Chapter 1
Sustainability in the Built Environment

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Abstract This introductory chapter sets the scene for the book, providing an overview of sustainability in the built environment. With a bias towards buildings and the urban environment, it illustrates the range of issues that impinge upon global carbon reduction and the mechanisms available to help bring about change. Climate change, and its impact on the built environment, is briefly introduced and sustainability in the built environment and associated factors are described. The specific topics relating to sustainable design and management of the built environment, including policy and assessment, planning, energy, water and waste, technology, supply and demand, and occupants' behavior and management have been highlighted. This chapter emphasizes the importance of a systemic approach in delivering a sustainable built environment. *Learning outcomes*: on successful completion of this chapter, readers will be able to: (1) Gain broad knowledge of sustainable built environment, (2) Understand the concept of systemic approach, and (3) Appreciate interdisciplinary aspects of design and management.

Keywords Sustainability · Built environment · Building · City · Design · Management

1.1 Introduction

Climate change is one of the major challenges the world has faced since the start of the twenty-first century. Greenhouse gas emissions due to the burning of fossil fuel are considered as the main cause of global warming. Approximately 50 % of

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energy consumptions and carbon dioxide (CO_2) emissions are from buildings for heating, cooling, and lighting in developed countries. Around 20–30 % is used in transport, while the remainder is used for industrial processing. The development of a sustainable built environment requires a solution which is drawn from complex systems that encompass design and management, the integration of technology and its users and an evaluation of the performance of the whole process. Sustainable development, amongst other issues, requires the rapid and successful uptake of technologies and designs in both new construction and refurbishment. The control and management of the integration of the complex interactions of humans, climates, buildings, and energy systems is also essential within a context of rapidly evolving financial incentives, regulations, and policies which are driving and encouraging changes in environmental engineering. In the past, advanced technologies and methods have been developed in isolation, for example, in urban planning, architectural design, services design, facilities management, and construction. However, it is now necessary to evolve a series of inter-linked systems through genuine interdisciplinary collaboration and dialog. This will support the development of boundary-spanning methodologies that are capable of measuring, monitoring, managing and directing whole system operations, outputs, and impacts. There are two key challenges to the development of such an integrated approach. One is the compartmentation of built-environment professions; such as urban planners, architects, and engineers while the other is the differing perceptions of sustainability of policymakers, built environment professions, industry stakeholders, and end-users. It is important for built environment professionals to overcome these challenges and promote collaborative working between these different constituencies. It is also important to persuade clients that sustainable building design, construction, and operation can save money in terms of energy and water consumptions that can also result in healthier buildings with a consequent price in productivity. This book aims to provide a broad range of knowledge relevant to sustainability in the built environment. Through the content of different chapters, readers will be able to assimilate the range of topics necessary to analyze and synthesis solutions in sustainable built environment design.

1.2 Climate Change Impacts

Climate change and global warming will most certainly impact buildings throughout the world (Parry 2007). The latest assessment of the intergovernmental panel on climate change (IPCC), demonstrates that a range of impacts are expected in the future (IPCC 2007a, b). The extent and seriousness of these impacts in the longer term will depend on the extent to which efforts to mitigate greenhouse gas emission are successful (GO-Science 2008). The impacts on the built environment, for example (Dawson 2007) will be:

- Sea-level rise;
- Increased flooding and droughts due to changes in patterns of rainfall, with knock-on effects on drainage systems and water management;
- Increased incidence of heatwaves which can damage infrastructure (e.g., by softening of road blacktop (tarmac)) as well as threatening human health;
- Increased incidence of storms which can damage building and other infrastructure;
- Health impact due to increased heat stress and migration of diseases;
- Changes in demand for goods and services such as more year-round outside activity, and more air conditioning in the summer.

In the GO-Science report, it is stated that these impacts will affect both physical infrastructure of built environment and the lifestyle and wellbeing of the people and communities that live within it (GO-Science 2008). The changes will have implications on the way we live in and operate our buildings. Therefore, built environment needs to change and adapt to these changes in the aspects of: mitigation of greenhouse gas emission, urban and indoor environmental, urban drainage systems, management of waste, eliminate adverse impact on people's health, and wellbeing.

There is a vast array of studies focused on seeking to quantify and predict the impact of our changing climate on the urban environment. For a thorough review of the literature concerning climate change and buildings, readers are directed to de Wilde and Coley (2012). Figure 1.1 shows the mechanisms in which climate change is expected to impact on buildings. It is evident from the 'impact on buildings' column that there will be some profound and devastating consequences in the worst instances. Furthermore, when we look at the 'effects on occupants and key processes', illness, injury, and mortality are startling factors that 'jump out' from the process diagram. In summary, it illustrates the concerns that are currently being raised in politics, industry, and academia regarding this matter.

The two main approaches in this area are *adaptation* and *mitigation*. Adaptation involves designing buildings which respond to the climate change in order to cope. This involves designing buildings with: (1) greater flexibility; (2) intelligent energy management systems; (3) smart appliances; and (4) a view to managing them better. In contrast, mitigation strategies look at reducing energy consumption from the urban environment in the first place. This involves the diffusion of low and zero carbon technologies in buildings that help minimize energy use and thus greenhouse gas emissions.

In a study that looks at balancing adaptation and mitigation in the US and Australia, Hamin and Gurran (2009) note that increasing housing density and the mix of land use is an mitigation strategy, whereas revising infrastructure and capacity is solely an adaptation strategy.

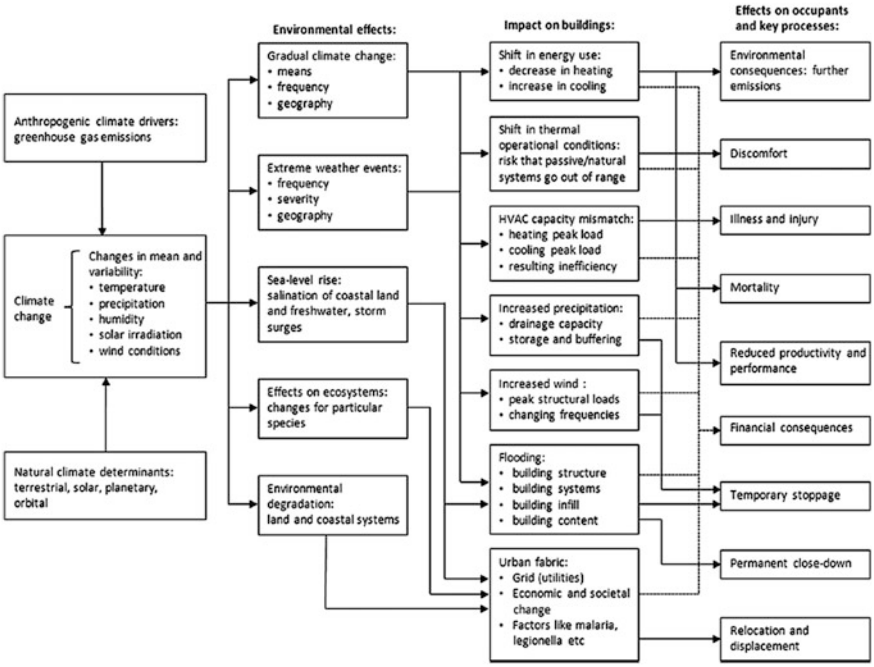


Fig. 1.1 Schematic overview of the main mechanisms in which climate change impacts on buildings (*source* de Wilde and Coley 2012)

1.3 Sustainability

What does *'Sustainability'* really mean and what are the implications in a wider context? The concept of sustainable development had its roots in the idea of a sustainable society (Brown 1981) and in the management of renewable and non-renewable resources. The concept was introduced in the World Conservation Strategy by the international union for the conservation of nature (IUCN 1980). In 1983, The *United Nations General Assembly* passed resolution 38/161 (UN 1983) establishing The world commission on environment and environmental development (WCED). It published a report entitled *Our Common Future* (Bruntland 1987), otherwise known as *The Bruntland Report*. Famously, it coined the three pillared definition of 'sustainability': encompassing economic, environmental, and social factors (Fig. 1.2) with 'sustainable development' at the epicenter.

Moreover, key to the central theme of their definition is the marriage between *environment* and *development*. The two being inextricably linked. That they coexist, a second definition was born: the definition of 'sustainable development'. It reads: *'development thatmeets the needs of the present without compromising the ability of future generations to meet their own needs'* (Bruntland 1987). While

Fig. 1.2 Triangulated definition of sustainability

politically sensitive, sustainable development is a concept not readily embraced by all governments.

Looking back at a publication in 2001, the UK Department of Trade and Industry's (DTI) Foresight Programme produced a report entitled *Constructing the Future* (DTI 2001). When addressing actions for sustainability, recommendations noted: (1) the promotion of 'smart' buildings and infrastructure; (2) improvements in the health and safety of those employed in the construction industry; (3) enabling supply chain integration; (4) investing in people; (5) improving existing built facilities; (6) exploiting global competitiveness; (7) embracing sustainability; (8) increasing investment returns; and (9) the need to plan ahead. In addition, the report also outlined the changing demands that would impact on the built environment. These included: changing population demographics, knowledge-based working practices and climate change. It also suggested actions based on *whole life thinking* and the use of advanced technology, materials, and processes. In response to this, a UK research consortium composed of academic and industrial partners was initiated: the *design construction and operation of buildings for people* (IDCOP). The need to ask more precise questions raised four key research aims; to better understand: (1) the impact that the use of buildings have on the environment and quality of life of occupants/users; (2) the changing demands being made of existing buildings; (3) the potential for technical/operational developments to improve the performance of the building; and (4) the barriers to implementation. Figure 1.3 shows the research framework they adopted when attempting to look into these issues. The ostensible drivers for change, i.e., product, people, process feature at the heart of the approach, based on the premise that: *'a better understanding of the fundamental relationships between buildings, people and the environment is required if real improvements in the 'sustainable' performance of the urban environment are to be achieved'* (Jones and Clements-Croome 2004).

Reflecting upon the phenomenal economic growth of the BRIC nations (Brazil, Russia, India, China) and the newer set of emerging economies (the CIVETS: Colombia, Indonesia, Vietnam, Egypt, Turkey, and South Africa), energy

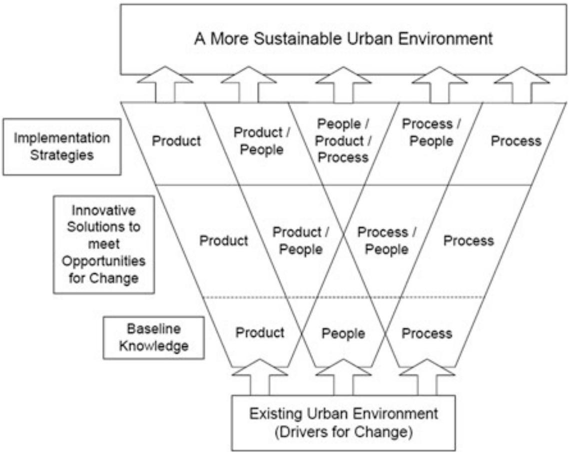


Fig. 1.3 Interaction between research themes and key drivers (*source* Keith Jones and Derek Clements-Croome 2004)

consumption, carbon emissions and demand for raw materials and fossil fuels will inevitably increase in the short term which is a worrying prospect. China alone is expected to contribute 36 % of global energy growth: a 75 % increase between 2008 and 2035 (IEA 2010). And to fully appreciate the magnitudes involved: China's carbon emissions associated with cement production in 2009 were approximately twice the UK's total carbon emissions for the same year. Interestingly, it is worth noting that most of the world's carbon emissions from a historical perspective, originate from the *developed world*, exacerbated from efforts since the dawn of the industrial revolution.

Observing events from 1950 onward, it could be argued that *population* could be a causal factor for changes in temperature and carbon emissions (UN 2008; IPCC 2007a; Marland et al. 2003). Delving into numbers; since the late nineteenth century world population has quadrupled and energy demand has increased by a factor of 60 (Azapagic and Perdan 2011). The average person today consumes approximately 15 times more energy compared to someone 130 years ago (Mullersteinhagen and Nitsch 2005). World population stands at 7.1 billion in 2012, with growth forecasts placing figures between 8.01 and 8.26 billion by 2025, and 9.15–11.03 billion by 2050 (UN 2008).

Continuing with demographics, household sizes in the UK are decreasing. Between 1961 and 1991 mean household size decreased from 3.01 to 2.48, by 1998 this figure dropped to 2.32 and remained on a stable course until 2002 (ONS 2004). Looking forward, projections place figures in the region of 2.28 by 2011 and 2.13 by 2031 (CLG 2006). Decreasing trends may have roots in social structures and increased disposable income. Nevertheless, it is fair to assume that energy per capita is increasing, characterized by fewer people benefitting from 'shared services' such as communal heating or lighting (Yohanis et al. 2008).

Another demographic phenomenon is *urbanization*. Lured by the romanticism of 'a better life' with higher salaries, or worse, pushed by the absence of farmable

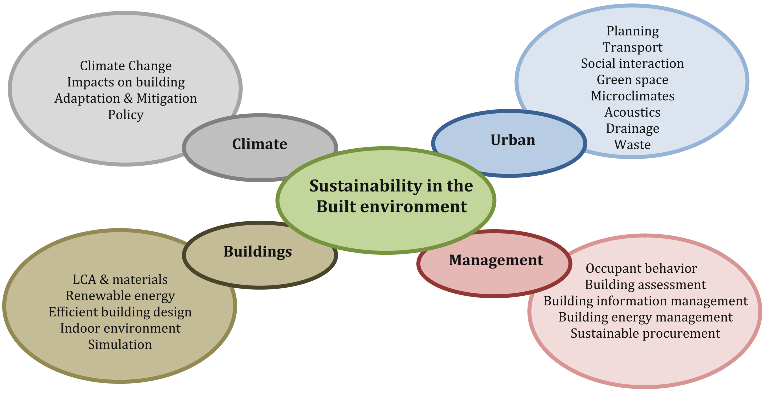


Fig. 1.4 Sustainability in the built environment: associated factors

climate, people are moving from rural areas to towns and cities on a mass scale. Since 2007, more than half of the world's population now reside in cities. For less developed countries, the intensity of this shift is much greater, with estimates expecting urban populations to nearly double within the next 40 years from about 2.6 to 5.3 billion people (Madlener and Sunak 2011). China's urbanization rate has risen from 23.7 % in 1985, to 36.1 % in 2000, to 45 % in 2007. With a predicted rate of 50 % by 2012 (CURC 2008), a *'substantial pressure on resources and the environment will be experienced'* (Li and Yao 2009). City populations need housing, municipal buildings, and a supporting infrastructure that consume vast quantities of energy, water, and natural resources during construction and operation.

When expanding on the ideas in Fig 1.1, it becomes ever more apparent of the wide ranging issues and concepts that sustainability encompasses. One essential ingredient that consolidates the individual components is *the built environment*. Principally, this includes: (1) climatic factors; (2) general urban issues; (3) buildings design; and (4) the management of buildings. Figure 1.4 shows the holistic connectivity between these themes and an extension of these ideas in diagrammatical form.

The chapters within this book address each of the themes listed in the outermost rings, adding detail and insight through description, examples, and case studies.

1.4 Systemic Approach in Built Environment

The successful implementation of a technology, method, or process has been limited by a lack of integration and understanding across various organizational boundaries and between divergent sets of stakeholders. The reframing of technical aspects of energy efficiency requires a holistic framework to include the social and organizational dimensions (Li and Yao 2012). Fundamental research is needed to develop a holistic framework that is capable of evaluating the options involved in a variety of energy management concepts, advances in technologies, the dissemination of energy-saving measures to different stakeholders, local energy generation and distribution planning, and validating what actually happens (measurable, reportable, verifiable) in buildings' energy consumption. The transition to a sustainable built environment requires guidance from complex systems that encompass policy and regulation, the integration of technology and its users, and an evaluation of the performance of the whole process. The built environment is regarded as a complex system including multielements which interact both directly or indirectly (Godfrey 2009; Nicol 2011).

A conceptual systemic framework for a research strategy focussing on the built environment is proposed, illustrated in Fig. 1.5. The concept of a systemic research framework encourages collaborative work among professionals from different disciplines including policy-makers, urban planners, architects, engineers, etc. (Yao 2011).

The key points about the framework are:

- *Integrated whole-life thinking*: Policy, regulatory, benchmarks, and assessment/evaluation mechanisms are needed throughout the whole life of the urban infrastructure and buildings. This means better integration between the planning, design and operation, and management stages. The careful alignment of evolving financial incentives, regulations, and policies, environmental awareness education alongside advances in technology is required to drive and

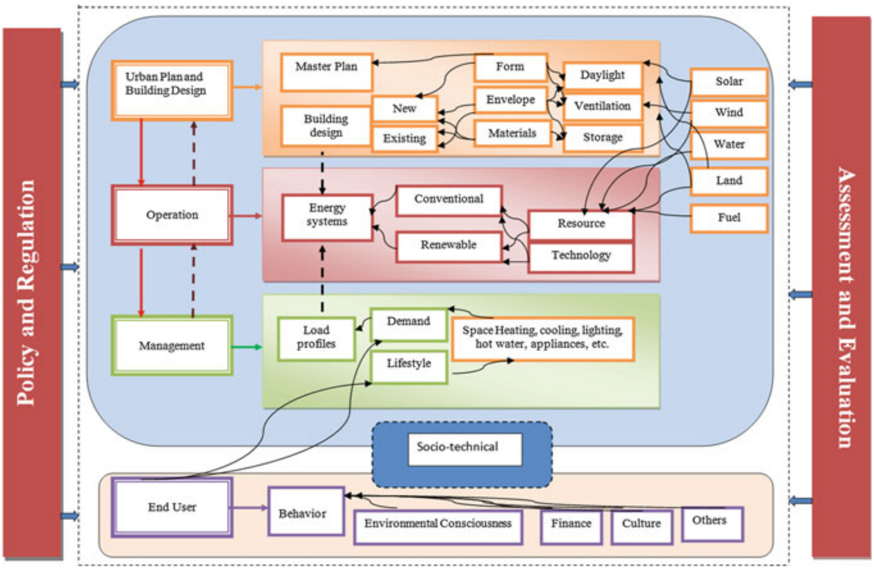


Fig. 1.5 The integrated approach in built environment research

manage the move toward a low-carbon built environment as well as to avoid pernicious outcomes.

- *Integrated design process*: Traditional sequential processes of passive building design, energy system integration, and operation need to be challenged in order to change their direction and become collaborative processes. Collaborative briefing including planners, architects, engineers, managers, and assessors should be considered at the very early stages of development (cf. Soft Landings, Leaman et al. 2010). Urban built forms, materials, water, and vegetation will have a great impact on energy demand from buildings in terms of usage of passive solar, wind energy, natural ventilation, and daylighting (Salat 2009). An optimum urban plan and building design can significantly reduce the energy burden on energy systems. Renewable energy needs to be carefully integrated into building and built-in energy systems to form a maximum efficiency energy system for buildings. Building materials can play a role of thermal storage in conjunction with the application of solar energy. The growing demand for housing and commercial developments in the twenty-first century, as well as the environmental pressure has increased the focus on sustainable urban drainage and waste management systems.
- *Improved operational management*: To achieve energy efficiency in a building, energy system operation and management is vital. Control devices are usually incorporated into the energy system. However, poor control design, poor management, and a lack of knowledge of occupants' behavior and expectation results in significant energy waste. Research into better management practices, alternative technologies, and the provision of feedback loops are needed.
- *Understanding occupants*: Research into end-user behavior on energy consumption in buildings is required, particularly in residential buildings (Ouyang and Hokao 2009). Key questions are the provision of improved, clear information to assist occupants with managing energy consumption, managing expectations, and gathering data on actual performance.
- *Embodied energy*: There is widespread use of highly energy-intensive building materials, and little consideration for life-cycle issues. New standards for building materials are necessary along with new planning and design processes to include embodied energy and increasing the longevity of buildings. The authority for building materials and energy efficiency standards are currently in separate agencies, rendering the development and subsequent enforcement of standards for building materials problematic.
- *Renewable energy and exergy*: Although highly energy efficient or nearly net 'zero carbon' buildings will reduce energy demand, some demand will remain in the building stock for space heating, hot water, and appliances, etc. Decarbonization of the built environment will require a combination of demand-side and supply-side measures. The supply and cascading of energy will become an issue for strategic planning at the city and town levels. There is a need to establish relative technical and economic merits of the different options for renewable energy sources for heat supply to urban areas to replace fossil fuel energy. The issues of balancing heat supply and demand need to be clarified and

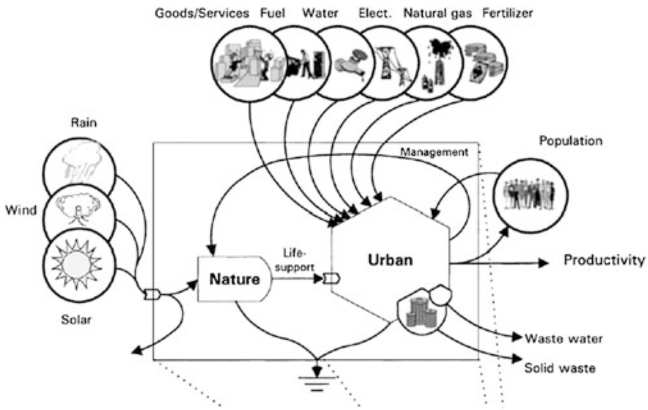


Fig. 1.6 A conceptual diagram representing energy flows in Taipei (*source* Huang et al. 2001)

understood. Renewable energy such as ground source heat pumps, wind, and solar energy can play a major role for rural communities and low-density developments. The control and management of integrating the complex interactions of humans, climatic phenomena, building operation, and energy systems is a key measure.

Sustainable urban environments are systems. They comprise of many components with inputs and outputs. When attempting to model the complex energy flows and interactions between the components, *systems modeling* can be drawn upon to provide a framework in which to facilitate such an exercise. In 1971, ecologist Howard Odum and colleagues developed an energy systems language, initially used for ecological modeling. This language involved the use of symbols to represent energy flows and processes. Using Odum's system, Huang et al. (2001) suggest that the principles of ecosystems can be applied, in general, to other systems—cities. Odum's system generates a layered hierarchy of *energy* consumption ('energy' being the total quantity of energy consumed to acquire something, measured in Solar Joules). Figure 1.6 shows Huang's representation of a city (Taiwan) illustrating the energy inputs and outputs to and from the city. The concept is a useful tool when considering urban sustainability as it links humans with their energy demands and activities.

Another concept that falls into this line of enquiry is *maximumempower*. The 'maximum empower principle' states that organic systems are self-organizing, whereby they arrange themselves to make the best use of the energy they consume through use of control and feedback mechanisms. Again, parallels can be drawn between cities and eco-systems here. Although energy systems modeling and energy accounting are not featured in detail within this book, it is worth noting the principles as energy system modelers use *energy* analysis for modeling energy flows in sustainable systems. Those of which include buildings.

1.5 Policy

Since the oil crisis in the 1970s, the energy agenda has slowly worked its way to the top of conversational topics; being one of the most widely discussed today. Whether talked about in political corridors, boardrooms or bedrooms, energy impacts on each and every one of us. And in some instances; profoundly. Tagged to the notion of energy security and economic stability, is *environment*. Debates began to broaden during the 1980s when environmental concerns were ushered into the limelight, bought about by oil spills, drought, global temperature rises (Fig. 1.5), ozone depletion, and the like. A year after the Brundtland report's release, The *United Nations Environment Programme* and *The World Meteorological Organization* formed IPCC. It is responsible for assessing climate change risk. The panel released a series of reports (1990, 1995, and 2001), with the most recent fourth assessment report (AR4) in 2007 (IPCC 2007a, b). Heralded as one of the most comprehensive climate change studies ever undertaken, AR4 states within its summary that: *'the increase in observed average global temperatures is very likely due to anthropogenic greenhouse gas concentrations'*, estimated to have increased by 70 % from 1970 to 2004. The report findings are generally considered 'compeling evidence' within the scientific community, substantiating climate change. The report suggested that through improved energy efficiency, approximately 30 % of the projected greenhouse gas (GHG) emissions in the building sector can be avoided with a net economic gain.

A comprehensive suite of international policy measures have subsequently been introduced, including: the *United Nations Rio Earth Summit* where *Agenda 21* (UN 1992) was created; the *Kyoto Protocol* (UNFCCC 1997) which set legally binding emission reduction targets; the *Johannesburg Summit* (UNFCCC 2002) proposing a road map; the *Copenhagen Accord* (UNFCCC 2009) that stipulated a 2 °C temperature increase limit; and future UNFCCC efforts that will undoubtedly provide additional policy (e.g., Doha in 2012).

1.5.1 UK Policy

The UK is politically ambitious in this area. Having introduced the *2008 Climate Change Act* (DECC 2008a, b), supplemented by *2008 The Energy Act* (DECC 2008a), and the *2009 Low Carbon Transition Plan* (DECC 2009), the UK arguably has the toughest climate change policy in the world. And with a target of reducing emissions by 2050 by 80 % from a 1990 baseline, a multifaceted approach is essential. Facilitated by these acts, numerous programs and schemes have been rolled out nationally; each one, attempting to reduce carbon emissions using differing mechanisms. For example, the *Low Carbon Buildings Programme* (DECC 2006) was a £137 million suite of grant program aimed at bolstering the acquisition and installation of Microgeneration technologies over a six year period.

Other financial mechanisms include *The Warm Front Scheme*, part of the *UK Fuel Poverty Strategy* (BERR 2001), introducing subsidies and grants worth up to £3,500 per site (or £6,000 where renewable technologies are recommended) in reducing heat loss; and *The Boiler Scrappage Scheme*, co-ordinated by the energy saving trust (EST), issued homeowners with a voucher worth up to £400 which could be used to partially offset the capital cost of upgrading their existing boiler.

Aside from this, UK government also uses the *Planning* system and *Building Regulations* as powerful mechanisms for leverage. The *Merton Rule* (stipulating that new developments need to generate at least 10 % of their energy needs from on-site renewable energy equipment) coupled with the progressive tightening of building standards (Lim and Yao 2009) that address issues such as thermal insulation in Part L, are all weapons in the armoury to bring about change. In addition, building assessment methods such as the government's standard assessment procedure (SAP), the code for sustainable homes (CSH) and the BRE environmental assessment method (BREEAM), all provide extra tools in the battle against climate change.

1.6 Design and Management

Buildings facilitate a hive of activities from domestic purposes to industry, to administration to leisure, and beyond. Buildings are central to life. Not least providing shelter, but when designed and managed successfully, they can promote social interaction, foster well-being, bolster productivity, and support cultural advancement.

The commonly quoted statistic is that buildings consume in the range of 40–50 % of total energy consumption in developed countries, globally, and on a country basis (DECC 2010; IBE 2011; IEA 2012). Possible discrepancies occur due to the inclusivity of construction materials. Incidentally, this figure is true for the UK and mirrors findings by the *European Commission for Energy* (2010) who found that buildings are responsible for 40 % of energy consumption and 36 % of total European CO_2 emissions. All said these gloomy statistics present an ideal opportunity—the opportunity to reduce a significant quantity of carbon emissions from within the sector. Naturally, we ask ourselves—*how can this be achieved?*

When searching for answers, it is worth noting a building's *energy end-uses* (i.e. HVAC equipment, space heating or cooling, domestic hot water, lighting, appliances, and other miscellaneous building services). In doing so, it provides some valuable clues. Focusing on these end-uses and thinking 'vertically', it is evident that careful consideration of: (1) urban planning; (2) architectural design; (3) energy supply and demand; (4) climate; and (5) the way we operate our buildings hold the key to cutting carbon emissions.

1.6.1 Urban Planning

Urban planning addresses energy use at a high level. And getting it right can help harmonize our existence with the environment. From the organic development of towns during the Classical period, to the first planned cities of the Egyptian and Mesopotamian eras 3000 BC, to the eco-cities in the Middle East, the importance of good urban planning cannot be overstated. Early decisions have long lasting consequences.

Land use, road, rail and pedestrian networks, transport links, street plans, building density, and layout, all these issues can have profound impacts on the longevity of a city's energy consumption. Ill-considered planning can result in poor urban ventilation, unsatisfactory levels of urban comfort, dysfunctional spaces, the exacerbation of the urban heat island effect (UHI), and lack of green spaces that promote well-being. Figure 1.7 shows an iconic graph (Newman and Kenworthy 1999) illustrating the hyperbolic relationship between urban density and energy consumption. It is worth noting here that European cities have a relatively low energy consumption as well as urban density.

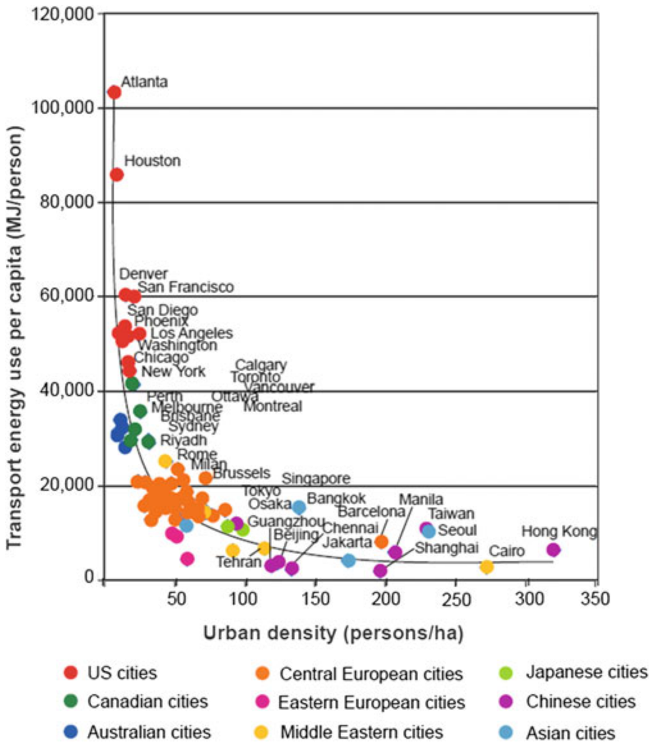


Fig. 1.7 Relationship between urban density and energy consumption (Newman and Kenworthy 1999, updated in 2012 provided by Prof. Peter Newman with permission of use)

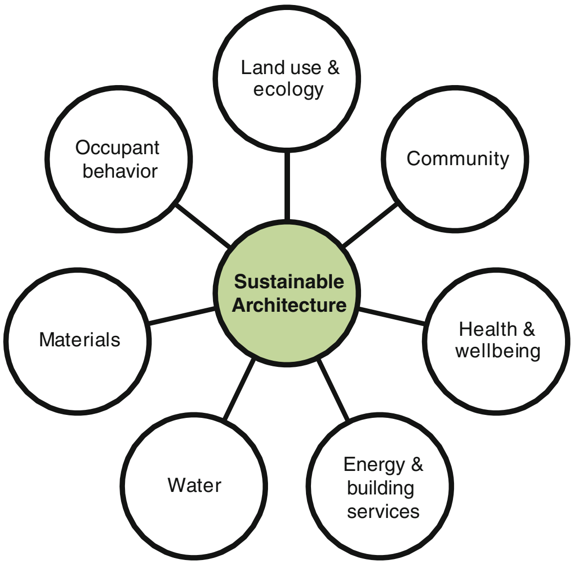
Sustainable urban planning is a relatively new concept. At one end of the spectrum are established cities that strive to be ecologically friendly, retrospectively; while on the other, swirl the engineering dreams that are maturing into a reality, in the desert. Masdar Eco-city, Abu Dhabi is a $22 billion dollar, 10 year project. Due for completion in 2014, it will cover 6 km^2, will be the home to 50,000 people, 1,500 businesses and is powered by 200 MW of renewable energy technology (a solar plant, photovoltaic modules, and wind turbines). Cars are banned, so inhabitants use a *mass public* and *personal rapid* transit system, with silent electric vehicles criss-crossing a blocked layout. China, one of the countries with largest construction market in the world, moves to sustainable low carbon eco-cities development. For example, Sino-Singapore Eco-city covers 30 km^2 and accommodates 350,000 residents aimed to become a showcase of sustainable development of cities/towns and serve as a model for sustainable development for other cities in China (http://www.tianjinecocity.gov.sg/). Its vision is to be a thriving city which is socially harmonious, environmentally friendly, and resource-efficient.

1.6.2 Architectural Design

Arguably the most noticeable component of sustainable urban environments is its buildings. Under the umbrella term *sustainable architecture*, a whole raft of factors comes into play. Figure 1.8 shows some of the key themes which shape the practice of modern day architecture from a sustainability perspective.

It is evident that the concept of sustainable architecture goes beyond the physicality of the building itself, but instead, views it as a holistic process. It

Fig. 1.8 Sustainable architecture and associated factors



emphasizes context. And it emphasizes its connection with environment and people through ideas about community, occupant health, and wellbeing. Building material resource and their availability are also considered. Sustainable architecture asks questions about: how to use materials more efficiently; how are they sourced; and are they renewable? And, as one expects, minimizing operational energy consumption is always at the forefront of design. An attention is paid to the impact of form (shape, texture, aspect ratio, glazing, etc.), building services (e.g., heating/cooling systems), local climate, and thermal performance at the early stage of urban planning.

The concept of *carbon lock-in* is also worth mentioning here. The term commonly refers to instances where systems are installed (e.g., heating), with a *fixed* efficiency, and remain irreplaceable for many years, usually for its engineering lifetime due to high replacement cost or service disruption. Inability to replace, users are 'locked' into a time period, during which time that system produces significant carbon emissions compared to more efficient systems. Carbon lock-in occurs within the design of building envelopes (building's 'skin' construction) as well as building services. Upgrading or improving the performance of the existing building stock is known as *retrofitting*: an up and coming area within industry.

With a demolition rate of 1 % in the UK, unsurprisingly nearly all the buildings by 2050 (approximately 70 %) are already standing today or in the planning phase (BRE 2012a, b). What is clear is the need to engage with building maintenance and refurbishment of the existing building stock, combined with efficient facilities management processes to sustain energy savings in the long term. Roberts (2008) and Boardman (2007) discuss the enormity of this challenge and the policy mechanisms available to government to enable industry and homeowners to tackle such issues.

Another concept that heavily features within sustainable architecture is *passive design*. Passive design utilizes the principles of building physics to enable building services to operate without using energy (or very little). Techniques range from correct building orientation to maximize sunlight in reducing heating and lighting energy demand, to more elaborate ideas such as multilevel displacement ventilation that uses natural air buoyancy effects to replace the need for mechanical ventilation. Within industry, a Passive Standard exists—*Passivhaus*. Quoted as the fastest growing energy performance standard, some 30,000 Passive buildings have now been built internationally (BRE 2012a, b).

1.6.3 Waste and Water

Water is essential to life. Buildings use water: *potable water* for occupants to drink, and *non-potable water* for other uses such as flushing toilets, industrial processing, and other utility. It comes as no surprise that urban environments use water, and a lot of it. With climate change forecasts predicting increased frequency of floods and drought (IPCC 2007a, b), the manner in which we manage water will be of utmost importance. Water security has received increased attention over the past decade in both policy and in academic circles (Cook and Bakker 2012). Reducing water consumption therefore, is vital for the security of food production, servicing buildings, essential human activities, and many other uses.

Water sustainability from a building services approach, includes an abundance of technologies, from spray taps with sensors, to gray and rain water recycling systems, to full on-site waste water treatment plants. Green roofs will also help with sustainable urban drainage and bio-diversity.

With the reduction of energy, comes the reduction of waste. The two being synonymous. It is frequently voiced that 'we live in a throwaway society'; that it is cheaper in many instances to replace products compared with repairing them. This type of society will continue to flourish, until waste and resources become prohibitive factors. The parameters of *time* and *consumption discount rate* have been found to be significant predictors of municipal solid waste (MSW) per capita (McCullough 2012). The indirect cost of time to maintain a product, and when it breaks, shop for and purchase a replacement, often outweighs the desire to reuse it. Consequently, those with higher incomes fall prey to this notion. Second, if the benefits of repair are equal or less to those of replacement, then replacing is generally favored. For example, if repairing a broken kettle costs as much as replacing it with a newer and better alternative (with more features and a warrantee), then repairing it seems unattractive. Waste, be it electrical appliances, paper, glass, plastic, timber, industrial, food, or garden waste, and even metal that is increasing in 'raw material' value, appears to be continually generated on mass. The resulting diminution of landfill sites has caused much concern within environmental politics and the waste management industry. Furthermore, our planet's needs sustainable environments to implement robust waste management strategies and recycling processes to help protect its resources.

1.6.4 Energy Supply and Demand

With a headstrong desire to meet the energy needs of new populous cities and megacities, the question of energy supply and demand comes into sharp focus. The energy supply mix remains heavily reliant on fossil fuels (coal, oil, and gas) in which to generate electricity and heat. Although the UK energy output of renewables has increased since 1996 (Fig. 1.9), primarily driven by policy, its uptake is not anywhere near the rate required to deliver the 'paradigm shift' that's needed to seriously curb the harmful effects of climate change

Decarbonizing the electricity grid continues to present new challenges (Shackley and Green 2007), however the talk of 'smart grids' and microgrids, combined with intelligent energy management systems, smart meters and renewable energy technology widens the scope for a more sustainable energy distribution network. The diffusion of building integrated renewables (e.g., solar photovoltaics, micro-wind, solar thermal, and biomass boilers) appear to be

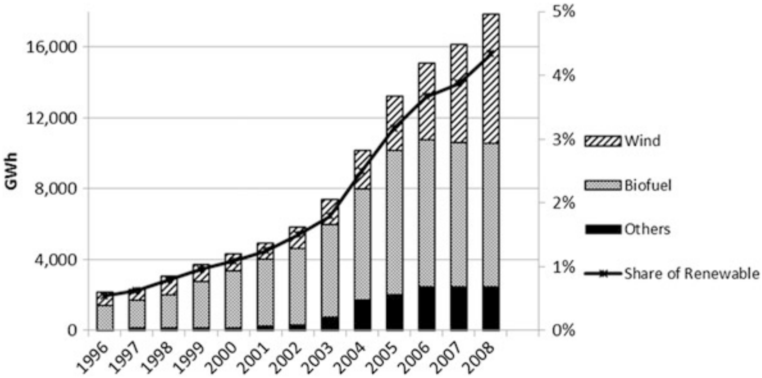


Fig. 1.9 UK Renewable energy generation (Renewable obligation basis) (*Source* ONS 2009)

bolstered by policy instruments such as planning and the *Feed-in Tariff*, guaranteeing a price for each kWh of electricity generated which is fed back into the electricity grid. Fortunately, early teething problems in the renewables supply chain seem to be dissolving, increasing the public's perception, and acceptability of various technologies across the urban landscape.

Operating on the opposing side of the energy equation is demand-side management (DSM). At a high level, demand-side initiatives tackle energy reduction at a national, regional, and city-scale. Spacial planning, urban transport, infrastructure, and social housing are typical issues on this agenda. In the Chinese context, where urban sustainability issues require urgent attention, Li and Yao (2012) look into the research challenges and opportunities involved in building energy efficiency. Discussing on policy, technology and implementation, they comment on the state of current affairs, developmental progress, and future direction. In their conclusions, they state that: (1) policies, standards, codes, and assessment tools, together with strict compliance procedures are necessary; (2) R&D, technology innovation and implementation programs should be carried out continually to help identify new research challenges, provide lessons, and raise public awareness of sustainable development; (3) there is an urgency to develop *tools* to help with project life cycles, planning, facilities management, and post occupancy evaluation in an integrated fashion; and (4) understanding building users' energy demands, expectations, behaviors, and lifestyles is vital when striving to create a resource conservation society. An emphasis on *integrated thinking* emerges from their work. When drilling down to a building level, operational management, and challenges associated with changing occupancy behavior are more pertinent (Yu et al. 2011). This is covered later in the sub-section entitled 'management'.

1.6.5 Management

Occupant behavior and the manner in which we operate our buildings is arguably more important than the building itself (Janda 2011). There is little strength in high performance materials and outstanding build quality if the building's users do not operate the building as it was intended. This notion asserts the importance of the role in which occupants play in determining the overall energy consumption of buildings. An influential paper by Wood and Newborough (2003) cites studies from the US (1978), Holland (1981), and the UK (1996) which found that occupant behavior alone was responsible for 26–36 % of total domestic energy use. Other studies report that occupancy issues could vary the consumption of identically built houses by a factor of two (Seligman et al. 1978; Baker and Steemers 2000) or even three (Shipworth 2010).

Facilities managers are expected to increase their engagement with operational issues, while householders are faced with reducing demand through interventions associated with the building's energy end-uses. DSM programs attempt to typically influence when we use energy, characterized by financial incentives inherent in pricing tariffs. Energy behavioral awareness is bought to our attention through public information services, utility companies, schools, and other organizations. Commonplace, are messages telling us to 'switch off lights', 'turn our heating down', and to 'conserve water when washing the dishes'. Influencing behavior change is hugely challenging as deeply ingrained behaviors are difficult to re-shape (Stephenson et al. 2010). Tackling the management of buildings requires a holistic approach and one that is implemented with care and insight, avoiding the potential pitfalls.

1.6.6 Technology

If a fourth pillar was proposed in shaping the definition of sustainability, it would reflect *technology*. Indeed, the institute of development studies (IDS) has a center with the acronym social, technological, and environmental pathways to sustainability (STEPS). It is without any doubt that sustainable development depends pivotally on technology. In an early study that looked at intervention policies to achieve a 'sustainable city', Camagni et al. (1998) derive solutions based on *technology*, territory, and lifestyle strategies. Technology blossoms and provides us with new innovative products at an alarming pace. Information technology (IT), renewable energy technology, building services technology, and sensor technology, are all incremental in providing us with solutions for sustainable urban environments—now and for the future.

When it comes to buildings, technology is at the forefront in achieving sustainability. Building structures, the building envelope, building services, and the equipment found in buildings all reply on technology in one form or another.

Considering the existing building stock and the retrofit boom that is about to occur, the industry will rely heavily on technological solutions in providing answers to some very complex problems. What systems and materials will best integrate with existing structures and services? Turning toward new buildings, technology has the potential to overcome typical pitfalls by providing cutting-edge solutions. The development of phase change materials, wireless sensor networks, holistic energy management systems, and web-enabled services will all contribute to the intelligence of buildings in the near future, and for some already built. Exciting eco-city projects such as those in Masdar, Abu Dhabi, and Eco-cities in China will undoubtedly set the trend for technology in future sustainable built environments. One example is the exclusive use of electric vehicles to get around the city at Masdar.

Information technology and computing has enabled the modeling, simulation and analysis of systems, and processes within many areas of the built environment. Using computational techniques to implement mathematical equations, computational fluid dynamics (CFD), and generic algorithms can enable analysts to model a multitude of phenomena that occur within urban environments. By no means an exhaustive list, this includes the analysis of: energy (energy and exergy) flows, resource flows, transport movement, microclimates, indoor environments, acoustics, heating, cooling, ventilation, air conditioning, natural and artificial lighting, appliance use (Lim and Yao 2012), and structural components. Aside from building physics processes, computing can also aid in modeling occupant behavior (actions), environmental, and social and economic systems that are also integral to sustainable urban systems.

1.7 Conclusion

The principles of sustainability draw together many facets, not least of which include those governing environmental, economic, and social interactions. Applying the concepts of sustainability to the urban environment (buildings, infrastructure, transport, etc.) raises some key issues for tackling climate change, resource depletion, and energy supply. Buildings and the way we operate them play a vital role in tackling global greenhouse gas emissions. In addition, international policy is well established in supporting carbon reduction and the UK in particular has set some challenging targets aimed at reducing energy from the buildings sector. With the aid of planning systems, building regulation, and green building assessment methods, new urban developments are tightly controlled and foster a culture of energy efficiency together with social enhancement, an area of construction that previously received less attention. Other factors such as water, waste, energy supply, and demand are also keenly observed in policy measures and mechanisms. Engaging with energy efficiency in the context of an old building stock is presenting unique challenges that require careful approaches in providing answers. It is recognized that technology will play a huge part in enabling industry to deliver robust solutions that are fit for purpose. Further to this, information technology and advances in computing science will increasingly feature in building energy management and influence how we interact with indoor environments. It appears that a common message is repeated within the literature which underlines the need for holistic thinking and an integrated approach. Finally, as we head into an uncertain future with demographic and climatic change at our doorstep, combined with resource depletion and energy security issues, striving to achieve sustainable urban environments becomes a prerequisite if mankind is to thrive on Earth.

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