Chapter 19:

CLIMATE CHANGE AND BUILDING DESIGN

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Introduction

Climate change is now seen as the key environmental challenge to the planet and its people for the remainder of the 21st century. Predicting both the form that climate change may take over the next 50-100 years, and the impacts that those changes may have on the natural and built environment, continues to be a complex and contentious area of research. The latest Intergovernmental Panel on Climate Change (IPCC) report states that warming of the climate system is now clearly identifiable, and that from the 1950s many of the observed changes are unequalled over previous millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea levels have risen, and the concentrations of greenhouse gases have increased (IPCC, 2013). Envisaged future changes to weather patterns, based on various emission scenarios, have regional variations, but the major foreseen changes include warmer and drier summers and milder and wetter winters. There is a general scientific consensus that climate change arising from global warming is the result of increased greenhouse gas emissions from human activity, and the built environment, through the fossil fuel energy it uses to function, is a major contributor to those increased emissions. Historically, climate has shaped the built environment, but now the built environment is shaping the climate. In this chapter the potential impacts of climate change on buildings will be discussed and the options for changes to building design to make buildings more resilient to future climates will be considered (see de Wilde and Coley, 2012; Gething and Puckett, 2013; McGregor et al, 2013).

Climate change and temperature

Impacts

The average global surface (land + oceans) temperature increase by the end of the 21st century is *likely* to exceed 1.5 °C relative to the 1850 to 1900 period for most emission scenarios and is *likely* to exceed 2.0 °C for many scenarios (IPPC, 2013). As oceans generally warm less than land then temperature increases over land are expected to exceed these average values. In urban areas this warming will add to the already higher temperatures experienced in cities due to the Urban Heat Island (UHI) effect (Watkins et al, 2007). The impact of hotter summer days and much warmer summer nights will include thermal discomfort and difficulty with sleeping. There are suggestions that night time temperatures may be more significant then maximum day time temperatures in terms of health impacts upon people (PHE, 2013). Warmer temperatures are associated with several serious diseases, such as malaria, and an increase in food poisoning, air pollution and water contamination. However, the most serious thermal climate change impact upon people is the predicted increase in the frequency of heat waves. There is a direct relationship between very hot conditions and human illness and mortality. The European heat wave of August 2003 is estimated to have been responsible for around 35,000 excess deaths, with the elderly and the ill being most affected (Confalonieri et al, 2007). In France 91% of victims were over 61 years old (Salagnac, 2007). Studies in the UK suggest a possible 257% increase in heat-related deaths by the 2050s of compared to current mortality rates (Hajat et al, 2014). Figure 1 shows the total daily deaths in London during 2003 for people aged over 75, with a marked peak occurring during the August heat wave. It is believed that the European temperatures experienced during the summer of 2003 heat wave will become ’typical’ by the 2040s and could be considered ‘cool’ by the 2080s (Stott et al, 2004).

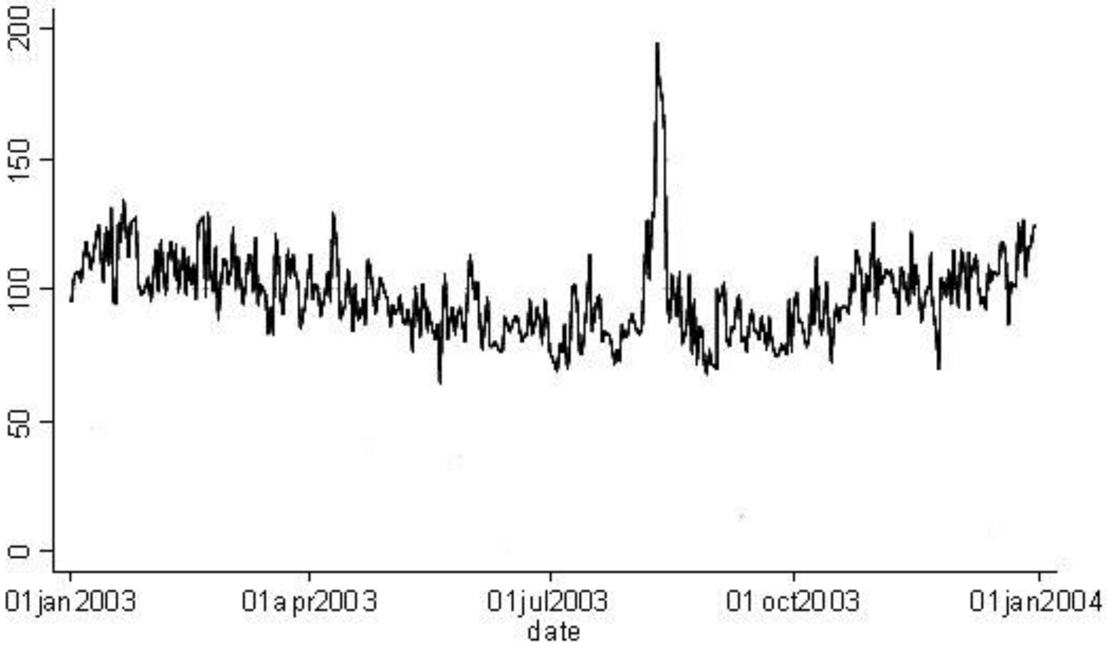

Figure 1 *Total daily deaths of people over 75 in London in 2003 (source: Greater London Authority, 2006)*

Responses

The first stage of managing higher future internal temperatures in buildings is to attempt to make the external air as cool as possible. Within the built environment this involves enhancing the green and blue infrastructure with parks, trees, open spaces, open water and water features. Parks and other open green spaces can be beneficial through their cooling effects in summer through shading and transpiration (Yu and Hien, 2006, Gill et al, 2007) and improved access for natural wind-driven ventilation. In addition, the presence of water, plants and trees contribute to microclimate cooling and are an important source of moisture within the mostly arid urban environment (Robitu et al, 2006). Urban surfaces should be cool or reflective to limit solar gain. Pavements, car parks and roads can be constructed with lighter finishes and have more porous structures. There is a growing interest in the use of rooftop gardens, green walls and green roofs for their cooling effect (Liu and Baskaran, 2003). Building surfaces, particularly roofs, should also have a high reflectance (or albedo) to solar radiation in order to minimise solar gain in the opaque fabric. This is a common practice in southern Europe but currently rare in cooler climates. (Santamouris, 2014). Figure 2 shows typical roof albedos for different roof materials while Figure 3 shows the results from a number of studies of the impact of urban surface albedo on average ambient air temperatures in urban areas.

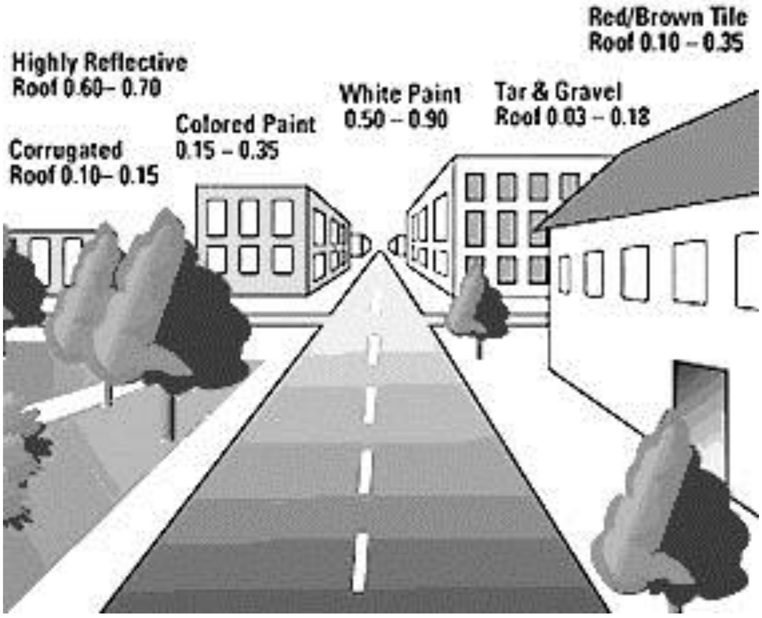

Figure 2 *Typical albedo values for roof materials* (source: EPA, 2007)

The key building fabric responses to climate change will involve solar shading, thermal mass, ventilation and insulation. The main building services considerations will include low energy heating and cooling systems.

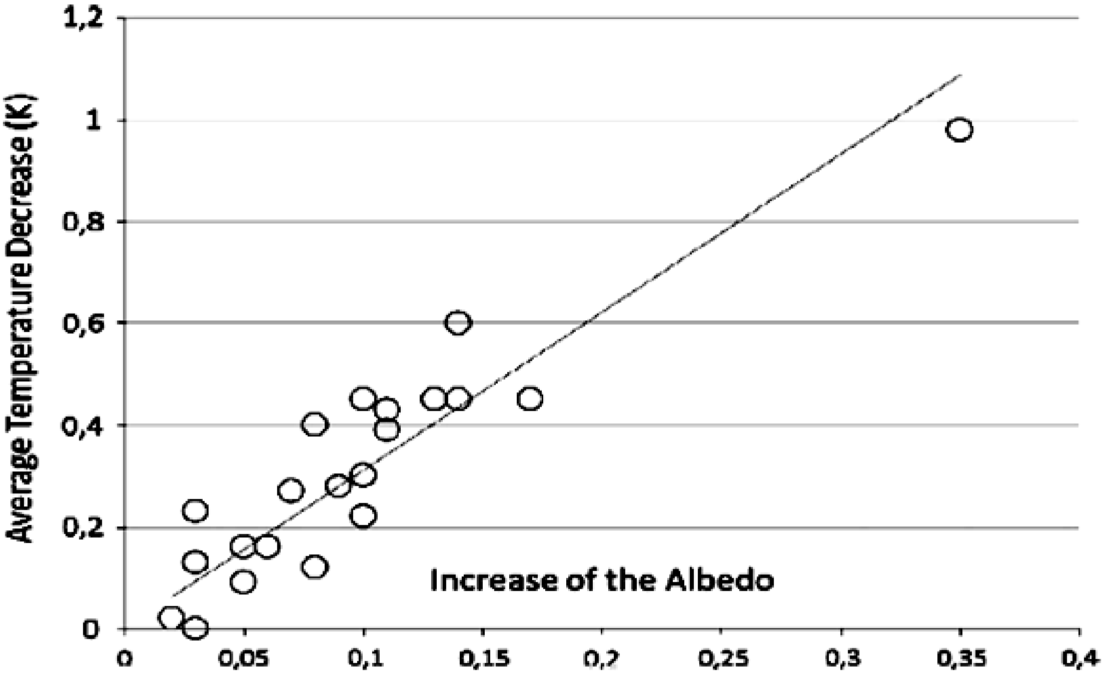

Figure 3 *Relationship between albedo values and average ambient temperatures in urban areas* (source: Santamouris, 2014)

Solar gain through windows and opaque elements will typically represent one of the largest heat gains in a building and so is one of the most important parameters to control in a warming climate. Shading devices can take several forms (louvers, blinds, shutters,) but they should all, ideally, be light coloured, porous, external and moveable. Roofs should be shaded at latitudes where the sun reaches a high altitude in its path across the sky. In climates that are already hot building form and layout are also used to provide shade – for example, by placing building close together or by forming courtyards. A detailed discussion of solar shading control is given in the CIBSE publication TM37 (CIBSE, 2006).

Thermal mass is related to how much heat a material can absorb and how quickly that heat is transmitted through the material. Concrete and stone are high thermal mass materials and the interiors of caves and cathedrals demonstrate how effective mass can be in keeping spaces cool even on very hot days. This is obviously a very useful feature in a warming climate but has the disadvantage that the heat is still stored within the building fabric at night, when the UHI has its greatest impact. Night ventilation (by opening secure vents and windows) can be used to purge some of the heat out of the building mass, leaving the building a few degrees Celsius cooler by the start of the next day. Figure 4 shows a typical temperature profile for an office with and without night ventilation.

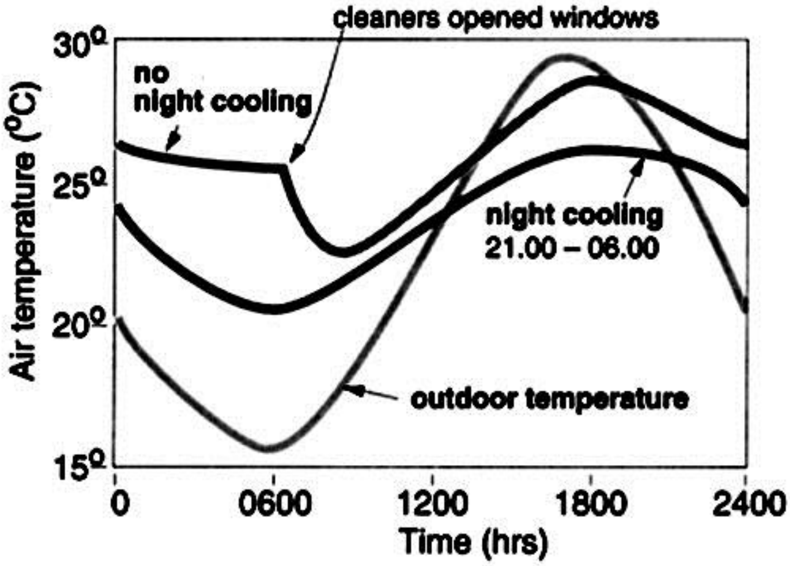

Figure 4 *Impact of night ventilation on indoor air temperature* (source: Rennie and Parand, 1998)

In addition to night cooling, ventilation is obviously also important in buildings for providing fresh air, removing stale air, controlling relative humidity and offering day time cooling in summer. Natural ventilation strategies involve wind driven forces (determined by wind speed and direction) and stack or buoyancy forces, which are driven by the height between inlet and outlet ventilation openings and the indoor-outdoor temperature difference. Future wind speed and direction scenarios are currently poorly understood but it is clear that in a warming environment the potential of summer time natural ventilation to cool building interiors may be greatly diminished (Barclay et al, 2012). This implies that the demand for active or mechanical systems to cool buildings will increase, with consequences for energy demand and possible waste heat injection into an already warm urban environment.

Thermal insulation is used in building envelopes to reduce heat losses in winter, minimise energy use and maintain thermal comfort. In summer insulation can have two impacts – it can reduce and retard external solar heat gains being transmitted through the opaque building envelope to internal rooms, but insulation can also impede heat generated within a room (such as solar gains through windows or casual gains from activity) from leaving the space. In a warming climate it becomes less clear how conventional insulation should be used in a future building design. As an alternative, for example, green roofs offer reasonable winter insulation but also provide summer cooling, biodiversity and longer roof life.

Heating systems are likely to require much smaller capacities in the future to meet reduced winter heating loads. The efficiency of a boiler is highest when it is running close to full output and so the required maximum output of a boiler sized using historical weather data will need to be revised each time the boiler is replaced (say every ten years). For buildings constructed to a very high insulation and air tightness standard, such as the Passivhaus approach (Dequaire, 2012), a warming climate may remove the need for a central heating system altogether and enable a space to achieve thermal comfort using just passive solar gains and casual internal gains from people and equipment. Indeed, in some instances the key problem may become one of overheating rather than overcooling (McLeod et al, 2013; NHBC, 2012).

It is very probable that the traditional passive means of cooling buildings (natural ventilation, thermal mass, evaporation) will not be able to ensure summer thermal comfort for future climate scenarios, especially in heat waves. Current active cooling systems are normally refrigerant-based air-conditioning units that have a high electrical energy consumption, and which use ambient air as a heat sink. There are alternative, more energy efficient cooling systems, which include the use of chilled beams, ground water, evaporative cooling and ground-coupled cooling (see GPG, 2001). Although there is little doubt that mechanical cooling systems will become more widely used to combat climate warming, they should always be the final step after all other passive cooling strategies have been designed into the building.

CIBSE (2005) have analysed how effective some of the above passive adaptive measures might be in combating climate change. They modelled the performance (space heating, risk of summer overheating, need for comfort cooling and performance of mechanical air conditioning systems) of a variety of building types for a current design hot weather year and future weather scenarios. For a new build detached house the adaptive measures examined included mass, solar shading, a reduction of ventilation during the warm part of the day and an increase in ventilation at night. Discomfort temperature levels were taken as 28°C in the living room and 25°C in the bedroom. Figure 5 shows the impact of mass on overheating in a living room for an unadapted house in London for a period stretching from the 1980s to the 2080s, expressed as the number of days in a year when indoor temperatures exceeded 28°C. The high-mass house performs significantly better than the equivalent lightweight house. However, a similar analysis for an upstairs bedroom showed only a marginal difference in performance. Figure 6 shows the equivalent living room results but including the influence of the adaptation measures.

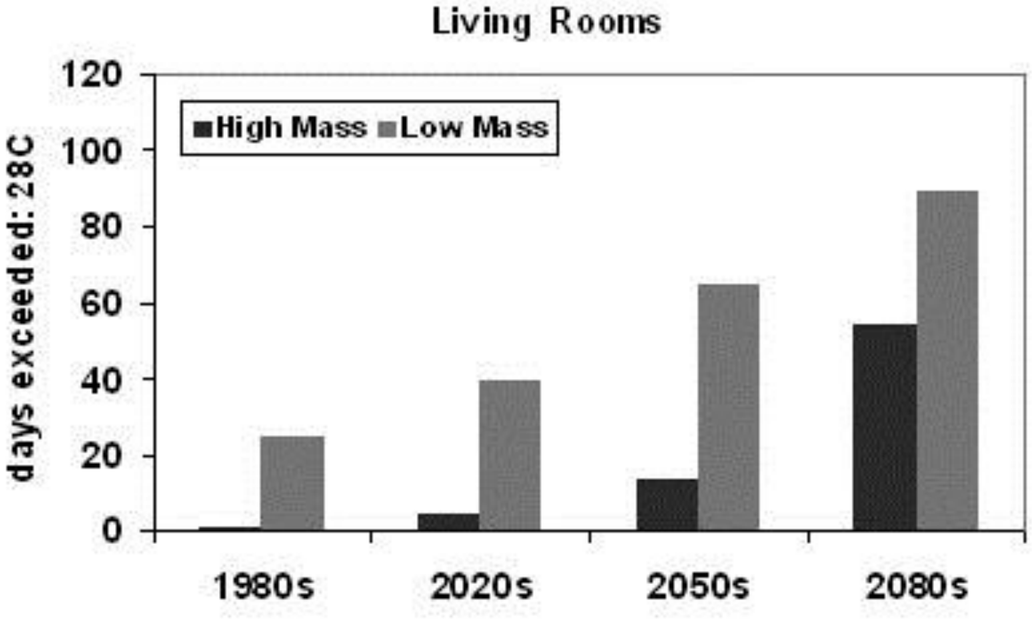

Figure 5 *Impact of mass on living room air temperature* (source: CIBSE, 2005)

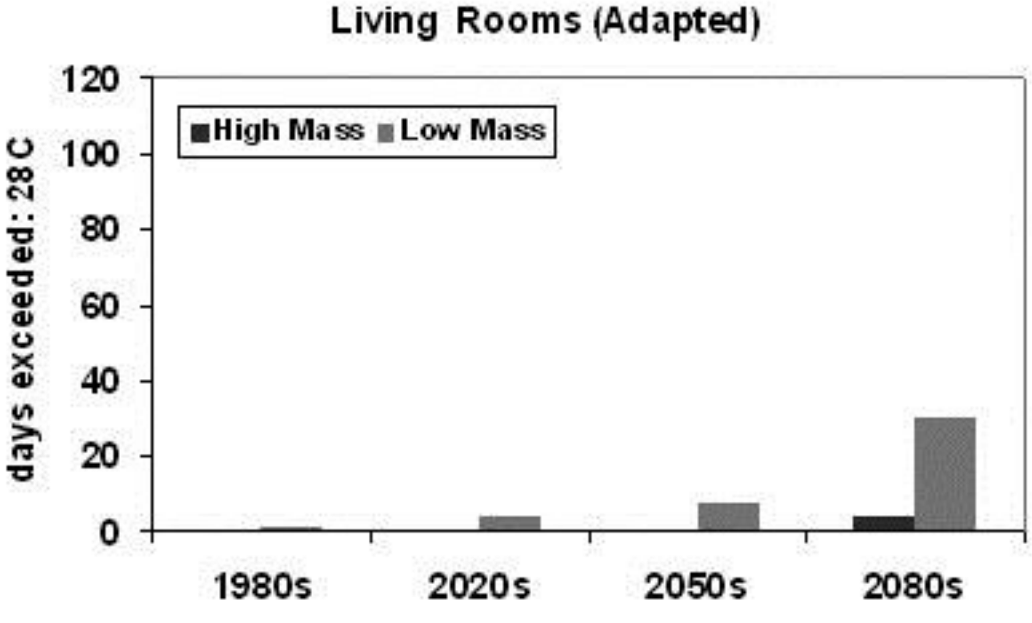

Figure 6 *Impact of mass + adaptation on living room air temperature* (source: CIBSE, 2005)

The adapted high mass is seen to perform significantly better and to provide a good level of thermal comfort in the living room up to the 2080s. The same is not true for the bedroom analysis, where even the high mass, adapted house displayed overheating problems by the 2020s. This type of finding is persuading some house designers to suggest that in future bedrooms should be located on ground floors with living areas at first floor level.

Climate change and precipitation

Impacts

The expected climate change patterns for precipitation are, typically, drier summers, wetter winters and a greater incidence of heavy rainstorms. More frequent and intense rainfall will lead to river flooding and the failure of urban drainage systems. Flooding is the most prevalent natural disaster globally, and worldwide economic losses from flooding have increased from around $0.5 billion in the 1980s to around $20 billion by 2010 (EM-DAT, 2012). Such flooding creates many problems, including building damage, disruption to transport, interference to water supplies and potential health risks (Ahern et al, 2005). Rising sea levels will add to flood risk for both coastal locations and low-level cities on or near rivers.

[b]Responses

Urban development and pressure on land use have meant that more buildings have been, and continue to be, constructed on what were traditional sacrificial flood plains. This has had the effect of distorting and damaging natural drainage systems, and the consequences are increasingly evident, with large scale flooding becoming more common. The impact of climate change will probably be to make these flooding events more severe and more frequent. At the urban scale flood risk management can use Sustainable Urban Drainage Systems (SUDS), which attempt to control and slow down the run-off of surface water following heavy rain. This approach includes the use of vegetated, gently sloping landscape elements, soakaways to allow the rain to get directly back into the ground, permeable and porous pavements and car parks and sacrificial areas, such as fields and ponds, to store flood water. A detailed description of SUDS is given by Susdrain (2014). For an individual building the aims of flood risk management are to minimise the risk of flooding and reduce the damage caused by flooding. Apart from creating physical barriers between floodwater and the building, other risk-reduction approaches include reducing the run-off of rain through harvesting of rainwater, providing permeable and/or drained ground surfaces and the use of green roofs (these suggestions are also part of a SUDS strategy). Green roofs, in particular, are seen as a potentially very powerful tool in adapting buildings to reduce climate change urban flood risk (Carter et al, 2007). In order to minimise flood damage to buildings from present and future events there are a series of steps that can be implemented. Floodwater will penetrate not just through obvious openings in walls but also through cracks, defects, service penetrations and other openings, and so general maintenance and repair of the structural envelope is important, particularly for buildings in known flood risk areas. All utility services, such as supply meters, electrical fittings and boilers, should be at least one metre above ground floor level, with pipes and cables dropping from first floor level. Drainage and sewer pipes should have one-way valves fitted to prevent the backflow of contaminated floodwater entering the building. In the USA the Federal Emergency Management Agency (FEMA, 2014) provides very detailed guidance on protecting buildings and utilities from flood damage. Flood resistant finishes, such as plastics, vinyl, concrete, ceramic tiles and pressure-treated timber, should be used in place of carpets, chipboard, soft woods and fabric, and gypsum plaster should be replaced with a more water resistant material, such as lime plaster or cement render. To reduce the amount of repair after flooding it is helpful to fix plasterboards horizontally on timber framed walls rather than vertically and to replace mineral insulation within internal partition walls with closed cell insulation. Several architectural practices are starting to specialise in the design of flood-resistant buildings (Baca, 2014), and some of the most advanced ideas for making buildings flood resilient can be found in Holland, a country that is, even before climate change, 6m below sea level. One architectural solution is floating buildings that rise and fall with water levels. Examples of this approach are described by H_2OLLAND (2013).

Climate change and wind

Impacts

The major interactions of the wind and buildings are in structural loading, wind speeds at pedestrian level and as a driving force for natural ventilation and cooling. There is a great deal of uncertainty about future patterns of wind speed and direction and climate models are not robust or consistent in their predictions. However, it is believed that there will be an increase in the number and severity of storms.

[b]Responses

The most important wind feature is the once in 50 year design wind speed used in structural loading calculations. Given that buildings might stand for to 100 years then it could be argued that structural building codes will need to review the design wind speeds and frequency of events to factor in safety margins in response to future climate change. Roofs suffer the greatest amount of destruction in high winds, mainly due to a failure to tie the roof securely to its supporting walls or supports. Low pitch roofs are very susceptible to wind damage and a better choice might be a mansard roof, which has two slopes on each side, with the lower slope being almost vertical and the upper slope being almost horizontal. Other design features, such as buildings having a more aerodynamic form or minimum roof overhangs, may appear beneficial but would need to be tested to ensure that other problems are not created – for example, small overhangs might exacerbate flooding problems.

Climate change and subsidence

Impacts

Paradoxically, under predicted climate change scenarios some regions of the world may be concerned with increased flood risk whilst others will be suffering from very dry seasons, water shortages and the risk of soils drying out. Reduced soil moisture levels have impacts on agriculture, flood control and buildings, where subsidence damage will become an increasing problem. Over the past two decades, Europe has seen a marked increase in damage to buildings as a result of soil movements. A new loss model developed by Swiss Re and the Swiss Federal Institute of Technology (ETH Zurich) shows that in France alone, economic losses from soil subsidence have risen by over 50% since 1990 (Swiss Re, 2011).

[b] Responses

Subsidence is already a significant cause of building damage and climate change is only likely to make things worse. Figure 7 shows the cost and scale of subsidence claims in the UK for a twenty year period and the relationship with summer rainfall.

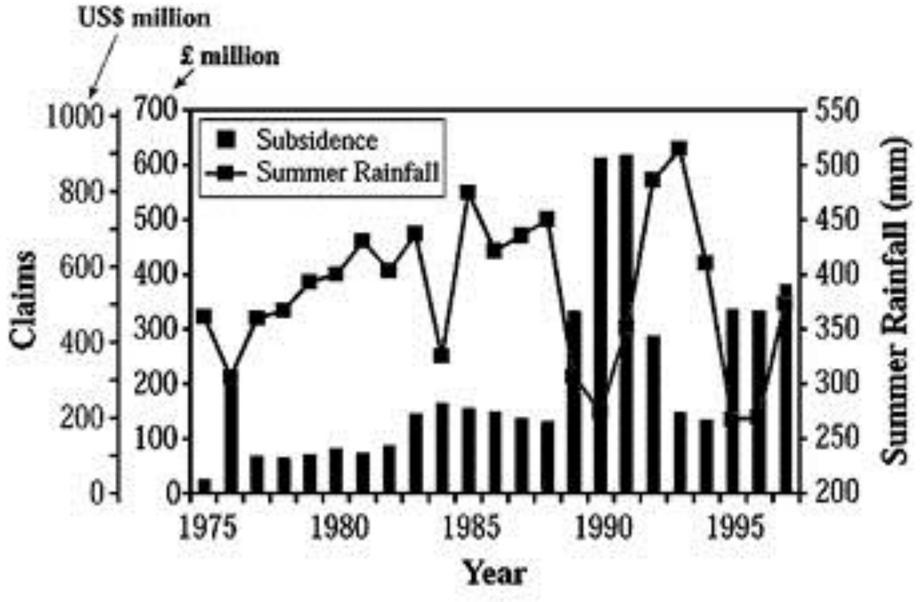

Figure 7 *Relationship between rainfall and subsidence* (source: IPCC, 2001)

For existing buildings it is not viable to underpin original foundations in a way that will make them climate change resilient, and so the incidence of subsidence damage to buildings will increase during the coming decades. To make new and future buildings climate change resilient it will be necessary to change the design of foundations to make them stronger, stiffer and deeper in order to resist movement. New foundation technologies, such as pile-and-beam foundations, are described in an NHBC publication (NHBC, 2007), which also highlights the importance of careful tree planting management to avoid soil shrinkage and foundation damage by roots.

Conclusion

The mechanical servicing of buildings is a relatively recent phenomenon, with its origins only beginning at the start of the 20th Century.   For thousands of years before then buildings had to modify the prevailing climate using only passive or low energy systems. It is not surprising that many of the building design issues relating to climate change resonate with elements found in the vernacular architecture and urban layouts of other countries. Features such as courtyards, wind catchers, narrow streets, green roofs, water features and houses raised on stilts all reflect a response to the contemporary local climate. It is too simplistic to say that since temperatures in London may one day resemble those already existing in, say, Lisbon then a linear design extrapolation can be implemented. The most obvious climatic difference is the different range of solar altitudes resulting from differences in latitude, but there are also cultural and historical traditions to respect. However, it is also true that there are lessons relevant to climate change to be learnt from vernacular architecture as it offers an historical perspective on how, globally, built environments evolved to deal with the challenges of changing climates.

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