and managing exchanges across this envelope, the separation between fields of indoor and outdoor study become less relevant. Thus, the passively ventilated building in an urban setting must consider the outdoor environment from which it draws its air (Höppe, 2002).

Where climatologists have contributed to urban design, it has often been in a formalised manner where climate concerns are the over-riding concern (e.g. Golany, 1995). While the meteorologically ideal settlement serves a useful pedagogical purpose, it does not recognise planning realities where climate issues are rarely a dominant concern. In most circumstances, climate will be considered within a broader environmental brief and it is the climate in the urban area, rather than just urban effect that is of relevance. Many sustainability issues relate to a climate whose parameters are largely set by the broader regional and local situations. For example, a major goal of sustainable planning is reduce domestic energy demand so design guidelines that focus on solar access and ventilation for energy gain and loss, respectively, are more likely to be incorporated into sustainable practice (e.g. Littlefair, 1998).

Most settlements already exist and decisions are constrained by the existing built structures. There is a need for a greater body of literature that can be drawn upon that provides solutions to existing problems (e.g. Bitan, 1990/91) and simple means of linking urban features to their climate consequences (e.g. Buckland and Middleton, 1999). As an example, the use of vegetation is widely advocated as a means of modifying a number of atmospheric properties and of controlling surface temperatures (e.g. Brown and Gillespie, 1995) however, there is very limited information available on the net impact of vegetation or the variation in environmental services with species and age.

The general acceptance of the city street as an object of study has greatly increased the scientific body of knowledge available. Most of the work conducted in this arena has focussed on how its geometrical properties influence energy and mass exchanges within the street and between the street and the overlying air. However, with few exceptions (e.g. Ahmed, 2003), there has been little research that links urban forms to levels of outdoor (dis)comfort in differing climate conditions. This requires a comprehensive model of human responses to non-steady climate conditions (e.g. Soligo et al., 1998) and a broader consideration of outdoor spaces including courtyards, parks, plazas and suburban streets that deviate from the canyon model (e.g. Capeluto et al., 2003).

## 5. Conclusions

The widespread inclusion of the principles of sustainability into urban plans provides an opportunity to place urban climate knowledge at the centre of the planning process. While there are many aspects of urban climatology knowledge that could be brought to bear on the subject, few are. The effects of building-group design on the outdoor environment is an arena where the work of urban climatology could be of greatest relevance. However, this would require a broader remit in urban climate research that gives greater consideration to:

1. The needs of designer (e.g. existing built forms and individual building needs),
2. A range of outdoor urban spaces,
3. The links between indoor and outdoor air,
4. Outdoor levels of comfort,
5. Case-studies that link design decision to measurable impacts and,
6. A wider variety of climates.

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