ENERGY-EFFICIENT BUILDING DESIGN: TOWARDS CLIMATE-RESPONSIVE ARCHITECTURE

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Contents

Summary

Among the most significant environmental challenges of our time are global climate change, excessive fossil fuel dependency and our cities' growing demand for energy –

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all likely to be major challenges of the twenty-first century and some of the greatest problems facing humanity. Globally, buildings account for around one third of energy use and are responsible for over half of total greenhouse gas emissions (Toepfer, 2007; Brugmann, 2009; Friedman, 2009). Studies show that the efficiency improvement capacity of buildings is significant: researchers have estimated that the current energy consumption of buildings could be cut by 30 to 35 per cent simply by using energy more efficiently. Another 25 per cent could be gained by transforming the existing building stock through retrofitting it into energy-efficient buildings (Hegger et al., 2007; Lehmann, 2008a, 2009). Such change would address both energy security and environmental challenges and help to secure social and economic development.

But why are our current buildings so energy hungry? It is worthwhile reflecting on the origins of the dependency of buildings on air conditioning, which evolved with twentieth-century architecture and is related to other developments that affected buildings in the 20th century, such as the emergence of the curtain glass facade, the lack of flexibility and adaptability of most buildings and their relatively short life span. Such reflection shows that many traditional passive design principles have been forgotten or marginalized. We can, however, still find them in heritage buildings from the pre-air-conditioning era, and we see that they are based on heat avoidance, the appropriate use of local materials, the use of natural cross-ventilation and the harnessing of natural energies offered by the location. This chapter sets out to explain design approaches to energy-efficient buildings and then presents three case studies of energy-efficient buildings in three different climatic zones. It concludes with a series of recommendations for a holistic pathway to more energy-efficient, low-to-zero-carbon, climate-adaptive buildings. High performance buildings are a key feature of energy reduction.

A move towards better design and building practices would ensure energy efficiency and limitations on emissions of greenhouse gases for decades to come. In fact, buildings are often described as the ‘low-hanging fruit’ in the challenge of creating a low-carbon future, because the implementation of energy efficiency in the construction sector has been long overdue and has already started to become a worldwide movement. Also, these changes are fairly inexpensive and easy to achieve (Kearns et al., 2006). An extensive glossary of terms at the end of the chapter gives the reader a wider understanding of the topic.

1. Introduction

The concentration of our energy supply on fossil fuels has had a continuous and drastic effect on the balance of nature, ecosystems and the overall environment, on water and soil, biodiversity and climatic stability. The use of fossil energy sources has led to a rapid rise in the emission of carbon dioxide and other greenhouse gases into the atmosphere. The use of energy by urban developments and buildings is of far-reaching importance. Estimates indicate that ‘at present urban agglomerations account for up to seventy per cent of all CO_2 emissions worldwide, and around forty per cent of CO_2 emissions can be attributed to housing construction and estate development’ (Scheer, 2002; see also: World Energy Council, 2004; Toepfer, 2007; IPCC, 2007, 2008). An increase in energy efficiency and a reduction of energy demand in buildings must,

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therefore, be a basic condition for any successful climate change policy (UNEP, 2007; UN-Habitat, 2010).

It is now widely accepted that human activities are contributing to accelerated climate change and that the built environment (including building design) will play a significant role in the mitigation of, and adaptation to, the impact of climate change (Brundtland, 1987). It is also increasingly understood that there is a complex interplay between various design strategies that can be applied to buildings and the opportunities for increasing their energy efficiency. Energy efficiency has become an integral part of building design.

Energy efficiency is the ability to use less energy more effectively to provide the same level of output. To avoid global warming we need to take energy efficiency as far as we can and make it a priority. This requires a transformation of how we generate, distribute and consume electricity (by introducing smart grids, new electric transportation and local distribution systems), as most electricity is still produced with the technology of the mid-twentieth century. Energy efficiency in buildings means employing strategies (in the design, construction and operation of buildings) that minimize the use of energy imported from utility companies. Commonly quoted examples include insulation of external walls and the use of high-performance glazing, solar hot water heating and low-energy fluorescent, or LED, lighting. Efficient energy use is achieved by using more efficient and effective technology in all processes of an integrated building design approach that takes advantage of the local climate to provide some, or all, of the heating, cooling, ventilation and lighting needs of the occupants (a 'harnessing nature' approach). Energy efficiency also helps to reduce emissions of greenhouse gases.

Today it is possible to build 'zero-energy buildings' (ZEB), which are buildings designed and constructed environmentally responsibly and which produce at least as much energy as they consume. On-site generation of renewable energy through solar power, wind power, hydro power or biomass can significantly reduce the environmental impact of the building. With on-site electricity generation, a 'zero-energy building' can be used autonomously from the electricity grid supply (off-the-grid), as all required energy is harvested on-site (MacKay, 2008).

The design of energy-efficient buildings is a complex task for architects and engineers. Truly sustainable design can only be achieved if energy efficiency is combined with material efficiency. It requires a sound understanding of the inter-linkages between various technical, environmental, social and economic criteria, as explained in the following parts of this chapter.

2. Definitions and Background

In future, all buildings will have to be energy-efficient by default. The next generation of great buildings will be 100 per cent 'green'.

The starting question is: what is an energy-efficient architecture (building)? Energy-efficient buildings are an integral part of the overarching aim to achieve sustainable development. Sustainable development has been defined as 'development which meets

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the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland/UN Commission, 1987). Therefore, energy-efficient buildings have to be designed in such a way that they contribute towards the *larger* vision of building energy-efficient and environmentally sustainable cities. This is achieved by increasing the efficiency of resource (energy) use, but not by increasing resource throughput. This implies that energy is conserved wherever possible and energy supplies, to a large degree, come from renewable and non-polluting (non-fossil-fuels) sources. It recommends the thoughtful integration of rooftop solar power, solar thermal, wind power, biomass, geothermal or hydro, depending on the site's potential and the kinds of resources the site can supply to harvest renewable energy needs on-site.

In general, efficient-energy use – most of the time simply called 'energy efficiency' – is the goal of efforts to reduce the amount of energy required to provide products, services or a comfortable indoor climate. For instance, insulating a home allows a building to use less cooling and heating energy to achieve and maintain a comfortable indoor temperature, even if it is very hot or cold outside. Research shows that allowing interior spaces to be naturally ventilated means healthier interior environments and better productivity at workplaces. Importantly, energy-efficient buildings do not have to conform to a particular 'building style'; they can be existing buildings adapted for re-use. They are buildings that effectively manage natural resources by taking all possible measures to ensure that the need for energy is minimal during their operation (applying passive and active systems to harvest renewable energy sources). In these buildings, cooling, heating, ventilating and lighting systems use methods, technologies and products that conserve non-renewable energy or eliminate energy use. Cutting energy demand requires the use of design solutions, materials and equipment that are more energy-efficient.

Sustainable building design, also known as green or energy-efficient building design, is therefore the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle, from concept to design, construction, operation, maintenance, renovation and demolition. Although new technologies are constantly being developed, the common objective is for energy-efficient buildings to be designed to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy as well as water, materials and other resources and reducing waste and pollution.

An OECD report defines 'sustainable buildings' as buildings that are designed on the basis of holistic approaches involving the following five principles:

- resource efficiency: reducing energy needs and materials during construction
- energy efficiency: reducing energy in building operation
- pollution prevention: minimizing pollution, environmental impact and damage to health
- harmonization with environment: making the most of the site, reducing embodied energy and resource depletion
- applying integrated and systemic approaches (OECD, 2003).

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This chapter concentrates on energy use in buildings during their operation, because this is the main field of influence for the building's designer (the architect, engineer or planner). Operational energy reduction is frequently regarded as *low-hanging fruit* that can easily be implemented. However, depending on the level of energy services, the operational energy consumption can be up to 80 per cent of the total energy demand of a building, along with construction, demolition and the embodied energy in the materials (WBCSD, 2009).

The built heritage plays an important role in the shift towards a low-carbon society; it contains a large amount of embodied energy. It also offers a large resource of knowledge about design principles and how architects used to operate within the constraints and challenges of extreme climatic conditions, such as, for instance, in a tropical or hot and arid climate. Unfortunately, much of this knowledge has been forgotten, and has not been sufficiently discussed and researched.

'Climate-responsive' means that the building's facade and systems can respond to different climatic conditions, to weather-related changes and to shifting day/night conditions. One of the fundamental principles is to design buildings 'low tech', where passive strategies are employed before active ones. Traditional buildings are a great educational source as they frequently achieve 'more with less': high comfort for building occupants, good indoor air quality combined with surprisingly low energy requirements. Following the first oil crisis in 1973, a series of architectural pioneers of a low tech approach, such as the European architects Nicholas Grimshaw, Norman Foster, Renzo Piano, Peter Huebner, Jourda & Perraudin and Thomas Herzog, just to name a few (Tzonis, 2006), proposed environmental alternatives for more energy-efficient buildings.

Energy simulations on the computer can be used at the earliest design stage to assess various design options and alternative building forms, and to explore the effectiveness of different energy conservation and energy use reduction measures. Ideally, energy simulation should continue throughout the entire design process to ensure the desired reductions in energy consumption are achieved, to avoid over-heating and to minimize peak energy load. Computer simulation enables the designer to define the *ideal* building shape, facade envelope, size of openings and type of glazing, effective sun shading and so on, as early as during the conceptual design phase. Energy simulations are important to refine the final building design, and the use of computer-based tools to solve energy design problems has grown rapidly (Clarke, 2001).

3. Passive and Active Design Principles for Energy-efficient and Climate-responsive Buildings

Holistic strategies and integrated approaches:
The most successful solutions are now the highly effective combination of passive design principles with some well considered active systems, for buildings that are built to last longer.

Before electrical heating, cooling and illumination became common, architects used a combination of passive design principles to ensure that interiors were well lit and

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ventilated through passive means, without any use of mechanical equipment. However, since the early 1950s most architects and engineers have simply employed air-conditioning systems for cooling, as energy from fossil fuels was cheap and plentiful, and air-conditioning systems allowed for deep-plan buildings, internalized shopping mall complexes and other highly inefficient air-conditioning dependent building typologies.

The biggest energy consumers in buildings are technical installations for cooling interiors and lighting. The extensive use of glass surfaces in the facades of buildings (especially in hot, tropical or subtropical climates) and materials that easily store the heat in summer frequently lead to solar overheating, which has led to the widespread use of mechanical systems (air-conditioning systems) (Aynsley, 2006). Buildings in the tropics are a particular challenge due to the high humidity and temperatures. However, the tropics are home to almost two-thirds of the world's population, so practical and achievable solutions are of particular relevance. With more careful building design, energy-hungry air-conditioning systems could be avoided in almost any climate. Instead of the use of mechanical air-conditioning systems, substantial improvements in comfort can be achieved by the informed choice of materials appropriate to basic passive energy principles and the optimization of natural ventilation (cross-ventilation, night-flush cooling, mixed-mode systems), summer shading and winter solar heat gain. Solar and wind energy can provide heating, cooling and electric power.

On the other hand, buildings from a pre-air-conditioning era frequently display a convincing application of passive design principles, such as their optimized orientation, the use of evaporative cooling, strategic use of thermal mass, trompe walls, ingenious sun-shading devices for the western facade, solar chimneys, courtyards allowing for cross-ventilation of hot air at the highest point in the room, and natural cross-ventilation adjustable to the changing directions of a breeze. Sub-slab labyrinths for fresh air intake, activating the thermal mass, have recently seen a comeback in many projects. Such underground air chambers, called thermal labyrinths, are frequently used to ventilate rooms, with air cooled naturally by traveling a long distance underground through channels in the earth. Energy savings from the use of thermal labyrinths can be significant (Daniels, 1995, 2000). In addition, the use of local materials with less embodied energy (combined with local workforce and locally available technical know-how) has recently led to regional 'styles' in architecture.

Successful buildings of the future will increasingly rely on the critical examination of, and learning from, buildings of the past (Vale and Vale, 1991, 2000; Hyde, 2000). There is so much we can learn from such studies, e.g. which passive design principles have delivered the most energy savings? How has adequate active and passive thermal storage mass been provided? There is a good reason why passive design principles have traditionally been preferred to (and are now once again being chosen over) active systems. 'We need solutions for buildings that can do more with less technology', argues engineer Gerhard Hausladen, adding: 'The optimization of the building layout and detailing of the facade system are essential for an integrated approach to the design of low-energy consuming buildings and cities' (Hausladen et al., 2005; 41). Just optimizing buildings through the application of passive design principles can deliver energy savings of up to 80 per cent (Hausladen et al., 2005).

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A building's location and its surroundings play a key role in regulating its indoor temperature, the illumination of space and the capacity to minimize energy use. For example, trees and landscaping can provide shade or block wind, while neighboring buildings can overshadow a building and thus increase the need for illumination during daytime. This is why the designer needs to understand the site conditions and the effective application of passive design principles fully (Hall and Pfeiffer, 2000; Gauzin-Mueller, 2002; Treberspurg, 2008).

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Biographical Sketch

Dr Steffen Lehmann is the Professor of Sustainable Design and Director of the Research Centre for Sustainable Design and Behaviour (sd+b) at the University of South Australia. Until July 2010, he held the Chair of Architectural Design in the Architecture School at the University of Newcastle (NSW). He has been a professor holding a Personal Chair in Australia since December 2002. Professor Lehmann has held the UNESCO Chair in Sustainable Urban Development for Asia and the Pacific, from 2008 to 2010. He received his doctorate in architecture from the Technical University of Berlin, an AA Dipl. degree from the Architectural Association School in London, and a Masters degree from the University of Applied Sciences in Mainz. Between 1990 and 1993 he worked as an architect with James Stirling in London and with Arata Isozaki in Tokyo, before establishing his own ideas-driven, research-based practice in Berlin. Since 1992 he has been practising as a registered architect and urban designer in Germany, where he established his own practice, the Space Laboratory for Architectural Research and Design (s_Lab) in 1993 in Berlin, to pursue a more ethically correct practice. He is the General Editor of the *Journal of Green Building* and a member of the editorial boards of 4 academic journals. For more information, see www.slab.com.au