Building for climate change: planning and design considerations in time of climatic uncertainty

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The climate change discourse is touching all fields and aspects of scientific inquiry and research, as well as everyday life. This paper reviews some of the more pronounced aspects of planning and building design that are directly related to climatic issues. It attempts to show how the exacerbation of climatic extremes and 'freak' weather events influences people's living and working environments, and why the formulation of alternative, climate adapted principles and practices is no longer a 'luxury' that can remain along the fringes of the planning and building disciplines.

Keywords: Building materials, Climatic stress, Energy conservation, Indoor environment quality, Post-occupancy evaluation, Sustainabe architecture

Introduction

Massive scale planning and construction dominated the post-WWII world, be it in the developed or the less developed countries (LDCs). Convenient and accessible means of travel and telecommunications enabled the rapid spread of technologies, materials, styles, concepts, approaches and theories. With accelerated urbanisation, increasingly standardised and uniform building systems were employed – on coastal plains and highlands, in mountains and deep valleys, from the tropics to the deserts, and from the equatorial regions to the permafrost. Cheap fossil fuel made electric lighting and ventilation – and finally, air conditioning – available to the masses, and central heating and cooling systems took their place as the preferred means for tempering the thermal environment. For a certain period things seemed to be advancing as planned, until economic volatility, deteriorating environmental quality, and extreme weather events focused attention on the interface between architecture and climate.

The climate change debate has been going on for some years now, recently reaching the point of general agreement among most experts that we are within a process of increasing climatic uncertainty, where climatic extremes are becoming more frequent and more extreme, and they are probably going to be even more so in the future.[1] These discontinuities already have an impact on communities and livelihoods, and this impact is expected to become more pronounced in the years to come.[2]

Among such impacts the authors can point out the flooding of lowlands, primarily – but not only – flood plains. Melting ice and rising sea levels, alongside concentrated downpours, are bringing populated regions under water, flooding people out of homes and work places. The list of these events is lengthening and their locations are diverse – the US and UK, Ireland, Central Europe, the Balkans, Bangladesh, Australia and elsewhere. Such events have long term results, such as subsidence and the spreading of mould in buildings, with pronounced structural and health problems. At the other end of the scale is desertification – the expansion of deserts – bringing previously temperate areas within the border of drylands, with deserts worldwide growing by over 50% between 1980 and 2000,[3] affecting energy demands for cooling, increasing water consumption to compensate for rising evapotranspiration, and even raising morbidity and mortality in regions adjacent to deserts, and even rather far away from them.[4]

While climate change is often discussed under the singular heading of global warming, the authors' focus here is on trends and phenomena that are much more local in nature: the changing climate of urban areas and indoor environments. These smaller scale modifications share some of the characteristics of the global trends in terms of their causation, but have crucial differences in terms of their timing and intensity.

Urban heat island (UHI)

The characteristics of buildings and built clusters are now recognised as factors influencing the climatic patterns of entire urban regions, and the demand that buildings place on ecosystems is continually widening. Because of these larger scale impacts, the urban built environment is a growing subject of interest to physical geographers and climatologists. At the same time, more and more building designers and urban planners have become concerned with physical processes in the surrounding natural environment. In this way, the relationship between architecture and climate has become a common focus for academics and practitioners, whose

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1 Urban canyon, Manhattan, USA, Nov. 2009. The combination of high-rise construction and heavy traffic has created an urban environment that is burdened by overheating, air pollution and noise – which in turn has decisive impacts on thermal comfort and well-being, public health, and energy consumption. The Urban Heat Island (UHI) has become one of the major sources of concern among urban climatologists and planners. (Photo: I.A. Meir)

disciplinary fields were previously remote but have recently converged.

The most thoroughly documented form of inadvertent climate change is the UHI, or the growing tendency of cities to be warmer than their surroundings. The temperature difference between dense urban centres and the open outskirts of the city may reach 10°C or more, and the effect is most pronounced on calm cloudless nights. Understanding the characteristics and causes of the heat island is a core issue in urban climatology, which has developed into an established and dynamic field of research (for a review see Arnfield 2003).[5] It includes a burgeoning effort to measure and model the patterns of energy exchange in cities, and its growth is due in no small part to the work of T. R. Oke, whose *Boundary Layer Climates* (1987)[6] made the underlying principles of climatic modification accessible to those with an interest in shaping, as well as studying, the built environment.

The intensity of urban warming, though related in a broad way to the very size of the urban population, is more closely linked to the practice of architecture than first meets the eye. As cities get denser and their buildings higher, urban canyons get deeper and the exposure of their surfaces to the sky becomes ever more restricted (as expressed by a smaller 'sky view factor'), limiting skyward heat dissipation. Incoming solar radiation is trapped and heat retention of the buildings and structures intensifies, and the ventilation of the urban spaces becomes more problematic due to the density of construction and lack of open, continuous urban spaces. Thus, temperatures in city centres have been found to increase with density, or with the height to width ratio of their urban 'street canyons' (Figure 1) – a tangible architectural entity that not only represents the fundamental building block of the urban fabric, but also tends to contain people. And the climatic comfort of pedestrians in streets and other outdoor spaces has become a significant concern among architects, who are increasingly involved in urban design.

There are ample reasons for this concern: pedestrian friendly streets give city dwellers an alternative not only to air conditioned building interiors, but also to air conditioned vehicles. There is no doubt that the domination of motorised transport has utterly transformed urban architecture, and we now know that it is transforming climate as well. Car travel increases drastically with low density patterns of suburban sprawl, meaning that the physical urban pattern, which reflects innumerable decisions by architects and planners, is partly responsible for ever increasing levels of vehicle fuel consumption and emissions. Two of the side effects of growing urban mobility are greater levels of 'anthropogenic' (or human made) heating, and more severe air pollution, both of which intensify the UHI effect. Still another factor influenced by architectural decisions is the replacement of vegetation with 'waterproofed' heat retaining paving, and one of the solutions promoted recently to counter urban heating and absorb excess carbon is the 'green roof' – adding yet another level of value to an architectural device.

It is critical, however, that the UHI is not monolithic – within the urban canopy, or the spaces contained between buildings, it is more like a collection of islands, each with its distinct microclimate. In terms of the actual climatic stress experienced by a pedestrian, a narrow shaded street in a compactly built neighbourhood may be considerably more comfortable on a summer day than one which is fully exposed to direct sun, even if the air within it is slightly warmer. Other microscale features, including urban parks and streams, may greatly improve the climate that is encountered in their vicinity even if their effects do not extend throughout the city.

Urban environmental effects may prove lethal when conditions reach extreme values. The summer of 2003, one of the hottest in European history, will be remembered for inflicting many casualties. France alone recorded nearly 15 000 deaths above average for the season, and these were directly connected to nights in which the temperature did not dip below 29°C. We can assume that the air temperatures in the crowded city centres were even higher than this, and reached even higher levels inside the buildings – and this gives us a formula that links physical planning with morbidity and mortality. True, the polemics regarding anthropogenic contribution to climatic changes has not been resolved yet, but more and more evidence attests to our non-negligible influence.[7] Whichever the case, it is clear that what happens outdoors in terms of heat or cold directly affects energy consumption indoors.

Buildings and energy

When standard sources of fuel are unavailable, people tend to use whatever they can find for cooking and heating, including animal dung and waste materials.[8] Combustion of these materials is a health hazard, especially when they are burned in a closed space.[9] People of the wealthy world are ostensibly spared these problems since they have access to available, relatively inexpensive forms of energy. Today, about half of the energy consumed in industrialised countries is invested in buildings, primarily for heating, cooling, lighting, movement, but also in the production of the materials, and the construction and demolition of buildings. Mechanical systems such as air conditioning have enabled the development of unique building types that rely on high energy input for their normal operation, as opposed to the traditional, vernacular and historic precedents.

A prime example can be found in high rise buildings that are dependent on mechanical user transportation systems (i.e. elevators) and on pumps to raise water to high levels (including fire extinguishing systems). Deep plan office buildings require artificial lighting, ventilation and air conditioning due to the distance of the main part of the space from the façade. Buildings with shells of glass and steel lack insulation, as well as thermal mass to store energy, and are thus unable to regulate their inner climates without exorbitant heating and air conditioning systems, be they in dry or humid climates.[10] The inappropriate design of buildings often creates indoor conditions defined as sick building syndrome or building related symptoms, which directly affect the tenants' wellbeing, health and productivity, thus also affect the economy in very complex and long term ways (see, for example, Fisk 1999).[11]

It has become more and more apparent that the sustainability of such structures over time is doubtful, since the energy sources on which these buildings rely are being depleted at a worrisome rate. Both researchers and petroleum companies estimate that the turning point will take place between 2010 and 2020 when the extraction of petroleum will reach its peak rate and go into decline, though demand may continue to increase.[12] These estimates are based on consumption trends and present development, but already energy demand is growing exponentially in relation to the potential supply. The economy of China (estimated to have grown by over 9% in 2006) and other fast developing countries is based on the growing exploitation of dwindling fossil sources of energy. The present rate of energy consumption cannot continue indefinitely, and this threatens the future of the building types most common in our modern cities – or more correctly, the wellbeing and even the survival of their tenants.

The prevalent building and construction styles in the world's largest cities, especially in the city centres, create knotty environmental problems. One of the most tangible is the UHI referred to above. The intensification of the UHI contributes to the consumption of more energy to the air-conditioned buildings found in these heat islands; and this, in turn, probably exacerbates the heat island phenomenon as well, creating a vicious circle, a potentially lethal heat ping-pong between indoors and outdoors.[13] A more environmentally oriented planning process which would take into account the need for natural ventilation and daylighting, solar and wind access to buildings could potentially limit such problems to a large extent. But it is not only the building types and the broader planning context that are the source of these problems, but also the materials from which contemporary buildings are built.[14]

Building materials

Buildings today follow two separate tracks in terms of the materials employed in their construction. On the one hand lie the modern materials commonly used: fired bricks and concrete blocks, cast concrete and steel, glass and metal cladding. These represent the developed world, and this architecture is imitated in the LDCs for institutional buildings and public construction. On the other hand, people in LDCs – representing the vast majority of the world's population – build their homes either with traditional materials employed in vernacular architecture (adobe and other soil construction techniques, bamboo, fabrics of various types, reeds, wood etc.) or alternately reuse waste materials, often reclaimed from waste disposal sites. Whichever the case, it is important to remember that the primary function of buildings is the provision of shelter for people to live and work in. As such, their main objective should be the provision of comfortable, healthy, secure and safe environments.[15]

'Comfort' includes thermal, visual, acoustic and psychological conditions that are agreeable and convenient. The actual requirements of thermal comfort, though, have been a constant source of debate since the first energy crisis of the mid 1970s. The original thermal comfort standards – i.e. the combination of air temperature, relative humidity and other environmental parameters, which is perceived by the majority of interviewees as 'comfortable' – were set by early researchers[16,17,18] as relatively strict and well defined. However, in recent years they are being reassessed and shown to be not only dependant on gender, health and age, as well as socioeconomic, ethnic and cultural background, but also on the willingness and readiness to accept environmental conditions other than those strictly defined by HVAC engineers. Such has been this shift, that even ASHRAE (2004)[19] defines thermal comfort as the state of mind that expresses satisfaction with the surrounding environment (ASHRAE Standard 55). Researchers have been expanding this definition by considering the relations between indoor and outdoor conditions as interrelating and in a dynamic balance, and by assuming that any person has a variety of possibilities to adjust to changing environmental conditions, among them behavioural adaptation.[20,21,22]

Such adaptive models of thermal comfort presume that the building has the ability to store heat or coolth so that the conditions within it may be comfortable on average – combining the air temperature with the radiant temperature of the surfaces within. To achieve this, a building has to combine a certain storage capacity – thermal mass – with thermal insulation. This means that the building envelope has to have two contradicting thermal properties.[23] Whereas technically this is not a problem, and various solutions exist for the combination of thermal mass and insulation, it is often argued that many of the conventionally used materials, such as reinforced concrete, aerated concrete, expanded polystyrene, glass and aluminium are so energy intensive in their manufacture that the operational energy savings they provide over the life span of the building do not necessarily compensate for the extra embodied energy that is required in the building's construction.[24]

Challenges shaping next paradigms

Design and construction in the near future will be challenged by the following three decisive processes: accelerated urbanisation in developing countries; the progressive depletion of fossil fuels and other natural resources; and the impact of human activities on the environment.

These topics have not yet attracted the attention they deserve in the architectural discourse, though they are critical to our future. The demographic trends of the last decades predict that by the year 2030, about half of the world's population will live in the cities of the developing countries.[25] These processes are not controlled and certainly are not planned. Their significance is in the addition of large numbers of people to cities whose existing services and infrastructure are already collapsing under current pressure. The residential zones springing up around the big cities are usually slums without infrastructure for water and electricity supply, and without orderly sewage systems. Surveys show that only about 40% of the urban population in Africa have access to running water (sometimes even limited to a single water tap in the centre of a neighbourhood), and that less than 20% are hooked up to any type of sewage system. The percentages in Asia and South America are higher than in Africa though not nearly as high as in the industrialised countries.[26]

In addition to the health implications of these two topics, there exists the problem of construction from non-standard materials (corrugated sheet metal, industrial waste, cardboard, polyethylene sheets etc.) that cannot provide adequate living conditions or thermal comfort. The tenants of these substandard structures also suffer from fuel poverty. Weak populations in the industrialised countries suffer from this phenomenon, too, though for different reasons: while fuel is widely available in developed countries, disadvantaged populations simply cannot afford to pay for it.

A fascinating discussion is taking place between public health professionals on the one hand, and atmospheric scientists and city planners on the other. These latter professionals deal with the problematic relations between the built-up space in which we live and the byproducts of the use of natural resources (including fuel). They study the effects of these factors on air quality both outside and inside buildings, and on our health. New studies, for example, point to a direct link between proximity of neighbourhoods and educational institutions to main roads, and an increase in asthma outbreaks in children, and between proximity of residential areas to power plants and acute respiratory system problems among children;[27] between sealed buildings with expensive, energy intensive air-conditioning, and sick building syndrome and building related symptoms; between unwise land allocation for building, and severe problems such as flooding, subsidence of buildings, penetration of contaminants, and more. The flooding of New Orleans in 2005 may be an extreme example of such improper land allocation, though it is definitely not the only one. Recent studies show areas potentially flooded under specific climate change scenarios, among them parts of the Netherlands and the UK, Bangladesh and areas around the Mekong river, to mention but a few (Figure 2).

Some of the world's environmental and climatic changes are connected to desertification processes. In the last 20 years, deserts have expanded by $\sim$50%, and today, drylands make up $\sim$45% of the world's continents. Yet our view of desertification remains ambivalent. Arid, sparsely populated zones are perceived as useless (beyond the exploitation of their limited natural resources), or as venues for problematic activities such as nuclear experiments and the disposal of hazardous waste. On the other hand, we must remember that deserts are home to and affect, directly or indirectly, some two billion people. The desert's expansion brings many people to the frontier and others to the heart of the desert, and this creates migrations of refugees and economically motivated immigrants.

2 Flood in Oxford, UK, Dec. 2008, one of several floods during that winter and thereafter. Building on floodplains has been a widespread unsustainable practice in many countries. In recent years this has caused repetitious flooding of residential and other areas, affecting structures and causing health problems due to humidity and mould growth. (Photo: I.A. Meir)

Although we often have a hard time relating to such macroscale events and chains of events, the following example may prove a good illustration of the immediate and intimate relations between the lifestyle of an individual and the global changes and effects. In the 1980s and 1990s a prolonged and extreme drought in the Sahel caused the death of 100 000–250 000 people, and affected 20 countries and 150 million people, 30 million of whom were in urgent need of food aid, and created 10 million refugees seeking food and water. Originally the Sahel Catastrophe was attributed to ignorant and primitive pastoralists of the Sahel and the way they overexploited their environment by overgrazing, thus causing desertification and drought. However, a few years down the line a strange connection was identified between cooling of the seas around Europe and a change in the monsoon regime, weakening the rain bringing winds, thus causing aridisation of the Sahel.

The sea water's temperature reduction was eventually attributed to global dimming, which is caused by aerosols in the atmosphere.[28] The source of such airborne particles is coal fed power plants, vehicles running on combustibles, and industrial plants. Whereas none of these sources was significantly present in the Sahel, all of them were in massive presence in Europe. Thus, what was originally thought to be the 'crime and punishment' of ignorant people and the way they took advantage of their environment, proved to be the unintentional influence of the affluent world on the poor and hungry African desert. And here is the right place to remind the readers that some 50% of all energy used in the industrialised countries is invested in buildings!

3 Sand storm, Negev Desert, Israel, Feb. 2009, one of four such storms in the first quarter of the year, which brought visibility down to less than 100m. Such storms, as well as the much more frequent dust storms, are potential health hazards. Buildings not designed for such conditions may turn into lethal traps due to large quantities of breathable dust particles in the air, accompanied by a rapid rise of temperatures and occasional power failures. (Photo: I.A. Meir)

This might have been the end of the story, coupled with some aid and development programmes intended to somehow improve the situation of the refugees and the hosting countries in the region, had it not been for an additional detail and twist of destiny usually disregarded. Some 50% of the global dust in the air today originates in arid Africa (Figure 3). This has been the impact of drying, causing the planet's atmospheric dust loading to increase by 33%.[2] This in turn has been shown to have a direct influence on morbidity and mortality, as demonstrated by a study connecting dust storms in the northwestern provinces of China with mortality in Taiwan.[4] Can this then prove to be a new nemesis for the industrialised, non-desert world?

These three trends or processes – urbanisation, depletion of natural resources, and human impact on the environment – should be a focus of interest for all planners and architects. The real challenge for professionals and decision makers lies in understanding the phenomena, and responding with appropriate policies, in the following fields:

(i) adaptation of design and construction to environmental constraints, particularly desert conditions, through the utilisation of alternative energy sources and materials
(ii) development of passive and hybrid heating and cooling systems for buildings and semi-open spaces
(iii) life cycle analysis of materials and buildings as a decision making tool enabling the comprehensive assessment of buildings and their components from cradle to grave or – even better – from cradle to cradle, thus minimising environmental impact
(iv) post-occupancy evaluation of projects aimed at the creation of benchmarks for future planning and design, but also at the immediate remediation of building and building systems malfunction[29]
(v) study of the urban microclimate and adaptation of settlement forms and patterns to the desert conditions
(vi) water policy and resources management
(vii) proactive contingency planning
(viii) study of refugee related problems such as food and water security
(ix) study of historic settlement and building patterns and construction technology allowing a better understanding of low-tech construction upgrade for the future.[30]

The major challenge of the coming years is to adapt buildings and settlements in general, and those in arid zones in particular – both in developing and developed countries – to the needs of the future. An interdisciplinary approach needs to be promoted as the essential basis for sustainable planning.[31] The abuse of the environment, desert and non-desert, cannot go on without heavy repercussions, and it is up to the planners and the architects to take a more active role in the decision making processes.[32] It is not a question of choice, but rather one of necessity – one might even say sheer survival.

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