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Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world ☆

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ABSTRACT

It is in cities that the negative impacts of a warming climate will be felt most strongly. The summer time comfort and well-being of the urban population will become increasingly compromised under future scenarios for climate change and urbanisation. In contrast to rural areas, where night-time relief from high daytime temperatures occurs as heat is lost to the sky, the city environment stores and traps heat and offers little respite from high temperatures. This urban heat island effect is responsible for temperature differences of up to 7 °C between cities and the country in the UK. We already have experience of the potential hazards of these higher temperatures. The majority of heat-related fatalities during the summer of 2003 were in urban areas.

This means that the cooling of the urban environment is a high priority for urban planners and designers. Proven ways of doing this include altering the urban microclimate by modifying its heat absorption and emission, for example through urban greening, the use of high-reflectivity materials, and by increasing openness to allow cooling winds. Buildings themselves can also deliver improved comfort and higher levels of sustainability by taking advantage of exemplary façade, glazing and ventilation designs. In addition, changed behaviour by building occupants can help keep urban areas cool. The technology to reduce the future vulnerability of city dwellers to thermal discomfort is already largely in existence. But there is a need for complementary policy and planning commitments to manage its implementation, especially in existing buildings and urban areas.

1. Introduction

The unique microclimate of cities is the product of their complex built environment, their lack of cooling vegetative surfaces, and their increased anthropogenic activity. These combine to create a thermal contrast between urban and rural areas. This distinctive temperature pattern is at its most pronounced during the night, when the release of stored heat and the containment of outgoing long-wave radiation in urban areas combine to make them systematically warmer than the countryside (Oke, 1987). This 'urban heat island' (UHI) effect is well documented (Landsberg, 1981), and can lead to temperature differences of up to 7 °C between the centres of large conurbations in the UK and their surrounding rural areas (Wilby, 2003).

As a consequence, the inhabitants of cities have difficulty in finding respite from high summer temperatures, and this threat to human comfort and well-being poses a significant challenge for urban planners and designers. The European summer heatwave in August 2003, the warmest August on record in the northern hemisphere, was estimated to be responsible for some 35,000 heat-related fatalities, over 2000 of which were in the UK (Larsen, 2003). The impacts of this event were felt most strongly in urban areas, because of a lack of night-time relief from high temperatures. Recent research has focused on identifying and reducing the vulnerability of high-risk individuals within the urban environment to future heatwave events (e.g. Fouillet et al., 2006; Lindley et al., 2006).

This problem will become increasingly heightened under future climate change scenarios and projections of urbanisation. The urban population of Europe is predicted to increase from 73% of the total population in 2000 to 80% in 2030 (United Nations, 2005) and temperature increases of 0.1–0.5 °C per decade are expected across the UK and Europe during the 21st century (Hulme et al., 2002; IPCC, 2007a). While the use of mechanical cooling in buildings enables a reduction in internal temperatures and restores the comfort level for occupants, it is not a desirable solution overall. It produces waste heat that is emitted directly to the surrounding environment of the building, which in turn intensifies the UHI effect. Moreover, the increased use of air-conditioning conflicts (Levermore et al., 2004) with current national policies to curb CO_2 emissions (DTI, 2003; Defra, 2006).

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Adaptive strategies for the built environment are to be preferred to the increased use of air conditioning. The building sector is currently responsible for over a third of global greenhouse gas emissions, and has been cited by the IPCC (2007b) as the sector with the greatest potential for carbon saving. The typical design life of 20–100 years for buildings means that their designers and developers have a responsibility to anticipate future climates and to avoid changes prejudicing the structural integrity, external fabric and internal environment of buildings (GLA, 2005). Such a forward-thinking approach to 'climate-proofing' can reap significant benefits in the long term, including substantial economic savings (UKCIP, 2004). Furthermore, detailed risk assessment and appropriate planning for adaptation can minimise risk and exploit opportunities, by seeking optimal options, which are mutually beneficial (Lindley et al., 2007). These approaches avoid mal-adaptation, such as the use of air conditioning, and encourage the development of buildings that improve thermal comfort while having lower energy use.

2. Current understanding

Some degree of warming in urban areas is inevitable, because of the delay between greenhouse gases being emitted and their full effect on the climate. Recognition of this reality has seen a shift in focus in the recent literature from greenhouse gas emission mitigation strategies to risk analysis and the identification of adaptive mechanisms (Lindley et al., 2006, 2007; McEvoy et al., 2006; Willows and Connell, 2003). Successful adaptation to minimise the occurrence of heat stress is, however, dependent upon a detailed understanding of the processes that lead to elevated urban temperatures. Fortunately, there exists a wealth of literature concerned with urban climatology across a range of spatial and temporal scales, extensively reviewed in recent publications by Arnfield (2003) and by Souch and Grimmond (2006).

2.1. Urban climatology

Urban areas contain buildings and environments with distinctive topography and bio-physical properties. This means that their energy receipts and losses are different from those of rural areas. The steepness of the urban–rural temperature gradient depends upon a range of meteorological and geomorphological variables. But maximum heat island intensity is generally observed on calm, clear nights following a day of similar conditions. In this scenario, the lack of cloud means that daytime solar radiation receipt is at its greatest. This leads to a large amount of heat being stored in the urban fabric, which is characterised by low albedo and hence by a high tendency to absorb heat. This heat is released into the surrounding environment as the external air temperature cools after sunset. But net losses of heat by long-wave radiation are at a maximum during the evening in the rural hinterland, and remain comparatively low in the city, where radiation is reflected or absorbed by buildings and by higher levels of air pollution. Under low wind conditions the difference is further accentuated, since nocturnal cooling is inhibited by the lack of ventilation to transport warmer air away from the urban environment.

The alteration of the urban radiative energy balance, and the reduction of heat loss by wind-driven turbulence in a city environment, are both consequences of urban surface geometry. The convoluted nature of the urban surface leads to radiative interaction between tall urban structures. Radiation which in a rural area would be emitted into the atmosphere is reflected instead between surfaces. This urban morphology is also responsible for lowering the 'porosity' of the city and limiting air flow through it (Britter and Hanna, 2003; Skote et al., 2005). Street canyon geometry is often measured in terms of the sky view factor (SVF) the proportion of sky visible in a 180° field of view, or of the aspect ratio, the height of the canyon divided by its width. Both are readily quantifiable measures of urban terrain (e.g. Chapman et al., 2001; Grimmond et al., 2001). They are also a surrogate for building density, which is a key variable in controlling heat island intensity. The overall size of a city, measured by population, displays a non-linear relationship with the urban–rural temperature difference (Oke, 1987). Even quite small centres are found to have a heat island effect. The gradient of this relationship differs, for example between European and North American cities, as a result of different development patterns and planning structures (Goudie, 2005). This means that SVF is generally accepted as a more robust indicator of heat island intensity than aspect ratio.

Although complex, the relationship between urban morphology and the urban–rural temperature difference has been shown to display an inverse linear association under the idealised UHI conditions outlined above, for a range of mid-latitude, developed cities (Oke, 1981). This means that more built up or denser cities have bigger heat island effects. However, spatial temperature variations within a city may not correspond quite so simply with SVF, owing to the myriad of other potential influencing factors that are present at the microscale (Eliasson, 1996). For instance, a key difference between the surface energy budget at rural and urban sites is the ratio of the latent to sensible heat fluxes. In rural areas, the surface is dominated by vegetation, from which water evaporates. In contrast, much of the surface in an urban environment has undergone waterproofing through the use of impervious materials, reducing the latent heat flux (Grimmond and Oke, 1999, 2002). Differences in land use, irrigation, wind speed and rainfall mean that evaporative cooling varies in urban environments. But even in densely populated areas the latent heat flux accounts for 20–40% of the net radiation balance (Grimmond and Oke, 2002; Grimmond et al., 2004). On a neighbourhood scale, the presence of a vegetated area or water body within a city can have a significant cooling effect on local temperatures (Graves et al., 2001; Spronken-Smith and Oke, 1999).

The day-to-day activities of city inhabitants also emit heat into the surrounding environment (Grimmond, 1992; Ichinose et al., 1999; Sailor and Lu, 2004). The energy consumed by traffic, buildings and people results in heat generation, which makes a significant contribution to the urban environment, particularly during winter. Estimates of its scale range from 71 W/m^2 in Lodz, Poland (Klysik, 1996), to 1590 W/m^2 in central Tokyo (Ichinose et al., 1999). This contributes between 1 and 3 °C to the heat island effect (Fan and Sailor, 2005). Data from energy consumption statistics suggest a more refined range for the mean annual anthropogenic heat flux of 20–160 W/m^2 for large cities (Oke, 1987), ranging between 20 and 40 W/m^2 in summer and between 70 and 210 W/m^2 in winter (Taha, 1997). The effect of this waste heat production is to create a 2–3 °C heat island in the central areas of such cities (Taha et al., 1992).

As discussed above, several studies have found urban morphology to be of fundamental importance to the timing and magnitude of the heat island effect (Arnfield, 1990; Oke et al., 1991; Swaid, 1993). In contrast, the thermal absorption and reflectance of urban and rural landscapes are not dissimilar (Oke, 1981). Nevertheless, Oke et al. (1991) suggest that the thermal admittance of the urban fabric and the canyon geometry are of approximate equal importance to UHI formation. Within a city, temperature patterns are dominated by an inverse relationship between temperature and distance from the city centre, but are also strongly related to land use, which is often a surrogate for urban morphology and geometry as well as to surface