Ali Sayigh *Editor*

Sustainable High Rise Buildings in Urban Zones

Advantages, Challenges, and Global Case Studies

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Introduction

This is our third book in the *Built Environment* series. The first was *Architecture: Comfort and Energy*, and the second was *Sustainability, Energy and Architecture*. In this book we are tackling an issue which is very important, namely, *high-rise buildings in the urban zones*. Examples from various parts of the world are discussed in details with a view to providing a positive and useful analysis as to why we build high-rise buildings. At the same time the drawbacks and negative issues which occur such as safety, complex services, energy usage, and lack of green environment and recreation facilities in having high-rise buildings are fully discussed. Depending on the locality, the cost of space and usability combined with comfort and ease of travel in the urban zone are some of the reasons taken into consideration when a high-rise building is planned.

The contributors attempted to answer the following most vital issues when designing a high-rise building:

1. The environmental impact
2. The safety and social acceptability
3. The energy consumption and comfort
4. The planning within the urban structure
5. The daily maintenance, services, and risks
6. Additional advantages gained
7. Optimization within the urban zones
8. Other positive or negative features

The book consists of ten chapters.

Chapter 1 *Kuala Lumpur City Center Integrated Urban Development Zone: A New Art of Urban Living* by Nila Inangda and Mastura Adam, Department of Architecture and Faculty of Built Environment in the University of Malaya.

This chapter mainly deals with the concept of Kuala Lumpur as a megacity. Details of planning and space, including parks, are well documented. The inner-city improvement was achieved by moving all government offices to Putrajaya, an adjacent city. The population growth has doubled and troubled over the last decade.

Also explained is how the city has changed from a mainly pedestrian city to an ultramodern vehicular city with constant traffic jams and numerous high-rise buildings within the last 30 years. Kuala Lumpur followed the US example in redeveloping its inner city to accommodate the fast growth of incoming wealth which has led to the reduction of suburban sprawl and inner-city decline. Kuala Lumpur is categorized as a world city based on five criteria: It is a commercial and financial center; it has an efficient and equitable city structure; it enhances the living environment; it has a distinctive city image/identity; it has effective and efficient governance. A description of the city within a city experience, referred to as the twin towers skyscraper of Kuala Lumpur, and its residents is given. A full planning design showing the zoning boundary of various services is included. The social, financial, and environmental impact on residents is given. High-rise buildings in Malaysia embody social mobility and ease of communication in addition to safety and security. This urban development is fully sustainable and flexible and functions well with a modest usage of energy. The architectural design and illustrations are of great value and insight to all those who are dealing with high-rise building design.

Chapter 2 *Sustainable High-Rise Buildings in the Netherlands*, by Wim Zeiler, TU Eindhoven, Eindhoven, the Netherlands.

High-rise building development is a result of the need for space arising from increasing business activities despite the large energy consumption that accompanies them. Having well-thought management services can reduce the energy consumption to an acceptable level. The author describes the historical development of high-rise buildings in Holland which was made possible by the invention of the elevator in 1853. Holland has little viable land for living which causes an extreme shortage of habitable land for its 16.5 million population. Therefore, Holland has no choice but to build vertically. The development of high-rise buildings is considered from its early days in New York in the 1930s to the present day showing the extreme high-rise buildings in Asia and the Gulf. The design of several Dutch high-rise buildings is discussed specifically with regard to the heating and cooling techniques. Professor Zeiler then describes several high-rise buildings stressing their importance and the need for them not only in Holland but everywhere in big cities and how some of them use innovative heating and cooling techniques taking into consideration the economics, the environment, and social acceptability.

Chapter 3 *Vernacular Tower Architecture of Sana'a: Theory and Method for Deriving Sustainable Design Guidelines*, by Khaled A. Al-Sallal, Department of Architectural Engineering, UAE University, Abu Dhabi.

The author looks at the old traditional buildings of Yemen which have distinctive pattern and style associated with the inhabitants. Professor Al-Sallal is of the opinion that contemporary architecture does not have a clear identity; it lacks order and unity ignoring energy, vegetation, and water. The Yemeni architecture is a wonderful vernacular architecture of multistory buildings. Each sector of Sana contains a mosque, a market, multistory houses, a public square, and an urban garden space.

The houses are between 6 and 10 stories high. A complete functional description of each building is given including its windows. All houses are naturally heated and cooled during the year which the author has researched and analyzed fully. In this chapter the meaning of sustainable architecture is fully explained.

Chapter 4 *Energy Consumption and Indoor Environment*, by Baizhan Li and Runming Yao, Faculty of Urban Construction and Environmental Engineering, Chongqing University, China.

A short history of high-rise buildings is given with an emphasis on population growth taking into consideration the cost of land in the large inner cities. The urban population of China is 54 % of the total population, and this could rise to 60 % by 2030. Additionally China has 19.5 % of the world population. Fifty-seven percent of the world's super high-rise buildings are in China. The indoor parameters such as lighting, air quality and ventilation, thermal comfort, acoustic, and safety of several high-rise buildings in China are discussed in detail.

Chapter 5 *The Increasing Demand on High-Rise Buildings and Their History*, by Manuel Correia Guedes, Department of Civil Engineering and Architecture, Instituto Superior Técnico, Lisboa, Portugal, and Gustavo Cantuária, Faculty of Architecture, University of Brasília, Brasil.

An extensive introduction of the necessity for high-rise buildings in modern life and a clear analysis of sustainability are given. A brief historical overview of tall buildings and a discussion on how to integrate them with green landscaping are presented. Thermal energy from solar gain is used to heat the buildings, and any other renewable sources must be used to achieve sustainability.

Chapter 6 *Sustainable High-Rise Building-Renewables and Public Perceptions*, by Neveen Hamza, School of Architecture, Planning and Landscape, Newcastle University, UK.

This chapter describes the social implications in the development, funding requirement, and policy mechanism for architects to design sustainable high-rise buildings. This can be divided into three parts: sociopolitical acceptance, market acceptance, and community acceptance. The passive design of high-rise buildings is explained through the case study of the Northumbria Police headquarters, Newcastle upon Tyne, and the case of the Chicago Federal Building by metamorphosis (2008) and Angel Square in Manchester. The three buildings were described outlining their important features in using renewable energy to meet their electricity demand. Photovoltaic and wind energy were the main sources. Also discussed is the use of photovoltaic integrated façade in some Chinese buildings with building cost offsets by claiming feed-in tariff. It is possible to use photovoltaic in buildings, but using wind energy may cause objections from the public point of view especially regarding safety and security, as in the case in Bahrain.

Chapter 7 *Environmentally Performative Design for High-Rise Buildings in North America* written by Mona Azarbayjani, School of Architecture, College of Arts + Architecture, University of North Carolina at Charlotte, USA.

The introduction states that 40 % of total energy consumption can be attributed to buildings, while by 2050, 70 % of the world's population will be living in urban areas. Architects must adopt feasible strategies in designing high-rise buildings such as:

1. Choice of location, having the correct orientation to enhance the solar gain especially in a cold climate or to reduce it in a hot climate zone
2. Using all passive measures and concepts such as shading, microclimate, ventilation, and storage of energy
3. Energy recycling within the building
4. Introduction of the use of renewable energy wherever possible

The author looks at two high-rise buildings in North America having an adequate design, the Manitoba Hydro Place and the Bank of America Tower at One Bryant Park. The first one is in Canada which has adequate daylighting and a natural ventilation system using specially operated windows. This structure was built with a double skin façade to enhance energy conservation especially in winter season and used a geothermal source for heating.

The second building is in New York and has several energy conservation systems such as displacement ventilation.

Chapter 8 *Assessing the Myths on Energy Efficiency when Retrofitting Multifamily Buildings in a Northern Region* by Jan Akander, Mathias Cehlin, and Bahram Moshfegh, Department of Building, Energy and Environmental Engineering, Faculty of Engineering and Sustainable Development, University of Gävle, Sweden, and Division of Energy Systems, Department of Management and Engineering, Linköping University, Sweden.

This chapter is devoted to energy saving in retrofitting multifamily buildings, mostly related to buildings in Sweden. Dividing the country into regions depending on their climate and solar gain, the Swedish government legislated that the average electricity consumption per meter square of built area should not exceed 154 kWh without compromising indoor comfort. The chapter describes a very comprehensive analysis to reduce the energy consumption to 50 % and the CO_2 up to 75 %.

Chapter 9 *High-Rise Buildings in the Context of Sustainability: Urban Metaphors of Greater Cairo, Egypt, A Case Study Sustainability and Strategic Environmental Assessment*, by Mohsen M. Aboulnaga, Sustainable Built Environment, Faculty of Engineering, Cairo University, Egypt.

The chapter is mostly devoted to high-rise buildings in Egypt, specifically those in Cairo. It is an extensive chapter with a global summary of various high-rise buildings at different parts of the world and their functionalities, starting with the Pyramid built more than 3000 years ago which over the years has been an icon to many architects in Japan and the USA. Some high-rise buildings have a population density of 36,000 per square kilometer. Another area covered is climate change and the effect of buildings, in particular high-rise buildings, knowing that 30 % of greenhouse gases emission is due to the building sector. Heating and cooling with proper ventilation could result into 80 % of energy usage. Another item discussed in this chapter is the embedded energy of buildings versus the operational energy. Several high-rise buildings are discussed from the Gulf region, their energy consumption, and the sustainability of such buildings.

Chapter 10 *High-Rise Buildings in Mediterranean Climate: "Illa de la Llum" Case Study in Barcelona*, by Cristina Pardal and Helena Coch, Department of Architectural Technology I, Universitat Politècnica de Catalunya UPC, Barcelona, Spain.

The chapter tackles the various aspects of the high-rise building such as façade design and its construction in using metal framing and cladding techniques. A good example is the building of Turning Torso. A full analysis of comfort requirements is outlined followed by the sociological concept of lifestyle in the Mediterranean climate zone and its architectural requirement. Several examples of high-rise buildings from the Mediterranean region are given with their innovative design features. The analysis includes the various adaptive measures which the architects and designers have to consider in this region.

Contents

Contributors

Mohsen M. Aboulnaga Sustainable Built Environment, Department of Architectural Engineering—Environmental Design Division, Faculty of Engineering, Cairo University, Cairo, Egypt

Mastura Adam Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia

Jan Akander Department of Building, Energy and Environmental Engineering, Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, Sweden

Khaled A. Al-Sallal Department of Architectural Engineering, UAE University, Abu Dhabi, United Arab Emirates

Mona Azarbayjani School of Architecture at the University of North Carolina at Charlotte, Charlotte, NC, USA

Gustavo Cantuária Faculdade de Arquitectura, Universidade de Brasilia, Brasil

Mathias Cehlin Department of Building, Energy and Environmental Engineering, Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, Sweden

Helena Coch Department of Architectural Technology I, Universitat Politècnica de Catalunya UPC, Barcelona, Spain

Manuel Correia Guedes Departamento de Engenharia Civil e Arquitectura, Instituto Superior Técnico - Universidade de Lisboa, Lisbon, Portugal

Neveen Hamza School of Architecture, Planning and Landscape, Newcastle University, Tyne and Wear, UK

Nila Keumala Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia

Baizhan Li Chongqing University, Chongqing, China

Bahram Moshfegh Department of Management and Engineering, Division of Energy Systems, Linköping University, Linköping, Sweden

Cristina Pardal Department of Architectural Technology I, Universitat Politècnica de Catalunya UPC, Barcelona, Spain

Runming Yao Chongqing University, Chongqing, China

Wim Zeiler TU Eindhoven, Eindhoven, Netherlands

Chapter 1
Kuala Lumpur City Centre Integrated Urban Development Zone: A New Art of Urban Living

Nila Keumala and Mastura Adam

1 Introduction

Kuala Lumpur (KL), the capital and premier city in Malaysia has a total land area of 243.7 km^2 located within the Klang Valley with a total population of 1,556,200 in 2005. Thus, its density reached 6386 persons per km^2. Planning wise, Kuala Lumpur is divided into six strategic zones under the Kuala Lumpur Structure Plan (2004–2020). The mega city is connected with the surrounding areas by highways such as KESAS, Federal Highway, NPE, ELITE, roads, and railways (Light Rail Transits and KTM Komuter).

Kuala Lumpur City Centre (KLCC) Zone situated within the city centre of Kuala Lumpur is shown in Fig. 1.1. The zone is covering 1, 813 ha and surrounded by major movement network crossing east–west axis as well as north–south axis; several hills such as Bukit Nanas, Bukit Ceylon, Bukit Tunku and the river valleys of Sungai Klang and Sungai Gombak as shown in Fig. 1.2 (Kuala Lumpur City Hall 2008).

KLCC zone is lively and attractive and like any other fast growing city, its population is expected to rise up to 245,600 people in 2020 from 128,721 in 2000. The employment of the City Centre in 2000 was 396,036 and is projected to be about 438,010 by 2020.

The relocation of federal government offices to Putrajaya has further changed the traditional role of the city centre as residential cum commercial in Kuala Lumpur setting into a commercial centre of attraction that could draw people back to the inner city. Apart from the social aspect, the inner city development is to follow the general principle of urban design guide line in terms of controlling the building heights, maintaining the city wide view and defining the visual corridors, this main

N. Keumala (✉) • A. Mastura
Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur 50603, Malaysia
e-mail: nimk@um.edu.my; mastura@um.edu.my

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Fig. 1.1 Development strategy city centre (Kuala Lumpur Structure Plan 2020)

commercial district now has the characteristic that creates an attractive and unique identity of a city to showcase Kuala Lumpur as A World Class City.

In aiming to reduce the Carbon footprint and traffic congestion, City Hall of KL is promoting the use of public transportation, facilitating pedestrian movement and organising the bicycle network around KLCC Zone. In order to improve the overall environmental quality of Kuala Lumpur City Centre zone, the green area is extended into the city centre. The existing community facilities in the city centre have been upgraded and additional community facilities shall be provided for the city residents within a comprehensive mixed-use development.

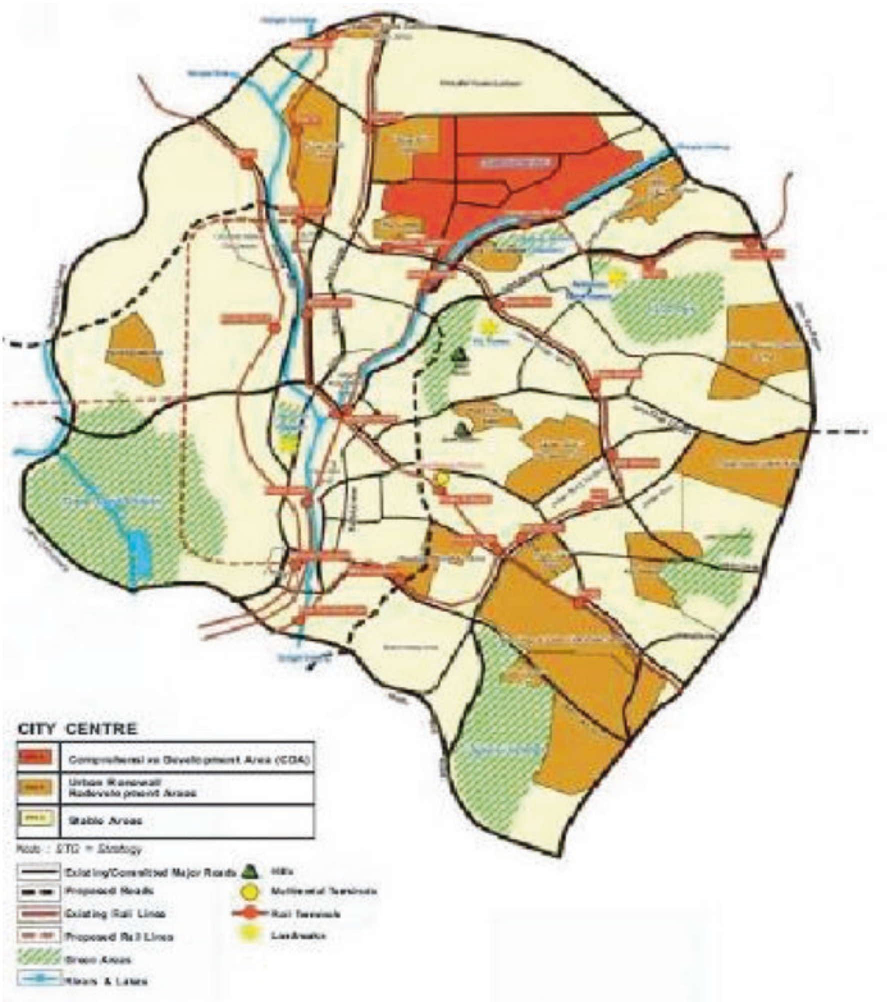


Fig. 1.2 Kuala Lumpur city-regions and strategic zones (Kuala Lumpur Structure Plan 2020)

2 Urban Living in Malaysia

The Kuala Lumpur region had a population of approximately 7.1 million, according to the 2010 census. This includes 1.6 million in the federal territory (core city) of Kuala Lumpur and 5.5 million in the suburbs (which include Putrajaya). The region has experienced strong growth since modern Malaysia evolved between 1957 and 1963. In 1950, the region had only 900,000 residents. By 1980, the population had more than doubled to nearly 2.4 million and by 2010; the population had tripled from its 1980 level.

Kuala Lumpur continues experiencing strong population growth. Since 1980 (the first census after the creation of the new territory), the city has experienced a population increase of 77 %. Yet, the suburbs and exurbs have grown far more rapidly. The suburbs and exurbs have grown 280 % and have added nearly 6 times the population increase of the city. This general distribution of growth continued over the past decade, with the suburbs attracting 83 % of the new population, while the city centre of Kuala Lumpur received 17 % of the growth. Indeed measures to facilitate the increase of the population in the inner city are seen crucial.

2.1 The Old Traditional and New Kuala Lumpur

Gurstein (1984) states that Malaysia has not had a long history of urban settlements, being a predominantly rural and village (kampong)-based society. The large urban settlements such as Kuala Lumpur were established as a 'traditional city' and a centre of tin-mining activity. Morphological studies on the growth of the town centres in Malaysia indicated that the early component of Kuala Lumpur includes the old shop houses, market, and places of worship with walkable streets. The shop house was a mixed-use vertical arrangement having a working space on the ground floor and the living spaces on the upper floors. The typical two-storey shop house, with the ground floor for trading and the first floor for residential use is still a standard feature in the centres of Malaysian towns and cities (Yeang 1992; Ismail and Shamsuddin 2005). These buildings' typology is important as they are the oldest extant urban dwellings in the country (Ismail and Shamsuddin 2005).

With the advent of globalisation and spread of the international style, Kuala Lumpur lost its essence of a traditional walking city. Economic growth became the agenda accompanied by the development of large commercial zones in the inner city. The increasing property price in Kuala Lumpur led city dwellers to search for affordable accommodation outside the city. This brought with it a myriad of issues including: separated land uses (zoning), severe traffic congestion due to the increased dependence on private vehicles and the urban heat island effect. Figure 1.3 below shows the Kuala Lumpur city growth throughout several eras from a small traditional and walkable town to highly congested city due to the urban sprawl to the suburbs (Mastura 2013).

However, over the last 10 years, many established developers in Malaysia have initiated alternative approaches to their development concepts in order to improve the quality of life for clients and their commercial objectives of improved marketability (Alias et al. 2011). In his research interviews with some of the major developers in Malaysia, Hamid (2002) underlined that real estate products are not only just the physical appearances of buildings, but includes a fine grain amalgamation of the environment, adjacent neighbourhoods, infrastructure, and the amenities such as seamless transportation, that make up the total development within the city (Alias et al. 2011). Accessibility is the ease at which amenities can be accessed without the need to travel excessively (Harvey 2000). These are the features emphasised in

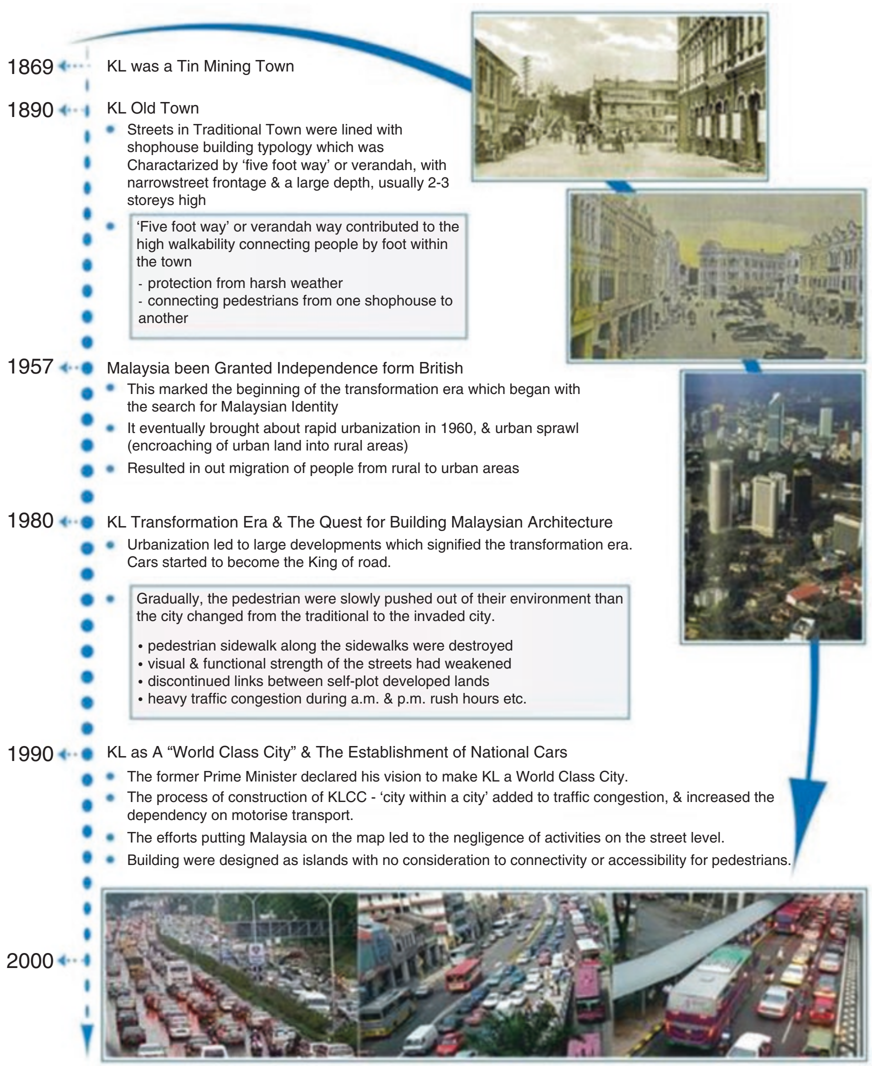


Fig. 1.3 The timeline of Kuala Lumpur city development from tin-mining town to metropolitan city (Mastura 2013)

many urban developments in Malaysia (Alias et al. 2011). Several measures have been formulated to improve the market positioning by the developers during recent years among which include the promotion of environmentally oriented and ecological-friendly development schemes, the provision of parks and recreation space, and support for green movements (Alias et al. 2011). These development schemes are seem to meet customer desires for a green and connected communal living lifestyle. The above mentioned components of the current real estate development in some way has adopted the concept of New Urbanism that has been emerged in the United States in the early 1980s as a reaction to growing urban sprawl (Alias et al. 2011; Fulton 1996). It advocates design-based approaches using traditional urban forms to help mitigate suburban sprawl and inner city decline in rebuilding developments for cities (Bohl 2000; Alias et al. 2011).

In a study by Alias et al. (2011) of the level of awareness of New Urbanism in Malaysia, the respondents from the development companies were not aware or well-informed of 'New Urbanism' in the first instance, however, they reckoned that the concept was not alien to the local context. They observed that the idea of emphasising the design concept such as addressing certain aspects of sustainability and ecological issues by providing large reserves of green area, water features, self-sufficient or compact inner-city neighbourhoods with complete facilities and amenities have been very much advertised by the reputable developers in the country, hence, is not a new phenomenon (Alias et al. 2011). Furthermore, this new approach is to mitigate the negative impact from the development during 1980 till 2000 to the urban community in KL as described in Fig. 1.3.

2.2 *Kuala Lumpur as 'A World Class City'*

In the 1990s, global financial capitals began spreading across the Asia-Pacific region. Major cities including Kuala Lumpur began to experience fundamental restructuring of their built environments to reconstitute the urban core for global management and service functions in the form of mega projects aimed at intentionally creating world class cities (Douglas et al. 2008). According to Douglas et al. (2008), as cities are the principle bases for foreign direct investment, both national and local authorities have been fully engaged in the business of attracting transnational capital to the city. It is hoped that these investments will build up the urban economy and bring about an increase in demand for the city's workforce, and in turn create an enlarged market for local businesses. Kuala Lumpur has welcomed these developments in the global economy, on the assumption that they will open local economies and intensify global investment (Bunnell et al. 2002).

Bunnell et al. (2002) state that the 'world class' urban investment in Kuala Lumpur city was increasingly understood as part of a national agenda to 'plug in' to global political, economic and social networks. Douglas et al. (2008) suggested that the increased involvement of different capital circuits implies the pull of cities towards world city formation and this is reflected in the built environment via new commercial spaces of production (such as business districts, techno parks and science parks) and consumption (such as shopping malls).

As the globalising process went on, in 1991, Dr. Mahathir Mohamad, the Malaysian Prime Minister at the time, launched a 'Vision 2020' or 'Wawasan 2020', a national vision aimed at transforming Malaysia into a fully developed nation by the year 2020 (CHKL 2004). The vision, articulated in the document 'Kuala Lumpur—A World Class City', encapsulated the ambition to make a city that would assume a major global role, for the benefit of all its inhabitants, workers, visitors and

Table 1.1 The five goals identified to achieve the vision of a world class city in the Kuala Lumpur Structure Plan (KLSP) 2020

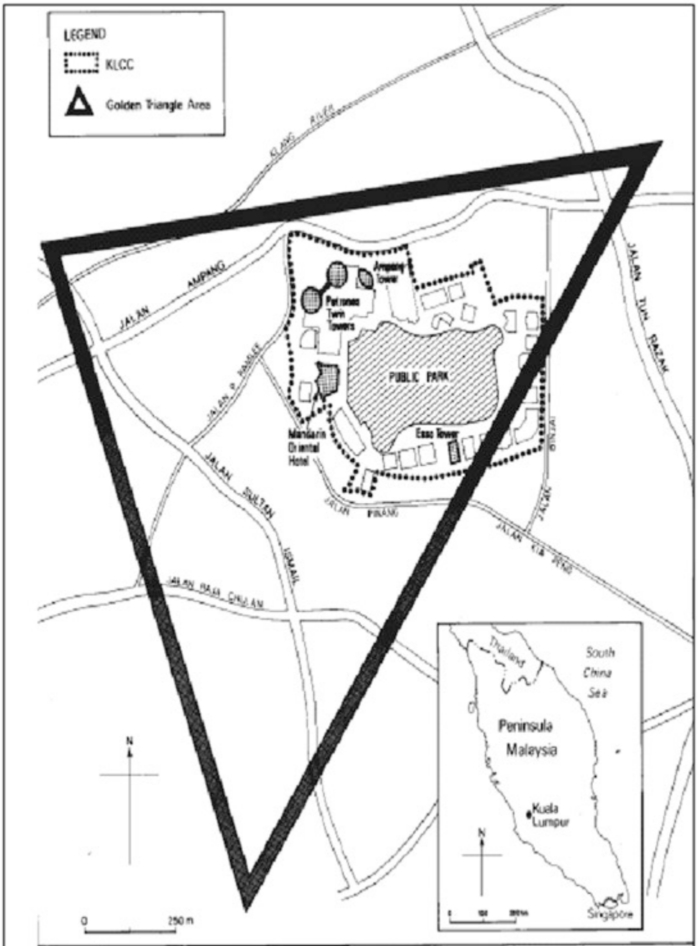
The goals	Description
Goal 1: To enhance the role of Kuala Lumpur as an international commercial and financial centre	Kuala Lumpur city to be effectively competitive with other cities in Asia-Pacific Region such as Bangkok, Singapore, Jakarta and Manila by maintaining a favoured position within the global economy for the benefit of all its inhabitants, workers, visitors and investors (CHKL 2004)
Goal 2: To create an efficient and equitable city structure	Kuala Lumpur city to have balanced development without compromising societal needs or adversely affecting the existing natural and built environment (CHKL 2004)
	It is therefore essential for Kuala Lumpur city to have good transportation and communication linkages within the city, country and the world. This is to ensure that all citizens are able to access infrastructure, utilities and facilities that are equitably distributed (KLCH 2004)
Goal 3: To enhance the city's living environment	Kuala Lumpur to establish the highest quality living, working and business environment with easy access to all facilities, as well as a healthy, safe and lively environment, so those who work and live in the city can enjoy the best possible quality of life (KLCH 2004)
Goal 4: To create a distinctive city identity and image	Kuala Lumpur to have its own distinctive identity which reflects the tropical climate and multiethnic population. It is expected to be manifested in the built and natural environment and the everyday way of life of the city's inhabitants as well as the various forms of cultural expression
Goal 5: To have efficient and effective governance	Kuala Lumpur to encompass good governance in meeting the goals, strategies and policies set out in the Habitat Agenda–transparent, responsible, accountable, effective and efficient administrative practices

investors. According to Vision 2020, Kuala Lumpur will strive to establish the highest standard of quality living, working and business environments, benchmarked against the best in the world (KLCH 2004). This was seen as necessary as it was believed that the developed city will be able to attract and retain national and international investors as well as skilled and professional workers, both local and foreign (KLCH 2004). In addition to the ambition to create a world class city, the government believed that it is important to ensure that the infrastructure, environment, city management, cultural, social and community facilities meet the highest expectations of the majority of its residents, workers, visitors and investors (KLCH 2004; Douglas et al. 2008). Five goals were identified in order to achieve the Kuala Lumpur Structure Plan 2020, as listed in Table 1.1 below.

In order to synchronise with the city's global aspirations of becoming 'A World Class City', two mega projects were undertaken at the beginning of the 1990s: the Kuala Lumpur City Centre (KLCC) and the Kuala Lumpur International Airport (KLIA). The two were subsequently followed by other equally important developments such as Putrajaya as a Federal Government Administrative Centre. They are discussed in the following section.

2.3 Living in KLCC International Zone: ‘City-Within-a-City’

The largest project undertaken to create a world class city was the Kuala Lumpur City Centre (KLCC) International Zone, built in 1992 on the site of the former colonial race course off Jalan Ampang. The project was located in the north-eastward expansion of the Golden Triangle Area (GTA) commercial district (Fig. 1.4). This mega project conceptualised a ‘City-within-a-City’ (KLCC Holdings Sdn. Bhd., circa. 1996a), which was proclaimed by the former Prime Minister Mahathir Mohamad as ‘among



Source: KLCC Holdings Sdn. Bhd. (*circa*. 1996b) *Kuala Lumpur City Centre*. Marketing brochure, np.

Fig. 1.4 The mega project of Kuala Lumpur City Centre (KLCC) in the marked boundary of the Golden Triangle Area (KLCC Marketing brochure 1996b)

Fig. 1.5 The Petronas Twin Towers, designed by Cesar Pelli and associates and completed in 1996 (The Aga Khan Award for Architecture On site Review Report, 2004)

the largest real estate in the world'. As cited in Bunnell (1999), the KLCC project may be understood in terms of regional economic change and was one among a myriad of 'Urban Mega projects' and considered to be economically 'miraculous' in the Asia-Pacific region.

The development of this 'City-within-a-City' included the Petronas Twin Towers which was the tallest building in the world up to the end of the second millennium. Its construction was part of the greatest boom in sky-scraper construction in history, led largely by rapidly urbanising societies in Asia.

The Petronas Towers formed part of a larger development project and was named after the state oil company whose new headquarters occupied one half of the building. The building consisted of two identical towers 452 m in height and joined by a sky-bridge at the 41st and 42nd floors (see Fig. 1.5). In addition to the Petronas Towers, phase 1 of the Twin Tower included a Concert Hall accommodating the newly created Malaysian Philharmonic Orchestra; a luxury hotel, the Mandarin Oriental; two other office blocks such as Ampang Tower and Esso Tower; and a 50-acre 'public park' (Bunnel and Nah 2004) (Fig. 1.5). Phase 2 of KLCC International Zone concentrates on the mixed-use urban living residential towers such as Troika Residence and Binjai Condo (Fig. 1.6).

Fig. 1.6 The KLCC master plan planned the area as an integrated mixed-use development where the public can work, live, visit, shop, and enjoys leisure time and cultural activities in a convenient and pleasant environment (KLCC Property Holdings Berhad (KLCCP) 2010)

3 Mixed-Use Development Criteria in Kuala Lumpur City Centre International Zone

The qualities that have been identified in the KLCC International Zone are discussed.

3.1 Variety of Uses

Urban areas are capable of accommodating a variety of primary and secondary uses or activities. The most significant criteria for the establishment of a mixed-use development is that the district must be multifunctional, that is, integrated with more than a single primary use in one place. Examples of these activities would include commercial, industrial, and residential uses. Jacob in 1965 made a similar argument in her book, *The Death and Life of Great American Cities* that an environment containing a number of primary functions will invite people outdoors at different times for different purposes while using a variety of facilities at the same time (Jacob 1992). This simultaneously creates a variety of choice of activities and experiences for users generated by a mix of compatible uses in close proximity (Bentley et al. 1985).

However, variety cannot be achieved by a random amalgamation of activities on a site but rather a variety of uses that mutually support each other (Bentley et al. 1985). Some activities act as magnets attracting people to the site. Everyone has to go home and go to work hence concentrations of dwellings and workplaces are primary uses of spaces in the cities. Unlike primary functions in a development with a variety of uses, secondary uses are enterprises which lack pulling power to attract people, but they become functional by people drawn to the place by the primary uses (Bentley et al. 1985: 30).

Time is also an important element in the system of mutual support. It is not only necessary for secondary uses to be sustained by their associate primary uses. These mixture of uses as illustrated with the help of images below, must keep people in the area over a long period of time because of the manner in which time is spent between work and home (see Fig. 1.7).

Fig. 1.7 Graphic representation of variety of uses such as retail, various types of eateries, offices, playground, recreation, parks and accommodation, in the sketch map of KLCC master plan

3.2 Concentration of People/Density

There has been vigorous debate over the century of what constitutes 'good' or 'bad' densities. Howard (1902) and Abercrombie (1922) responded against Victorian overcrowding by proposing the Garden Cities concept with extremely low densities. Jacobs (1992) reacted against this stating that high density stimulates a rich city life. In accordance to Jacobs's theory, opinions are changing, especially as sustainability supports close living. Though, higher density is generally considered an 'inferior' attribute in the economic sense, New Urbanism's main innovation with regard to density is to create a 'superior' asset: attractive, walkable mixed-use developments.

Density within the city's mixed-use development must be sufficient to support the variety of uses and activities. Density is a crucial factor when measuring the environmental impact of development, because it affects land consumption, stormwater runoff, automobile usage, and transit usage. Increased density also leads to economies of scale to sustain the commercial component of the development (Alias et al. 2011). In KLCC international zone, developments are significantly more compact on average than conventional suburban development and comparable in density to historic urban neighbourhoods.

3.3 Mobility and Connectivity

Within every mixed-use development, there is need for coherent movement strategies. People within the development should be connected seamlessly to their destinations by having easy access to transportation facilities. It is imperative for the district to have closely grained mixed uses, particularly with important activities that support daily life. These activities include: housing, employment, shopping, education, socialising, healthcare and recreation. They should be within a comfortable walking distance from residences catering to the less mobile populace such as the disabled, elderly, children and other marginalised s. A fine grained mix of uses further increases opportunities for marginal and part-time employment.

For a district to be permeable and accessible, all varieties of uses and activities must be within a 400 m radius creating a total distance of approximately 800 m diameter which equates to a 125 acre (50 ha) plot of land (Duany and Plater-Zyberk 1990). Understanding how places function is entirely depending on the movement flow that is connecting people to places within and surrounding the development area. People chose their desired route based on route directness, route quality, safety, comfort and enjoyment while walking (Mastura 2013). To a certain degree, pedestrians agreed on the interesting aspects of certain routes in KLCC International Zone area as they cut through markets and outlets which create a curiosity while walking (see Fig. 1.8). Pikora's finding that neighborhoods with attractive and

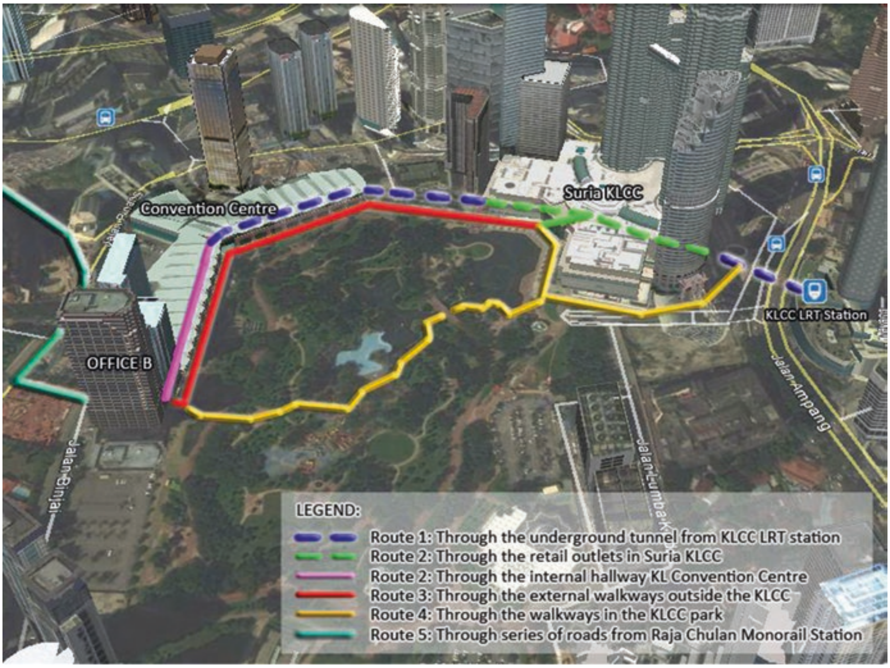


Fig. 1.8 Variety of route choices allow good experience among the community generating life and activity within the KLCC zone (Mastura 2013)

comfortable pedestrian facilities with close proximity to the local destinations such as shops and public transport are significantly associated to walking near home (Pikora et al. 2006).

3.4 Safety and Security

Safety is a critical factor in a mixed-use development. Urban centres can be considered safe if it provides streets and spaces where fear of attack or harassment is significantly reduced. Studies have suggested that homogenous residential environments exhibit lower rates of crime than areas with mixed uses (Greenberg et al. 1982; Greenberg and Rohe 1984) challenging the 'mixed use equals safety' assumption held by New Urbanists (Cozens 2008; New Urbanism 2009). The mixed use of spaces can bring activities to many parts of the city creating natural surveillance that enhances security and creates a perception of safety within the urban environment. Many of a city's safety issues are a result of separated land uses. Mixed-use developments in KLCC zone highly encourage social interaction and discourage crime with the provision of high-quality streets and squares that is safe, comfortable, and

Fig. 1.9 The view towards the KLCC parks with the map showing the greenery and scenery (Mastura 2013)

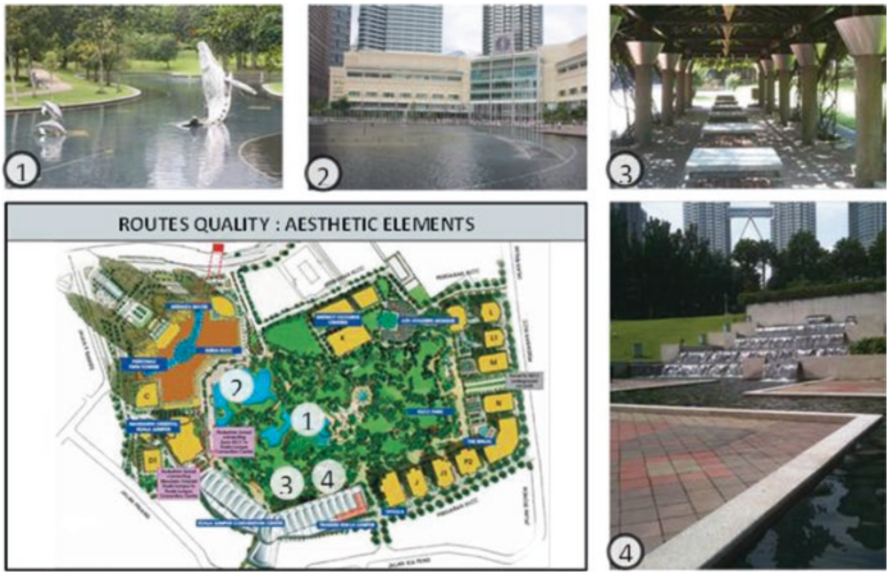


Fig. 1.10 The view towards the KLCC Park showing the softscape and hardscape for the outdoor activities for the community (Mastura 2013)

interesting to the pedestrian. Safety and security in KLCC International Zone are carefully configured to encourage the community to walking and enable neighbours to know each other and protect their communities (Figs. 1.9, 1.10).

3.5 Sustainability and Flexibility

Urban developments can be considered sustainable if resource consumption, waste and pollution are minimised and kept below in levels that are maintainable. If the mixed-use development is fine grained with highly permeable streets and compact urban forms, the area will be sustainable. The development is considered sustainable if:

1. It is designed at human scale and compact enough to accommodate walkable streets for housing areas.
2. There are robust with buildings and spaces that can change and be adapted over time to meet the emergent challenges and contribute to economic sustainability.
3. The development's design is logically distinctive, respects the local context and has a historical narrative within the urban fabric.
4. The energy and resource conservation is implemented within the built environment. For example, building materials, road construction, service infrastructure, etc. make use of environmentally efficient means to conserve resources.

3.6 Open Space and Livelihood

Open spaces are considered as integral in the master plan of KLCC International Zone that focuses to every inches of land whether enclosed or not, that is laid partly or wholly for public use as a park, sport and recreational ground, pleasure ground or walk or as a public square. The urban landscape in the middle of KLCC International Zone was planned as a focal point for the urban community from within and around the zone area to congregate in the outdoor spaces. KLCC parks attract a large volume of people who use the pathways for several reasons such as passing through to get to their workplaces, homes, or recreation areas and for fulfilling their tourist itinerary.

Open spaces that occur between compact developments serve as 'green lungs'. They remove the monotony of the concrete jungle and contribute with regard to safety, social interaction and aesthetic opportunities of the development. Furthermore, greenery is beneficial to the microclimate within the city, improving air quality and noise levels. Way-finders in KLCC International Zone are very clear and accurate, with little ambiguity, and they are placed at relevant spots throughout the area.

It appears that KLCC International Zone has embraced mixed-use development principles surmised in Table 1.2 below.

Table 1.2 Principles of mixed-use development emerged in Kuala Lumpur City Centre International Zone

Key concepts	Physical attributes
Variety of uses	A mix of shops, offices, apartments and homes on site. Mixed-use within neighbourhoods, within blocks and within buildings A range of types, sizes and prices in closer proximity Diversity of people—of ages, income levels, cultures and races
Concentration of people	More buildings, residences, shops, and services closer together for ease of walking to enable a more efficient use of services and resources, and to create a more convenient, enjoyable place to live
Mobility and connectivity	A network of high-quality trains connecting cities, towns and neighbourhoods together
	Pedestrian-friendly design that encourages a greater use of bicycles, rollerblades, scooters and walking as daily transportation
	Interconnected street grid network disperses traffic and eases walking
	A hierarchy of narrow streets, boulevards and alleys
	High-quality pedestrian network and public realm makes walking pleasurable
Safety and security	The revitalization of urban places depends on safety and security. Streets and squares should be safe, comfortable, and interesting to the pedestrian
	Properly configured, they encourage walking and enable neighbours to know each other and protect their communities
Sustainability and flexibility	Minimal environmental impact of development and its operations eco-friendly technologies, respect for ecology and value of natural systems
	Energy efficiency
	Less use of finite fuels
	More local production
	More walking less driving
	Quality architecture and urban design that focuses on beauty, aesthetics, human comfort and creating a sense of places
Open space and livelihood	Open spaces between compact developments serving as 'green lungs' Partly or wholly for public use as a park, sport and recreational ground, pleasure ground or walk or as a public square Removes monotony
	Contribute with to safety, social interaction and aesthetic opportunities of the development

Adapted from CNU (1997), Leccese and McCormick (2000); Alias et al. (2011), Mastura (2000) and A World Class City Goals (KLSP 2020)

4 New Urban Integrated Development in KLCC International Zone

4.1 An Analysis Study of Troika Residence

The vision for Kuala Lumpur Structure Plan 2020 is to transform the traditional city of Kuala Lumpur into A World Class City. Part of its development strategies that highly need to be considered is creating the KLCC inner city into a living environment that promises business and working environments with international standard of commercial and financial entertainment centre, a self-contained city complete with medium to high end residential zone (CHKL 2004). This mission is meant to attract the highest qualified expertise from both local and international citizens, to live and work in the city and to bring in the World Class City activities of international relevance and appeal to incorporating attractive living environment with high-quality facilities.

In Malaysia, people are now beginning to realise the advantages of sustainable building and are now moving towards better and more responsible development. Study on Sustainable Concept Awareness in Malaysia by Nazirah and Aini (2013) showed the active promotion of sustainable development by the government, non-governmental organisations and education institutions in the past 5 years has shown some encouraging progress in this field.

The above factors have influenced the emergence of innovative high technology building designs with latest inventions in this exclusive zone of Kuala Lumpur. Special effort has been put into each development to address the public demand and the development requirement for this new urban integrated zone (Fig. 1.11). Troika Residence is one of them, a mixed-use development of high luxury residence which was designed by Foster and Partner.

The Troika development scheme was commissioned to be managed by Foster and Partner in collaboration with GDP Architect as a co-architect in 2004 by the developer, Bandar Raya Developments Berhad (BRDB) (e-Architecture 2015). The choice of Foster + partner could effectively lead the branding of this BRDB residential scheme globally. The popularity of Foster + partner's name should endorse the image of a world class product which was not only well known as a market leader in terms of design, pricing and prestige but more of trust in bringing up the status of KLCC International Zone in achieving its goal of providing a world class high end quality residence with new style of urban living

4.2 Design Concept

As the first luxury mixed-use residential scheme in the precincts of Kuala Lumpur City Centre International Zone, Troika is located at the north-eastern corner of the KLCC Park (Fig. 1.11), within the Zone of Resident and Commercial Suites Buildings. It is encircled by HSC Medical Centre on the west, The Corinthian Residential on the north and on the east side is Jalan Binjai Residence.

Troika was built on 8600 m^2 site of KLCC prime land at the intersection of Persiaran KLCC and Jalan Binjai (Fig. 1.12). It was developed with 95,000 m^2 gross area and total floor area of 75,000 m^2 which was divided into three blocks This exclusive mixed-use residence was designed using precast concrete shear walls which framed a landscaped courtyard that linked to the KLCC Park. The shear walls were arranged as internal and external support of the three blocks. The layout planning of the three blocks was based on the result of analysing the site context and surrounding building, taking advantage of the South West green view of the KLCC Park and avoiding the traffic noise from the North East site (Fig. 1.13) (e-Architecture 2015).

Fig. 1.11 Kuala Lumpur City Centre, with Troika at the North East of KLCC Park and KL Landmarks the Twin Towers and KL Tower at the North West of the Park (Courtesy to Bandar Raya Developments Berhad (BRDB).)

Fig. 1.12 This map is showing the location of The Troika residence at the intersect of Jalan Binjai and Persiaran KLCC (Courtesy to BRDB)

Fig. 1.13 Pedestrian connecting the west to east part of the park showing direction toward Troika (Courtesy to Aaron Pocock)

Fig. 1.14 Visual linkage (Courtesy to Aaron Pocock)

This layout of twisted geometry of three sculptural towers (Fig. 1.15) is the result of a process-driven design concept that maximises the dramatic views of the KLCC Park, the KL Towers and the surrounding cityscape (Fig. 1.14). The unusual external and internal main structure, consisting of a number of slender sheer walls, supports

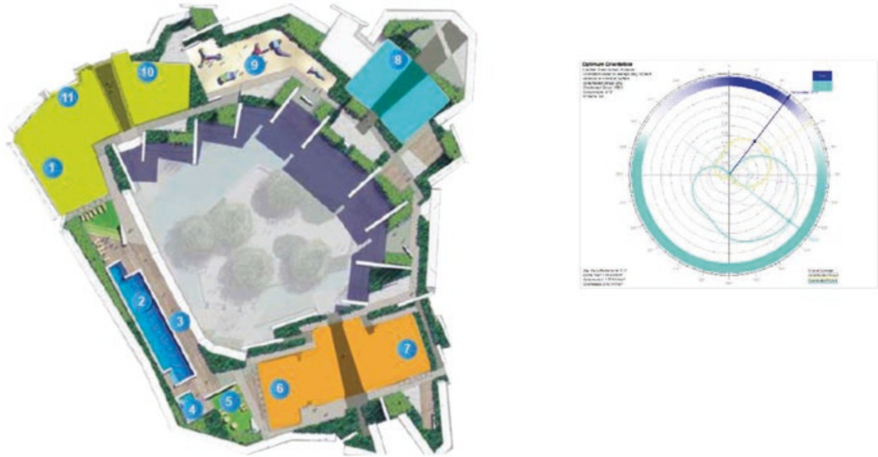


Fig. 1.15 Layout of the twisted geometry of three sculptural towers. Best orientation for Kuala Lumpur City Centre (Courtesy to BRDB)

a series of stacked blocks that sensitively rotate to frame the prime outlook for each apartment. The slim blade shear walls intelligently arranged and rotated the privately exclusive units that shade one another (Fig. 1.15).

The balcony overhangs and the massive curtain wall system applying low-E glazing were purposely implemented to control the internal heat gain.

At ground level, a 4-storey perimeter building circles a peaceful courtyard as a centre of the development and this enclosure partially opens towards the KLCC park. Shops and offices at this lower building are benefiting from the views and clean atmosphere of the landscaped courtyard, and connects the residents to KLCC Park (Fig. 1.15). This extended green provides a clear path connecting KLCC park towards the entrance of the units through the individual tower lift

The Troika incorporated three glass-clad residential towers of varying heights; the highest tower is 240 m with 50 storeys, while the other two towers are 160 m high with 38 storeys, and 177 m with 44 storeys. The three towers featured two double-volume glass-encased bridges connecting a sky lobby at the 24th floor (Fig. 1.16) with an incomparable panorama of the fast-changing Kuala Lumpur skyline (Fig. 1.17).

The three elegant towers of Troika provide 230 units of exclusive apartments including 164 various types of luxurious condominiums, 8 penthouses, 57 SOHO units of which are serviced (SOHO an acronym for Small Office Home Office). SOHO is a unit that provides the ultimate in flexibility, designed for use either as an office, an apartment or a combination of both. The tower also complemented with retail outlets, boutique offices and restaurants. It is an integrated development, a self-contained setup that tries to reflex the identity of the high end luxury new urban lifestyle in Kuala Lumpur City Centre, an exclusive one.

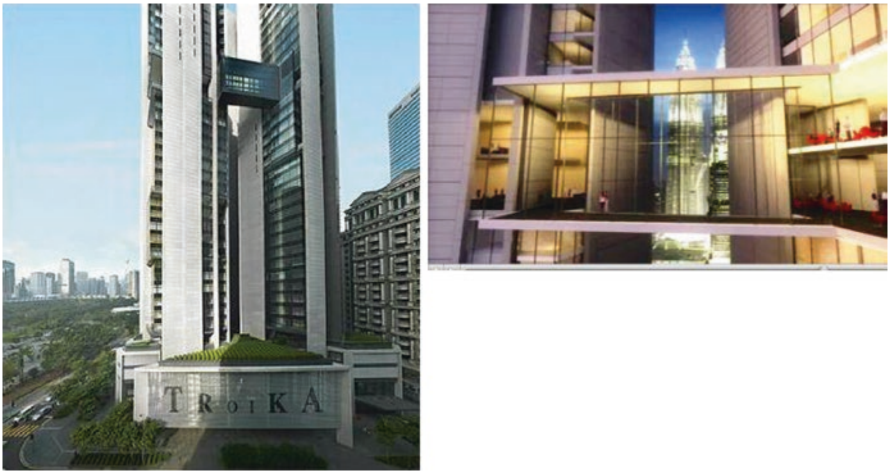


Fig. 1.16 The double-volume glass-encased bridges, an unique feature of TROIKA, with some 25,000 square feet of double-volume space spanning the three towers and connected by two sky bridges (Courtesy Aaron Pocock)

The shear walls defined the internal organisation of the apartments where the volumes grow and shrink within the sheer walls. There are 230 units, all with primary living areas focused towards the prevailing views. Many areas are self-shaded by the overhang that provides shelter to the balconies below (Fig. 1.18).

4.3 Sustainability Approach on Building Design

Layout of the twisting geometry of the towers (Fig. 1.19) which responds organically to neighbouring buildings, solar orientation, and distant views reflex a strong identity of the site. The open link courtyard is facing and connected to the KLCC Park. It created its own microclimate, where shade and wind-driven in through the landscaped courtyard naturally filtering the outdoor polluted air affected by the traffic (Fig. 1.19), tempering the excessive tropical humid and heat naturally to the apartments when the weather allows (RIBA 2012) (Figs. 1.20, 1.21, 1.22, and 1.23).

The core orientation of each tower is towards the centre east to provide 100 % space efficiency and flexibility of the layout floor planning. Furthermore the site plan showed how the three towers' blocks could be functioned as a parameter barrier to buffer the noise coming from the road site and heavy traffic of the Tun Razak highway. The intricately twisted geometric slender concrete shear walls also meant to function as vertical shading device to shade the opening that focuses towards North West orientation, it partially screens the penetration of solar radiation from coming directly into the building but providing sufficient day-lighting. The application of Low-E glass as curtain wall cladding helps in reducing the heat gain affected by the west orientation opening (Fig. 1.24).

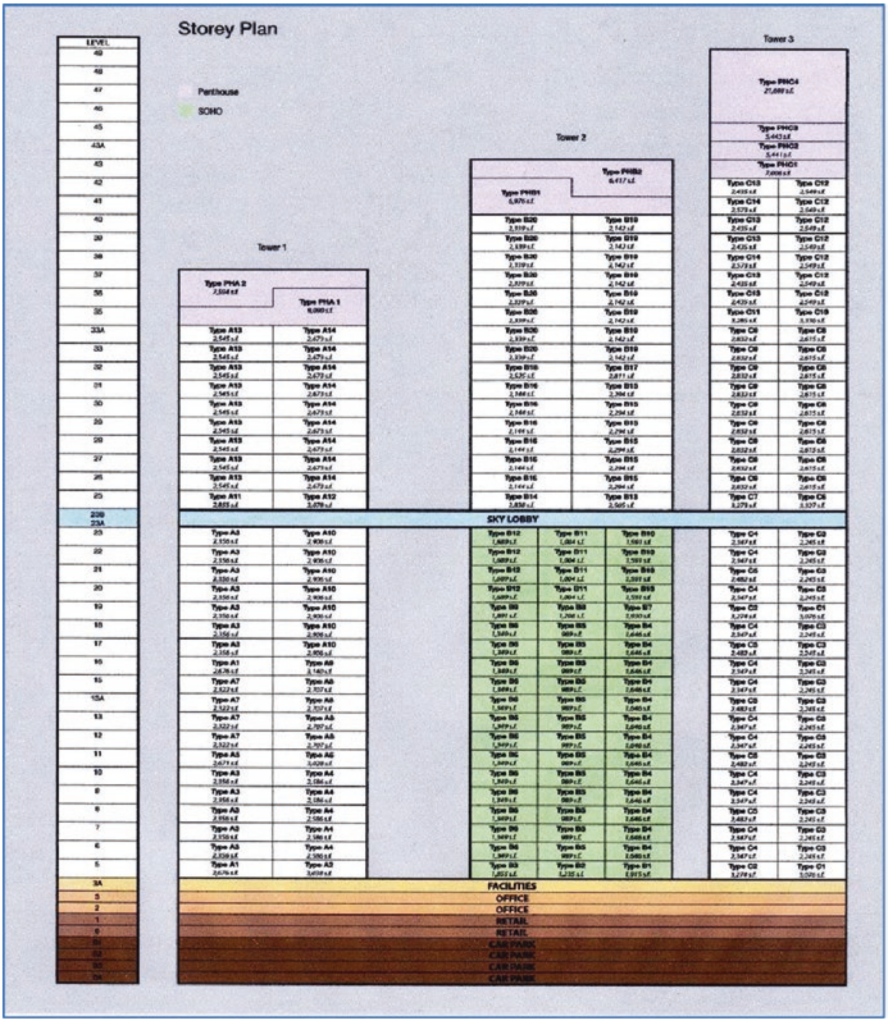


Fig. 1.17 The vertical storey plan showing the various types of unit houses in the three towers (courtesy to BRDB)

The strong character of the slim shear wall divided each floor into spaces with its own language featuring a firm statement of Troika high technology building identity. The twisted geometrical shear walls with natural finish given each space its own quality which is able to communicate with the active urban citizen as the way the lobby entrance welcomes visitors toward its own enclave and defined the space by the two shear walls. This uniqueness in the new style of urban feature design was recognised by RIBA and RIBA news (2012) that mentioned that Foster + Partner has come out with a very daring attempt to find a new functionally driven form for high-density urban living in tropical climates combining (Fig. 1.25).

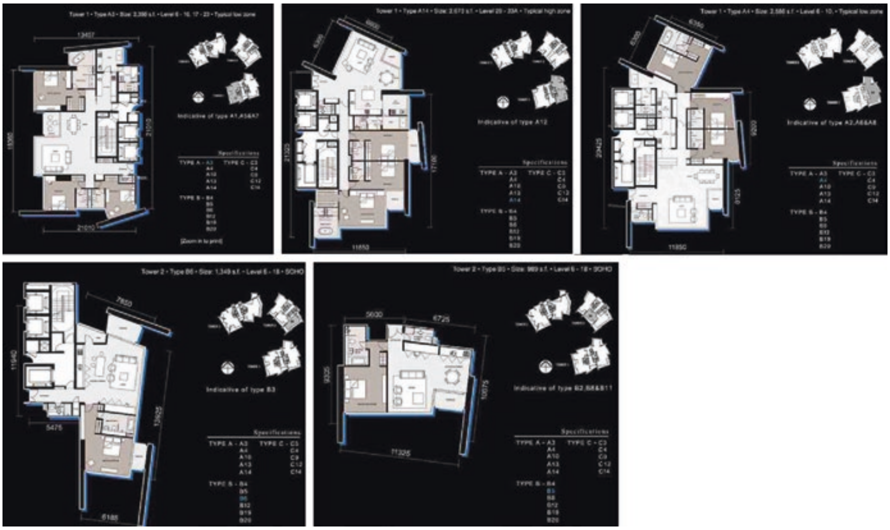


Fig. 1.18 The rotated housing of various types in block A (Courtesy to James Ong)

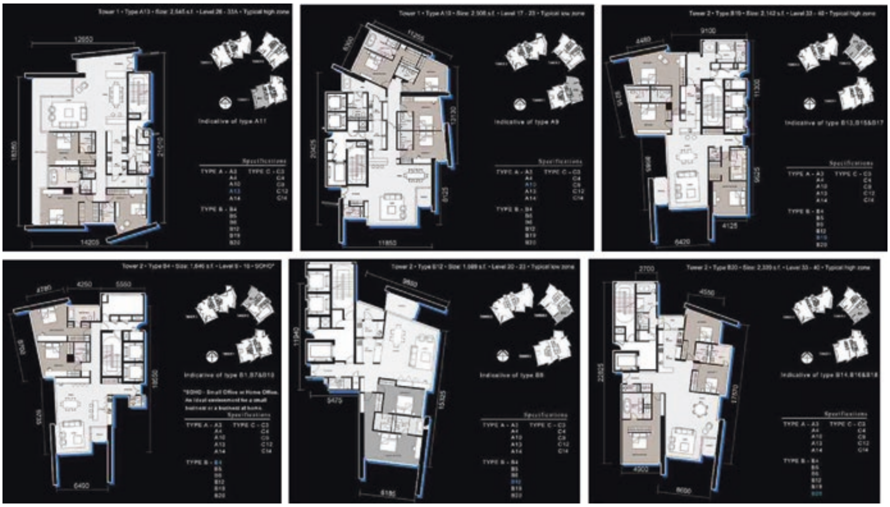


Fig. 1.19 The rotated housing of various types in block B (Courtesy to James Ong)

4.4 Innovative Structure and Construction System

Environmentally sustainable building construction in Malaysia has experienced significant growth during the past 10 years. The public is becoming more aware of the benefits of green construction. Abidin (2010) in her article Investigating the Awareness and Application of Sustainable Construction Concept by Malaysian

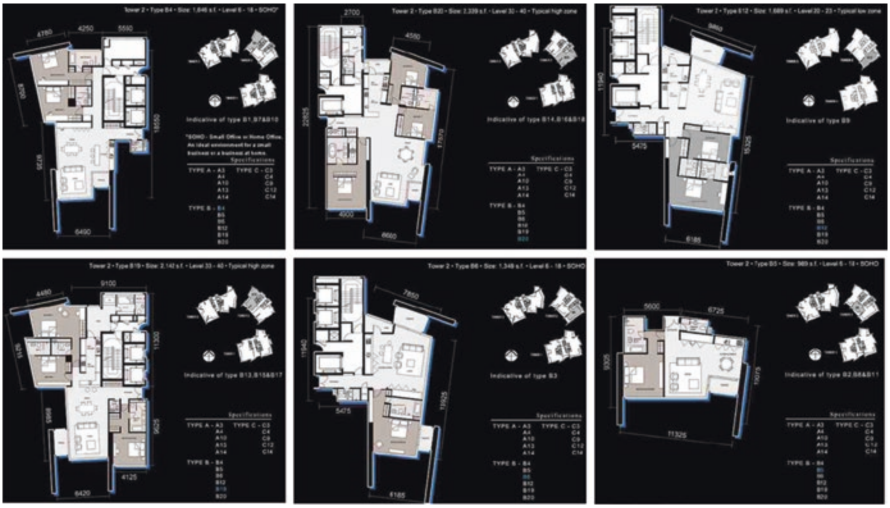


Fig. 1.20 The rotated housing of various types in block C (Courtesy to James Ong)

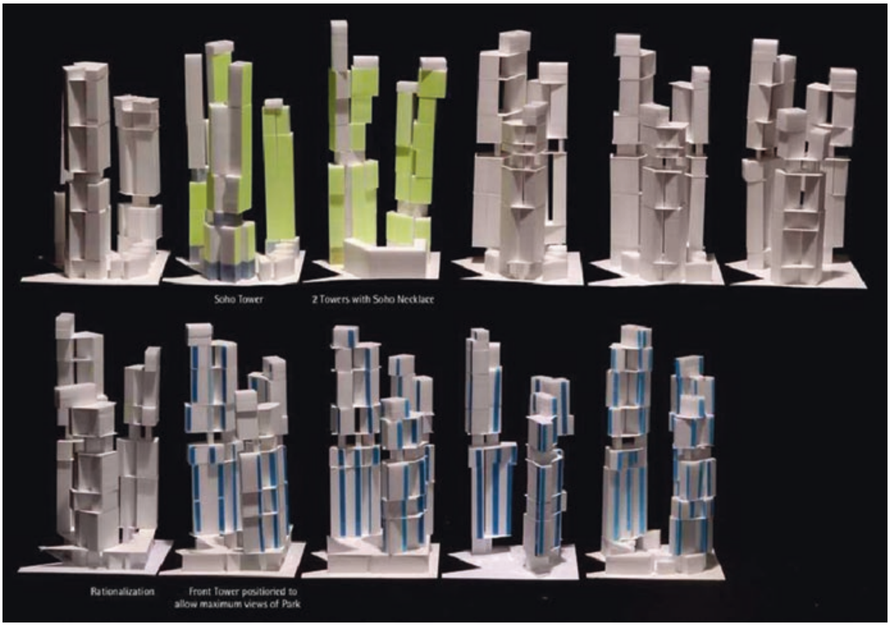


Fig. 1.21 Rationalisation on the rotation of each residential unit in providing a maximum view of KLCC Park (Courtesy to Foster + Partners)

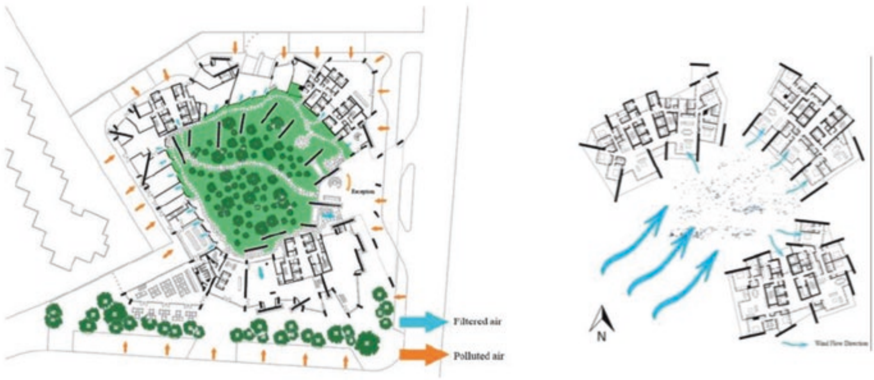


Fig. 1.22 The landscaped courtyard as natural air filter (Courtesy to Clyde Ong)

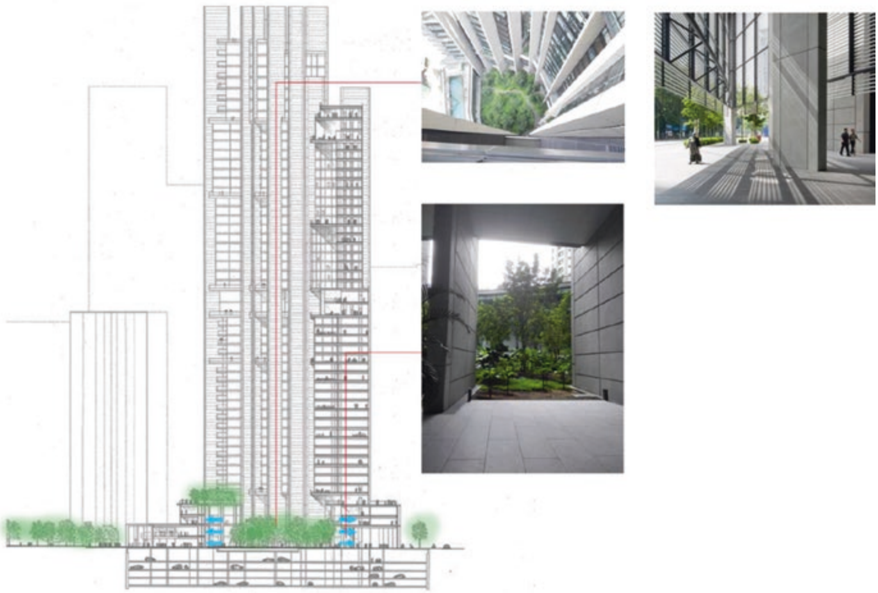


Fig. 1.23 Sectional perspective shows the green connectivity of landscaped courtyard, the park and the street entrance (Courtesy to Clyde Ong)

Developers, revealed that several large developers in Malaysia are beginning to implement the sustainable construction concept, as the large companies have the capability (capital, experience and expertise) to apply sustainable principles in their project.

As one of the strong developer companies in Malaysia, the developer of The Troika shared all the construction process challenges with the contractor of the project.

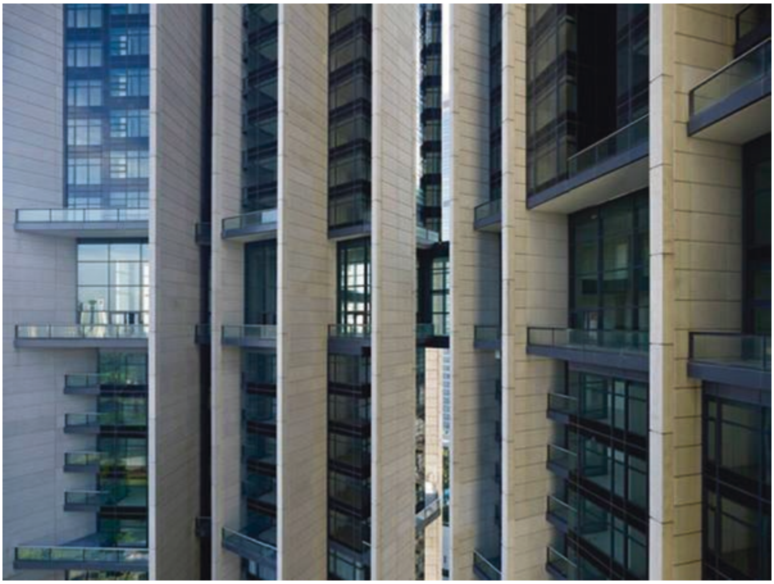
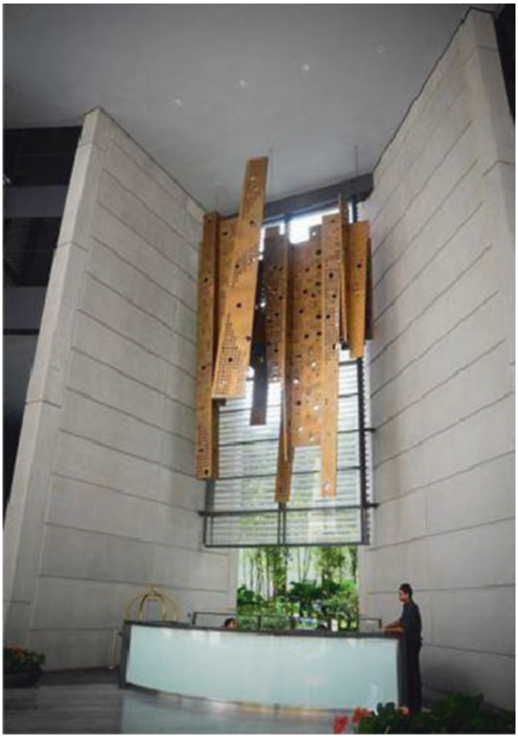


Fig. 1.24 Showing the advantage of twisted geometric external shear walls in creating privacy and shading to the residents' unit (Courtesy to Aaron Pocock)

Fig. 1.25 Counter of the entrance lobby (Courtesy to Irene Leow @ Troika KLCC)



All aspects of environmental sustainability were considered to fulfil the development requirement of providing and maintaining the high-quality environment of KLCC exclusive zone. The environmental policy and the site constrain required a well-planned project and site handling. Environmental protection during construction process was one of the very important aspects to be considered in sustainable building construction (Foong Kok 2012). The site constrains and the unusual design of the building required a well-organised construction plan and site handling started from the early planning stage.

The aim of the developer was to build the highest residential tower in KLCC International Zone. The constrains of the project site have provoked and motivated a stronger teamwork. The maximum height that concrete shear wall could reach is 200 m; the team work found an innovative way to construct a 240 m-high slender blade concrete shear wall for the tallest block of Troika Residence and set a new standard of height of 240 m for concrete shear wall.

In order to address the issue, the construction work adopted the Rail Climbing System (RCS) of construction, where the shear wall is being constructed ahead of the slabs. Only when three storeys have been completed, the slab work began. This system reduces the duration of time required per floor to seven working days (PERI 2012). To make the system work, the contractor has to work hand-in-hand with the formwork designer who suggested of applying reusable steel formwork to replace timber (Figs. 1.26 and 1.27).

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5 Conclusion

The goal of uplifting the role of Kuala Lumpur as an emerging international financial and commercial centre was achieved through the adoption of the new art of urban living as translated in the development strategy of the Kuala Lumpur City Centre Structure Plan 2020. In the structure plan, the City of Kuala Lumpur was first demarcated into zones with a variety of land-uses including the commercial, administrative, residential, heritage and open spaces. Thus, there is a need to properly connect these land uses with high consideration for the aspects of safety and security,

Fig. 1.26 The use of eco-friendly formwork, adapted VARIO system. http://www.perimalaysia.com/

comfort and pleasantness. In order to achieve this, a non-motorize transport network should be introduced throughout the development of the city centre to enhance walkability and mixed mode of transportation in meeting the sustainability goals. This is in line with the planning concept of New Urbanism that is encouraging people to walk within the Transit Oriented Development (TOD). Part of the advantages of this planning strategy will enhance commercial activities, thereby adding economic value to the public realm and curtail car dependency for going into the city. It also provides the initiatives of reducing carbon footprint in the drive for global sustainability. Although this development calls for high cost infrastructural investment measures, it is necessary in re-envisioning living standards for a better quality of life in urban areas. This is the current trend in the new art of urban living.

Similarly, the concept of the Troika Residence embedded within the Kuala Lumpur City Centre Integrated Development is an essentially self-contained approach. Troika is a part of the perimeter development surrounding the KLCC International Zone. The planning strategy serves well the concept of mixed-use integrated development and the new art of urban living. Made to spread over 2.13 acres,

Fig. 1.27 The construction of Shear walls applying Rail Climbing System (RCS). http://www.perimalaysia.com/

a two minutes' walk is achievable from the Ampang Light Rail Transit station which is approximately 250 meters away and another five minutes' walk to KLCC which is approximately 400 meters away from the Troika Residence. The Troika Residence comprises three residential towers housing a total of 172 luxury serviced apartments and 6 penthouses; 57 small office/home office (SoHo) units; retail outlets; boutique offices and restaurants. This emphasises the integrated mixed-use nature of its planning both horizontally and vertically. The planning had also centralised the landscape courtyard acting as a communal space which aimed at pulling people from within and outside the development area with the intention of increasing the level of safety and security by creating natural surveillance. Furthermore, the landscape was meant to reduce the heat effect at the pedestrian level. The use of the twisted geometric external shear wall creates privacy and provides shading to the residents units which is essential in Kuala Lumpur's tropical climate.

In conclusion, the design concept of Troika Residence was directed towards an attractive new living concept that serves to bring people towards the new art of urban living within an integrated mixed-use development. Though high investment cost applies, the overarching goal is achieved by the desire to meet sustainable international standards, efficiency, and equitable city structure which translates into the quality of life of the urban citizens in KLCC International Zone. As is demonstrated in the Troika development, this target is achievable through strategic urban master plan which needs to be sustained and balanced between nature and man-made provisions to support the green life concept for livelihood and attractiveness to the urban dwellers.

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Chapter 2
Sustainable High-Rise Buildings in the Netherlands

Wim Zeiler

1 Introduction: High Rise and Sustainability

The concept of vertical living and working has been hailed as a solution to facilitate fast growth and urbanization of cities worldwide (Drew et al. 2014). At the beginning of 2015, the global population was around 7.2 billion people (USCB 2015). In 2050, the human population will be probably more than 9 billion and 10.9 billion by the turn of the next century (United Nations 2013), 75 % of whom will be living in cities (Hargrave 2013). Tall buildings can address many of the environmental issues facing cities by providing high-density, efficient buildings that link to public transportation systems and offer the type of amenities demanded by tenants (Wood 2013). As city living takes center stage, urban building of the future have to foster sustainable qualities, essentially functioning as a living organism and engaging with the users within. Cities throughout the world are growing rapidly, creating unprecedented pressure on material and energy resources. Cities with their financial and administrative centers are a key asset to the countries' national economy and to the cities itself. The local authorities want in order to assure the city's dynamism ideal conditions for business to operate (Plank et al. 2002). To do so, the local authorities need to assure that the demand for office space can be met within the center of economical activities. In this context, tall office buildings are becoming increasingly necessary as a result of the efficient use that they make of the limited land available. Besides the focus on offices, more and more focus is also on mixed use of the tall buildings, where the offices are combined hotels, shops, and apartments. Some of the new tall buildings become almost a city on their own. The buildings need to help to optimize city-wide production, storage, and consumption of everything from food and energy to water (Hargrave 2013). As in large cities, almost three quarters

W. Zeiler (✉)
TU Eindhoven, Eindhoven, Netherlands
e-mail: w.zeiler@bwk.tue.nl

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of their energy consumption is in buildings; this will be one of the main concerns (Plank et al. 2002). The most intensive use of energy of state-of-the-art high-rise buildings usually results from the cooling (40 %) or heating (30 %) of space, while lifts use about 5 % of a tall building's energy and lighting and electrical appliance can make up about 25 % (Plank et al. 2002). Careful building services design can minimize the need for heating and cooling throughout the year for example by applying seasonal thermal energy storage.

2 Historic Development and Specific Dutch Situation of High-Rise Buildings

High rise had become possible at the end of the nineteenth century due to several technical finds and improvements in building techniques. Steel and armed concrete simplified high rise and the introduction of the elevator safety braking system in 1853 made high rise practically useful (ASHRAE 2011). Due to the population and economic growth in cities, taller buildings became very popular. ASHRAE Technical Committee TC 9.12, Tall Buildings, defines a tall building as one whose height is greater than 91 m. The Council on Tall Buildings and Urban Habitat defines a tall building as one in which the height strongly influences planning, design, or use (ASHRAE 2011).

Although the Netherlands is a rather highly dense populated country, with around 16.5 million people on an area of around 200 by 350 km with 40 % water, it has not real big cities. The biggest cities are Amsterdam and Rotterdam with both less than a million, however especially in the western part of the country all cities are more or less connected to each other. There is no free unused spTace left. Especially in the big cities there is now a trend towards higher buildings although the Netherlands have no real tradition on this. Although, in 1897 the first skyscraper in Europe was built, the White House, 42 m high was built in Rotterdam, see Fig. 2.1. As most of the country is below sea level, protected by the dykes, the soil is often of clay and sand, not the most stable underground to build high-rise buildings on.

The high-rise record for a Dutch office building went next to the 64 m tall GEB building in 1931 in Rotterdam. Only in 1969 this was taken over by the medical faculty of the Erasmus MC which was 114 m. Then in 1982, established high-rise foundation and Rem Koolhaas praise of high rise in Delirious New York were a major stimulation of high-rise buildings in the Netherlands and especially in Rotterdam. From 1986 a large amount of high office buildings were realized in the city center. Since 1991 for quite a long period the record of tallest building in the Netherlands was held by the head office of the Nationale Nederlanden with its 151 m (Architecture in Rotterdam 2014). This was taken over by the Maas Tower (165 m) the highest building in the Netherlands, see Fig. 2.2.

Internationally seen the Rotterdam Skyscrapers are but small ones. Even in 1931 New York already had set the trend with its 381 m high Empire State Building. In the

Fig. 2.1 The White House—Rotterdam 1897 (Rijksmonumenten 2015)

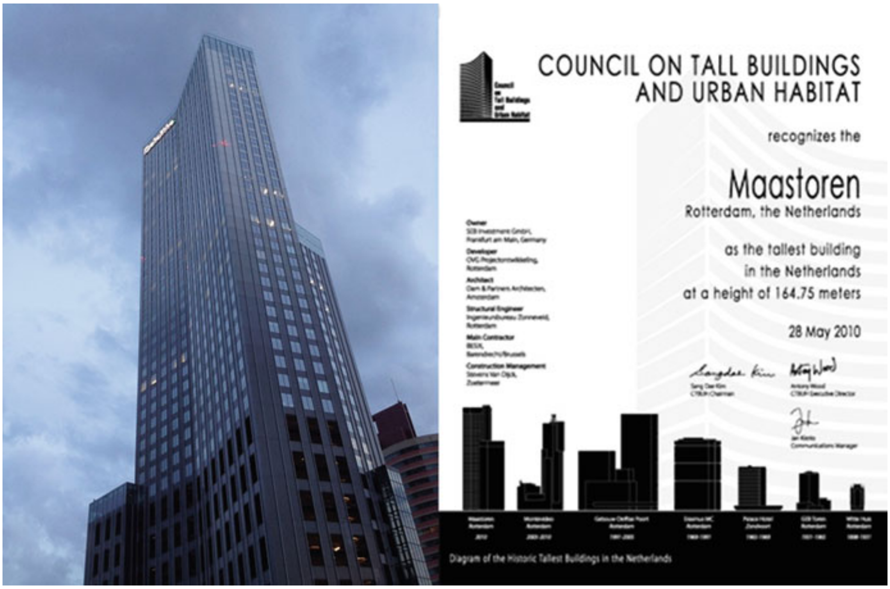

Fig. 2.2 Maas Tower Rotterdam, tallest building in the Netherlands

last decades, the sky seems to be the limit with Asia leading the way in extreme high rise with the Petronas Towers in Kuala Lumpur (450 m), the Taipei 101 (508 m) and the Burj Dubai (818 m) in the United Arab Emirates. The statistics of tall buildings are available at www.skyscraperpage.com.

3 Tallest Dutch Building: The Maas Tower

Maas Tower is a 44-storey office skyscraper complex designed by Odile Decq Benoit Cornette in cooperation with Dam & Partners. Construction started in October 2006 and on 9th December 2009 it was finished. Next to being the tallest building in the Netherlands, the Maas Tower also has some interesting notable sustainable features. The water of the River Maas is used, together with aquifer thermal energy storage (ATES) underground wells in the soil, for the thermal energy storage. The basic principle of an ATES-system is the extraction and injection of ground water into two separate storage wells, located a sufficient distance apart from each other. During summertime, water is extracted from the coldest well and used to cool the building. This heats the water from approx. 8–16 °C. The heated water is injected at the warm well and stored until the winter season. During winter the extraction/injection flow is inversed and the heated water (with a temperature of approx. 14 °C) is pumped back to the building. Using a heat pump the heat is extracted from the water and the cold water (6 °C) will be injected in the cold well. This means that district heating is not required and CO_2 emissions for the building are virtually halved when compared to a conventional design. The ATES-system of the Maas tower in Rotterdam uses a monovalent heat pump system and combines aquifer thermal energy storage and use of water from the nearby river Maas. The water of the river is led past a heat exchanger which is connected to the building's climate control system. In this way, the building can "absorb" the warmth which is still present in the river in the autumn because due to industrial residual heat the average temperature of the river water is still above 20 °C. As the river water strongly cools down in winter a possibility was created to store the summer heat. At a depth of around 150 m two wells were drilled for a doublet aquifer. One well contains the water which is warmed up during summer, while the other contains water which is cooled down to about 6 °C (Beerda 2008). During winter time, when the river water is too cold to heat the office building, the system pumps up water from the warm well and after extracting the heat it is cooled down and stored in the cold well, see Fig. 2.3.

In the warm months, the exact opposite is done. During the first warm months of a year, river water is being used, which is still cold enough at that time to cool the building (Beerda 2008). If the river temperature rises too much, water of the cold well is extracted. Energy storage in underground is not a new concept, but combining it with the use of river water made it a novelty. It is especially interesting to Rotterdam and some other cities in the Netherlands as there are many rivers and in the past often cities were initiated nearby rivers. In this way cities making use of

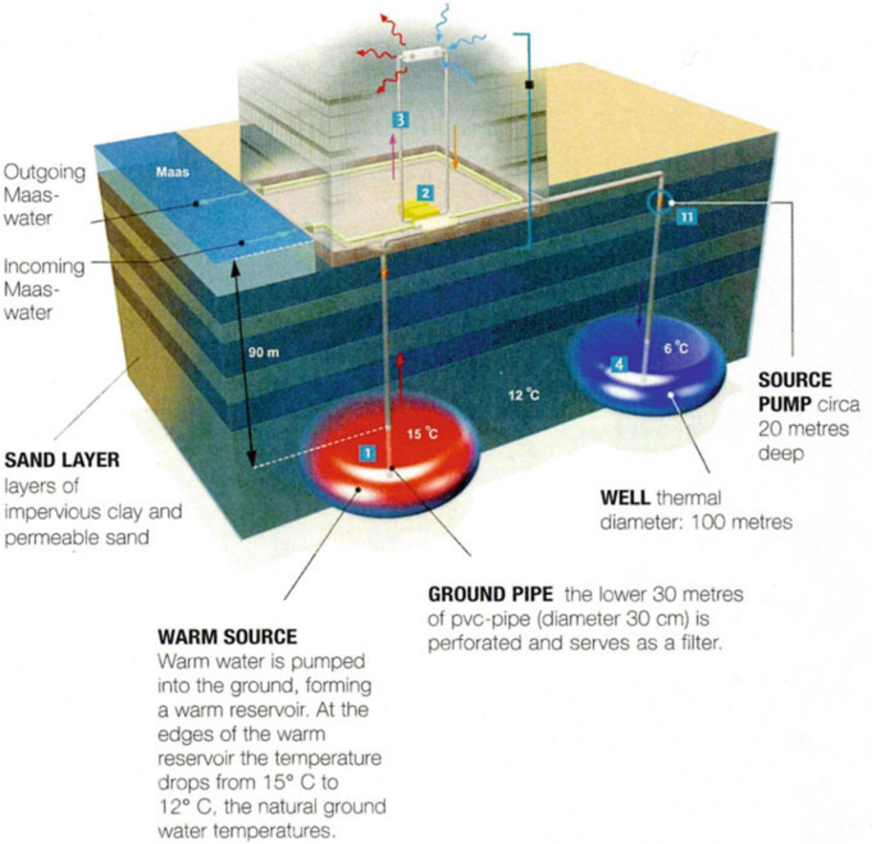

Fig. 2.3 Aquifer thermal energy storage system in combination with energy exchange with the water from the river Maas (Beerda 2008)

river water become energetic more economical, the ATES-system in these cases uses about 55 % less primary energy and their CO_2 emissions become half. The ATES-system of the Maas Tower was simulated and the results were validated by on-site measurements (Molenaar 2011). The results showed a seasonal performance factor (SPF) for supplying heat by the heat pump of approximately 3.8. This is slightly higher than the expected value of the SPF of 3.6 based on literature. Measurements showed that the heat pumps use approximately 78 % of the total electricity use of the complete ATES-system; the (transport and source) pumps use the other 22 % energy.

The SPF of 47 for supplying cooling is high compared to the values from literature with an SPF between 12 and 50 (Molenaar 2011). The Annual Performance Factor (APF) of the ATES-system for the year 2010 is 5.0. However considering the large amount of additional stored cooling the real APF is approximately 6.0. The usage of surface water (water of the river Maas) in combination with ground storage and heat pumps leads to advantages in four aspects (Molenaar 2011):

1. Maas water can be used as regenerator. Maas water can approximately be used during 3.270 h annually for the regeneration of heat and approximately 1.900 h annually for the regeneration of cold.
2. Maas water can be used to increase the temperature difference between the warm and cold well. By putting the Maas water system in sequence with the heat pump, the well water can be extra cooled in the winter and in the summer the well water can be extra heated. In theory this alignment leads to a reduction of the water displacement leading to a reduction of the electrical use of 3.5 %.
3. Maas water can be used as a direct energy source in midseason Maas water can approximately be used 5440 h annually as a heat source to the heat pump and it can approximately be used 3000 h annually for direct cooling supply. Using Maas water as a direct energy source hardly improves the energy efficiency; average of 1 % energy reduction.
4. Maas water can be used as backup for the wells of the aquifer Maas water and can also approximately be used 5440 h annually as backup by failure of and/or maintenance on the ground wells (as heat or cold source for the heat pump). Adding surface water to an ATES-system improves the efficiency (on average by 3.9 %) because common problems of ATES, such as a low-temperature difference between the warm and cold source, exceeding the design water displacement and an disturbed energy imbalance in the underground can be reduced or even solved.

The Maas Tower consequently has unprecedentedly low CO_2 emissions for a high-rise building. It is an iconic Dutch project for "building with water" and an undoubtedly strong statement as it towers over the water (OVG 2014a). Techniplan Adviseurs, the consulting engineering company who did the HVAC design, won the Innovation award of the Dutch consulting engineers association for the system's design. "The Maas Tower is a monument in the making and far ahead of its time" according to the jury of the prestigious FGH Real Estate Award when the building won this award. The building is much more than just tall. It is a perfect example of optimum integration into an urban environment.

4 The Biggest Building of the Netherlands: De Rotterdam

When your ambitions are greater than the available space you have two options: adapt either your ambitions, or the space. Architect Rem Koolhaas managed to add a third option: turn the city upside down. Or rather: stack it… (OVG 2014b). In order to accommodate all the cities of Rotterdam's massive plans Koolhaas' OMA Architecten designed an entire district with apartments, hotel, entertainment and leisure amenities, and offices. He then lifted the whole plan up and stacked it on top of each other: Literally a vertical city. Upon completion, De Rotterdam became the largest building

Fig. 2.4 Mixed-used towers of the vertical city concept of De Rotterdam

in the Netherlands at 162,000 m^2 of area and 149 m height. Its mass is broken down by three interconnected mixed-use towers, accommodating offices, apartments, a hotel, conference facilities, shops, restaurants, and cafes. De Rotterdam is an exercise in formal interpretation that is at once reminiscent of an imported mid-century American skyscraper, but epitomizes the off-center experimentalism of modern Dutch art of the foregoing century. Through De Rotterdam, which is the Netherlands' biggest construction project, OMA/Rem Koolhaas has developed the country's first vertical city, see Fig. 2.4.

It took 10 years to develop the building and is a good example of art out of creating space in high places in a country where ground-level square meters are seriously limited.

Koolhaas: "De Rotterdam is a persuasive design. Its fascination comes from the fact that, despite being an undoubtedly large building, it's actually formed of small parts that come together to form an exciting whole. This is in contrast to so many other buildings in Rotterdam that are just singular entities. De Rotterdam has an ambitious agenda: to be a residential building, a place of work, a recreation center and a hotel. For every component, we looked at how its circumstances, situation, and views could be best utilized. As a result, every part has a different character."

Everyday, 3000–4000 people will put De Rotterdam to full-time use: Through living in 240 apartments spread over 35,000 m^2; through working in 60,000 m^2 of office space; through using a four-star hotel whose 285 rooms occupy 19,000 m^2; through parking in a secure 25,000 m^2 garage with spaces for 684 cars; and through making use of 3500 m^2 of conference rooms, shops, restaurants, and cafés. In short, it's a building full of international appeal: in De Rotterdam sustainability is given the rightful attention while providing residents with comfort. In partnership with

Fig. 2.5 Under-floor heating/cooling of the apartments of De Rotterdam

Eneco, a sustainable energy supply concept was developed to equip the 44-floors apartments with under-floor heating and cooling by generating heat and cold from existing sources through heat pumps. The system allows high temperature cooling and low temperature heating because of the big active surface areas of exchanging energy within the rooms. The under-floor heating and cooling system makes use for cooling of cold water from the Maas, see Fig. 2.5.

The interior temperature of every room is controlled by its own thermostat and high performance. Heat-reflective double-glazing and windows to let fresh air inside reduce the cooling demand. The energy concept of De Rotterdam, see Fig. 2.6, is a high complex mixture of different elements combined with heat/power installation of the local City heating system, partly co-generation with biofuel, river Maas water cooling (Fig. 2.7), Aquifer thermal energy storage, and heat pumps.

5 Discussion Energy Performance of the High-Rise Buildings

In 2010 the European Commission launched the Energy Performance on Building Directive (EPBD) with the main targets to reduce CO_2 emissions with 90 % compared to 1990. It is specified that by 31st December 2020 all new buildings shall be nearly zero-energy buildings. Governmental buildings occupied and owned by public authorities, will have to be nZEB by 31st December 2018 according to the EPBD recast. The EPBD requires all newly build buildings to be nZEB in 2020 for different building functions. Existing buildings will also have to comply with this regulation towards 2050. Each European Member State (MS) has to work out a plan that includes an nZEB definition for different building functions, determining specific

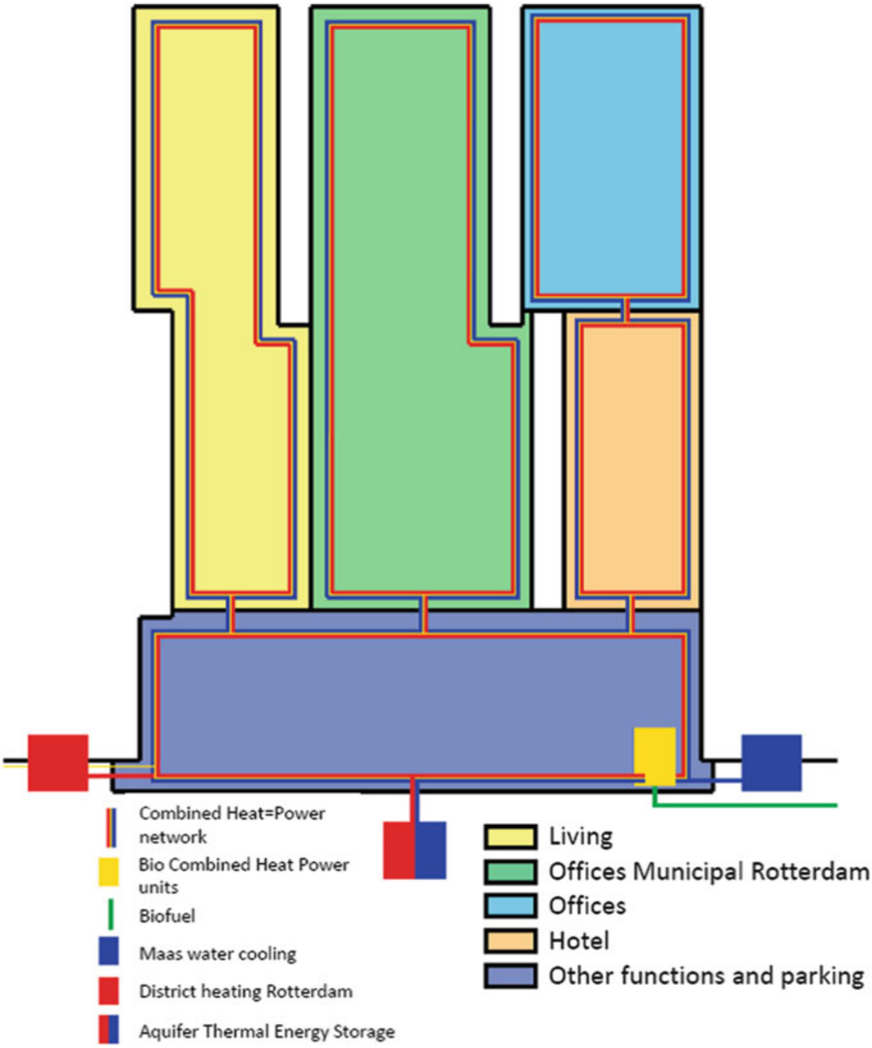

Fig. 2.6 Total energy system of De Rotterdam

building requirements. The definition of a nZEB is described within the EPBD recast in Article 9: "Technical and reasonably achievable national energy use of >0 kWh/(m^{2}a) but no more than a national limit value of non-renewable primary energy, achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal."

In the Netherlands performance is indicated by the Energy Performance Coefficient (EPC) which is described in the NEN 7120 norm. Currently, the EPC is 0.6 for residential buildings and will be lowered to 0.4 in 2015 according to a covenant of the new buildings sector, aimed at reducing the energy consumption of new

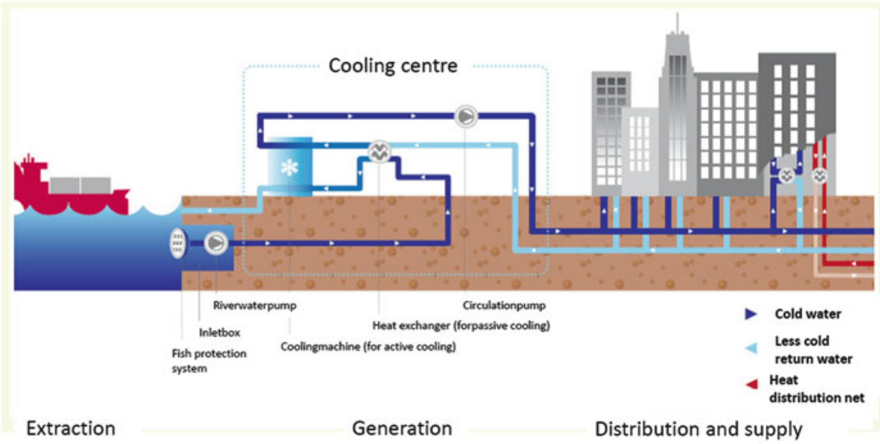

Fig. 2.7 Energy concept of the heating and cooling supply of De Rotterdam

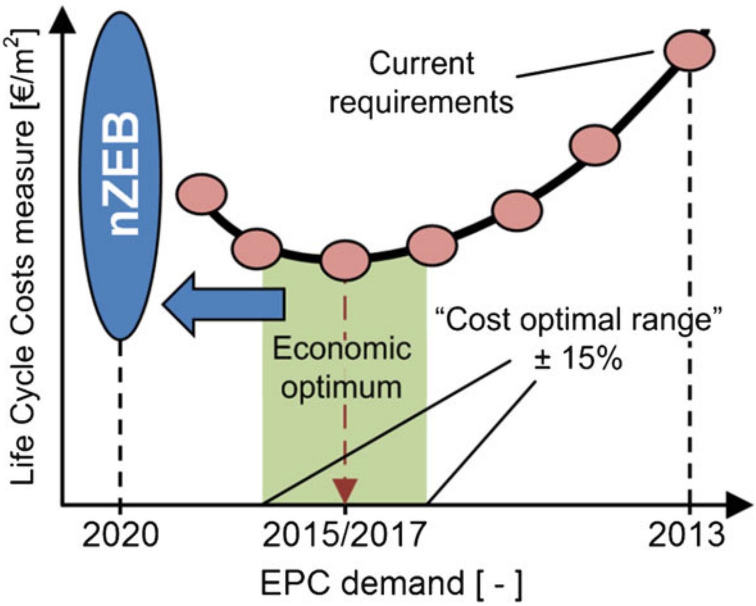

Fig. 2.8 Life cycle costs versus the EPC demand (Gvozdenović 2014)

buildings over time. In this signed agreement between the public and private sectors, a number of efforts have been agreed to reduce the energy use of new buildings by the year 2015 by at least 50 % compared to 2007 levels.

Cost-optimality Life Cycle Cost (LCC) calculations are essential for determining the Dutch nZEB definition, as they determine if the energy-efficient measures are cost effective and can be implemented in the building law. In the near future, EPC requirements will be reduced to values that lay within the “Cost optimal range,” see Fig. 2.8 (grey area), determined by calculating the LCC over a period of 30 years. In 2020 buildings will have to be nZEBs (blue area in Fig. 2.8). Current calculations show that nZEBs will result in much higher LCC values than the economic optimum. Therefore, an LCC method which also takes additional gains (e.g., productivity, resale value) into account is proposed. Effectively including these gains leads to lower total life cycle costs and the economic optimum shifts towards nZEB requirements (blue arrow in Fig. 2.8). Focusing on gains and including these in the LCC calculation method is an important foundation for the Roadmap towards nZEBs.

The cost-optimality is a crucial aspect for the introduction of nZEBs in the Netherlands. The special power generation of the Maas Tower as well as the collective power generation system of de Rotterdam ensures a substantial improvement in all areas compared to the requirements of the current Building Regulations. As a result, the EPC of the Maas Tower is 0.98 or 35 % less than the current Building Regulations. The EPC of the mixed-used sections of the Rotterdam are:

– Apartments 0.55 (31 % less than Building Regulations)
– Hotel 0.93 (7 % less than Building Regulations)
– Offices Mid Tower 0.82 (18 % less than Building Regulations)
– Offices East Tower 0.77 (23 % less than Building Regulations)

Although we are still far from an EPC of zero, it shows that high-rise buildings can perform almost equal to normal tall office buildings. Drew et al. (Drew et al. 2014) performed a study towards the environmental performance of different housing typologies ranging from a 215-storey supertall building to single family residences, including several scales in between (123, 58, 34, 16, courtyard, 3-flat, urban house and suburban house). They concluded that taking into account the operational and potential carbon offsets through on-site energy generation, the communities that perform best overall are the high-rise buildings (58 and 34 storey) with the taller buildings performing best. This shows the possible benefits of vertical communities (Drew et al. 2014).

6 Possible Future Solutions

The Netherlands, as a densely populated country, combined with high standards of living had always to (and knows how to) mold the natural environment to suit its needs (MVDRV 2015). Time and time again more land was won from the sea. Perhaps in the near future extra space will be found not just by increasing the country’s width but by expanding vertically. Architectural office MVRDR raised questions of global significance when designing their plan for the 2000 Hannover World expo fair: Can increasing population densities coexist with an increase in the quality of life? What conditions should be satisfied before such increases in density take place? What role will nature, in the widest sense, play in such an increase in density?

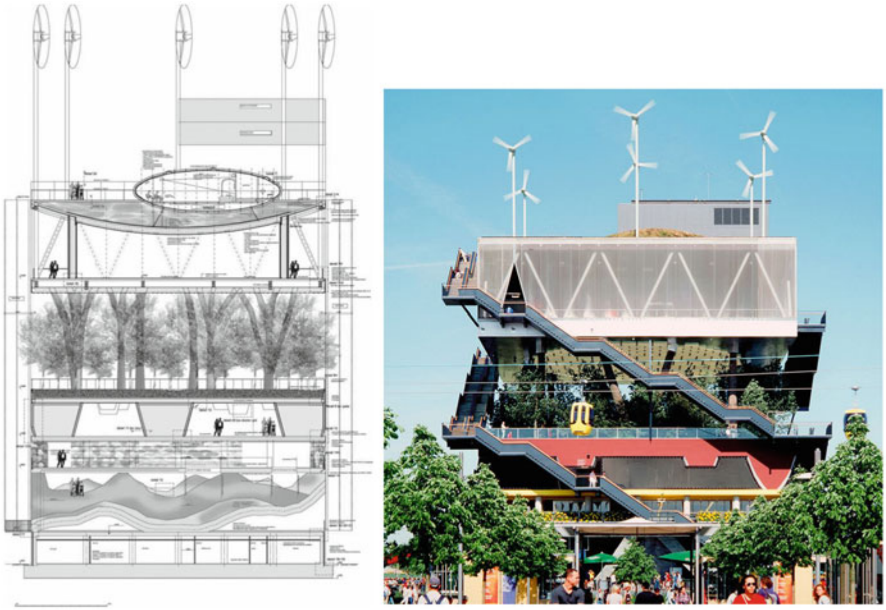

Fig. 2.9 Dutch pavilion World Expo Hannover

Is not the issue here “new nature,” literally and metaphorically? The Netherlands’ specific contribution to the ecological spectrum of the World Fair in Hannover 2000 showed was precisely a mix of technology and nature, emphasizing nature’s makeability and artificiality. Demonstrating that technology and nature need not be mutually exclusive, they can perfectly well reinforce one another. Nature arranged on many levels provided both an extension to existing nature and an outstanding symbol of its artificiality. It provides multilevel public space as an extension to existing public spaces (MVDRV 2015). It not only saves space, it also saves energy, time, water, and infrastructure. A mini-ecosystem was created as a kind of future survival kit. “Holland creates Space”: the theme for the Netherlands Pavilion at the 2000 World Expo in Hanover was to showcase a country making the most out of limited space. Six stacked Dutch landscapes form an independent ecosystem communicating cultural sustainability: progressive thinking and contemporary culture were combined with traditional values. The architecture suggests Dutch open-mindedness, while confirming the positive stereotypes of windmills and dykes. Of course, it also tests existing qualities: it attempts to find a solution for a lack of light and land. At the same time, the density and the diversity of functions builds new connections and new relationships. It can therefore serve as a symbol for the multifaceted nature of future sustainable high-rise buildings (MVDRV 2015). The Dutch pavilion at the Hanover World Expo 2000 (Fig. 2.9) demonstrated trends in sustainable high-rise building on land use by multilevel function, integration of renewable energy, preserving greenery, and reducing environmental impact within a natural setting (Rovers 2008).

Fig. 2.10 Triple bottom line approach for rooftop farming, presented by Zoellner (Zoellner 2013)

By working with nature cities can become more resilient to the changing climate, while reducing greenhouse gases through natural carbon "sinks." Embracing green roofs and facades helps to negate humans' impact on the environment, and to achieve livable, sustainable built spaces (Yong 2014). Arup's Cities Alive (Armour et al. 2014)—supported by the Landscape Institute and the Royal Botanic Gardens, Kew—describes the power of nature and the natural environment which could be used to offset a lot of effects. This to raise awareness of what the natural environment does, because it is often taken for granted (Yong 2014). Increasingly sophisticated technology will allow roofs, walls, and building façades to be "greened," creating a filter for pollution, absorb carbon dioxide by acting as a carbon "sink," as well as providing natural cooling and insulation to enhance air quality for city dwellers. Furthermore, green roofs retain a high amount of rainwater, so are perfect for harvesting, thus reducing the amount of water reaching urban sewage systems. Cities in the future will look vastly different to cities now (Arup 2015) with their green roofs, water roofs, vertical farming and even high-rise greening with trees like the Bosco-verticale by Stefan Boeri in Milan (Smith 2015). Brought about by concerns (over rapidly depleting natural resources, climate change and population growth, lack of physical space, transport networks with its intimate ties to oil prices and global food trade) food production systems, like vertical farming, could become integral elements in urban environments (Armour et al. 2014). Vertical farming techniques and urban agricultural systems, such as hydroponics, can potentially be utilized to help address the local food production as well as contribute to the environmental conditions within the cities. As a result of the economic, environmental, and social developments, Urban Agriculture will become part of the urban culture in the twenty-first century, see Fig. 2.10 (Zoellner 2013).

In Rotterdam, an architecture collective has reclaimed an old building in the center of the city and started using the roof to build an urban farm on top of it. As part of the 5th International Architecture Biennale Rotterdam, this first rooftop farm of the city on top of the Schieblock building was built as a Test Site. The garden houses vegetables and herbs (and some bees, too!), the urban rooftop farm,

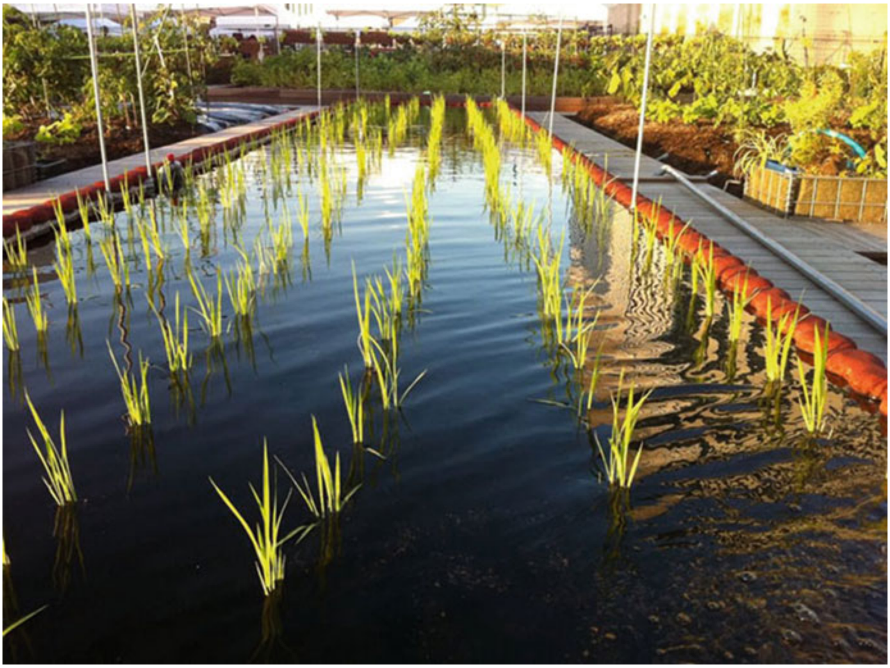

Fig. 2.11 Dakakker—Rotterdam (de Boer 2012)

called Dakakker, is an initiative of architecture firm ZUS and has sold its first veggies and herbs to local restaurants and shops. Also in Amsterdam, the Netherlands, the Zuidpark rooftop farm has opened its doors last year. Located along the city's ring road, Zuidpark focuses (more than other urban farms) on activities, workshops, and education, as well as on organizing special dinners with a view (Fig. 2.11) (de Boer 2012).

Europe's biggest commercial urban farm will soon be located in The Hague, Netherlands. A 1200 sqm greenhouse is to be placed on the roof of the De Schilde. Two of the building's top storeys, each measuring 1500 m^2, will be used for urban farming by city farming pioneer UrbanFarmers (UF) AG, a Swiss company. An indoor fish farm and boutique brewery are also included in the redevelopment plans (EuroFresh 2015).

7 Necessary Preconditions for Sustainable High-Rise Buildings Design

Until recently, tall buildings were mega-scale energy consumers with little regard for sustainable architecture. However, this is changing with a new generation of high-rise buildings that have been designed with energy conservation and sustainability as their principal criteria (Ali and Armstrong 2006; Ali and Armstrong 2008) The sustainable design of high-rise buildings should be paid more attention because high-rise buildings consume a large amount of natural resources and energy (Xu et al. 2006). This started already in the early 1990s with passive design. Passive design is essentially low-energy design achieved by the building's particular "morphological organization" (Yeang 1999). The Menara Mesiniaga in Subang, Malaysia, designed by Hamzah and Yeang in 1992, presents an early model building for the physical translation of ecological principles into high-rise architecture. The fifteen-storey tower expresses its technological innovations on its exterior and uses as little energy as possible in the production and running of the building. Ecological design, for Yeang, involves "the holistic consideration, of the sustainable use of energy and materials over the life-cycle of a building 'system', from source of materials to their inevitable disposal and/or subsequent recycling" (Powell 1999).

Sustainable design aims to meet the requirements of the present without compromising the needs of future generations by encouraging the use of renewable resources, alternative strategies for energy production and conservation, environmentally friendly design, and intelligent building technology. Intelligent building refers to a building that has certain intelligent-like capabilities responding to preprogrammed stimuli to optimize its mechanical, electrical, and enclosure systems to serve the users and managers of the building (Yeang 1996). The sustainability of a design for a high-rise building can be evaluated in the framework of international certification systems which have various sustainability criteria classifications aimed to minimization of environmental impacts of buildings (Gultekin and Yavaşbatmaz 2013). LEED (Leadership in Energy and Environmental Design) is one of the leading internationally recognized certification systems developed by the U.S. Green Building Council (Heller 2014). It guides designers to apply methods for meeting the criteria for sustainable sites, water efficiency, energy and atmosphere, materials and resources in terms of ecological sustainable design; the criteria for efficient use of resources and low operating cost in terms of economical sustainable design; and the criteria of indoor environmental quality and innovation and design process in terms of sociocultural sustainable design. Gultekin and Yavaşbatmaz (Gultekin and Yavaşbatmaz 2013) examined 13 LEED certificated high-rise buildings that are now in use: Bank of America Tower—New York 2009, The Visionaire Building—New York 2008 and Taipei 101 Financial Center—Taipei 2004 have LEED Platinum certificate; Conde Nast Building—New York 1999, The Helena Building—New York 2005, Eleven Times Square Building—New York 2007, 7 World Trade Center—New York 2007, 555 Mission Street Building—San Francisco 2009, Comcast Tower—Philadelphia 2008, Hearst Tower—New York 2006, and Solaire Building—New York 2003 have LEED Gold certificates; One South Dearborn Building—Chicago 2005 has LEED Silver certificate; and 30 Hudson Street Building—New Jersey 2004 has LEED certificate. According to results of the evaluation (Gultekin and Yavaşbatmaz 2013), ecological, economical, and sociocultural sustainable design criteria are largely met in the examined LEED certificated tall buildings. The compliance with sustainable design criteria for the examined LEED Platinum certificated tall buildings is 99 %; for LEED Gold certificated tall buildings 97 %; for LEED Silver certificated tall buildings 92 %; and for LEED certificated tall buildings 76 %. These examples show the possibilities of sustainable design for tall building design. While the concept of sustainability is becoming accepted, there is little worldwide consensus on what specific actions should be taken: an ecologically sensitive perspective, an energy-efficient approach, a bioclimatic approach, or a technology-conscious perspective (Utkutug 2004). Even up to now many different approaches are suggested (Mendis 2013; Jin et al. 2013; Navaei 2015; Milana et al. 2014; So et al. 2014; Raji et al. 2014).

8 Integral Design as a Solution for Sustainable High Rise

Sustainability is a crucial issue for our future and architecture has an important role to direct sustainable development (Taleghani et al. 2010). Although this path is not completely clear (Voss et al. 2012), the ultimate goal is clear: to design and build buildings that give more than they take (Gylling et al. 2011; Active 2013). In the Dutch Building Industry gaps of knowledge between the worlds of design and engineering were recognized by researchers as well as practitioners (van Aken 2005; Savanović 2009; Quanjel 2013). New approaches are needed to bridge the gap between architects and consulting engineers (structural, building physics and building services). The traditional building design process was a fragmented process where engineers and other experts were introduced after some of the most influential design decisions have already been made (Xu et al. 2006; Heiselberg 2007). This led in many cases to non-optimized buildings by nonintegrated addition of sustainable options like renewable energy systems or energy efficiency measures (Poel 2005; Brunsgaard et al. 2014). No longer conceptual building design should be done by architects alone, a whole design team with members from different disciplines is required to cope with the complexity of the current necessary sustainable development right from the beginning. During the conceptual building design process, synergy between different disciplines is essential to reach optimal sustainable building designs. King (King 2012) stated that in order to do anything meaningful in terms of moving to low carbon society, we need a consistent framework and design method, within which we can apply knowledge embodied in a design team.

Knowledge development in daily practice starts with effective collaboration between the participating disciplines in a design team (Emmit and Gorse 2007), making designing the most central activity in new product development. Concept designs can be seen as the basis of knowledge development within the design-team related to specific design solutions (van Aken 2005; Hatchuel and Weil 2003). For that reason concept generation is an essential part of the early design phase. During this phase, the most important decisions for the product/product-life cycle need to be made, even though relevant information and knowledge is lacking and domain experts might not be available and communication between them is very difficult.

Since the early 1960s, there has been a period of expansion of design methods through the 1990s right up to the present day (Cross 2007; Chai and Xiao 2012; Le Masson et al. 2012). However, there is still no clear picture of the essence of the design process (Horváth 2004; Bayazit 2004; Almefelt 2005a, b) and many models of designing exist (Wynn and Clarkson 2005; Pahl et al. 2006; Tomiyama et al. 2009; Ranjan et al. 2012; Gericke and Blessing 2012).

In the Netherlands, Methodical Design is a quite familiar design method in the domain of mechanical engineering and being taught at different educational institutes. The Methodical Design process (Kroonenberg and van den Siers 1992; Blessing 1994) is a problem-oriented method derived from the General System theory (von Bertalanffy 1976) and distinguishes based on functional hierarchy complexity levels during different design phase activities. This design method that was further extended into Integral Design through the intensified use of Morphological Charts (MC) was developed by Zwicky (Zwicky 1948) to support design activities in the design process (Savanović 2009). General Morphological analysis was developed by Fritz Zwicky (Zwicky 1948) as a method for investigating the totality of relationships contained in multidimensional, usually nonquantifiable problem complexes (Zwicky and Wilson 1966; Ritchey 1998; Ritchey 2004). Morphology provides an arrangement for supporting overview of the considered functionalities and aspects and their solution alternatives. Transformation of the program of demands by a design team, into aspects and functionalities listed in the first column of a matrix, and formulation of the different solutions and relations related to these aspects and functionalities listed in the related rows to them, forms a MC. The traditional main aim of using MC is to widen the search area for possible new solutions (Jones 1970). The MC is a key element that can improve the effectiveness of the concept generation phase of the design process as it is an excellent way to record information about the solutions for the relevant functions and aspects. The MC aids in the cognitive process of generating the system-level design solutions (Wynn and Clarkson 2005) and also has definite advantages for communication within group work (Ritchey 2010). The MCs to visualize sub-solution alternatives play a central role in the Integral Design approach for design teams as all the individual MCs are combined into one Morphological Overview (MO). The MO of an integral design team process is generated by combining in two steps the different MCs made by each discipline. First, functions and aspects are discussed and then the team decides which functions and aspects will be placed in the MO. Then, after this first step, all participants of the design team can contribute their solutions for these functions and aspects by filling in the rows within the MO. Putting the MCs together enables "the individual perspectives from each discipline to be put on the table," which in turn highlights the implications of design choices for each discipline. This approach supports and stimulates the discussion on and the selection of functions and aspects of importance for the specific design task, see Fig. 2.12.

In case of building design, MCs can be used to explicate discipline-based object-design-knowledge. Merging MCs of all involved disciplines results in an MO of the available object-design-knowledge within a design team. However, MO are not to be regarded as the end result of the team design process, rather as the initial phase based on which integral design can be done.

The description of the MO may read as minor implementation difference of the old MCs. However, it is a subtle but essential difference: the MCs represent the individual interpretation of reality, leading to active perception, stimulation of

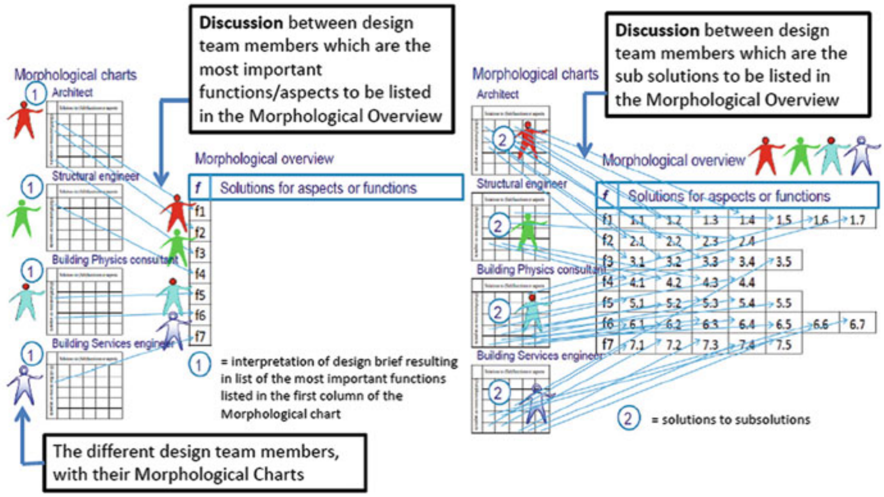

Fig. 2.12 Building the morphological overview; Step 1, the MO contains the chosen functions and aspects (*1*) from the different MCs. Step 2, the MO with the accepted sub-solutions (*2*) from the separate MCs

memory, activation of knowledge, and defining of needs. Within the MO, this individual result is combined with those of the whole design team. The MO is the representation of the design team's interpretation/perception and activated memory/knowledge: the design team's mental model (Badke-Schaub et al. 2007).

As the Integral Design start from the program of requirements, the method especially emphasizes the sustainable development necessary to achieve nZEB. Due to reflection within the design team during the process, sustainable thinking is developed, and thus it becomes more than just merely the creation of mapping disparate skill sets within the team. The multidisciplinary dialogues lead to knowledge sharing (the MCs), knowledge integration (the MO), and knowledge generation (new solutions which were not included in the morphological charts, but are inspired by them). During this process, the information from the morphological charts are discussed and explained to each other. Any barriers to communication are overcome by the team members by solving the misunderstandings and the development of a shared insight, which forms the basis for the MO.

9 Discussion and Conclusions

Many city planners see high-rise buildings as a way to address the fast-increasing need for a more sustainable concentration of infrastructure, energy and carbon offered by denser cities in answer to the growing population and urbanization (Wood 2013). High-rise buildings are viewed as a way to change the functional dynamic of a city towards a more sustainable direction. However, high-rise buildings alone are not the answer. Far too often the sustainability and impact of a single building is evaluated without considering the larger context. Skyscrapers only become truly sustainable when they are integrated into the urban social and economic fabric. This requires different approaches and a rethinking of the design process (Wood 2013). Sustainable tall buildings especially, an Integral Design process is necessary because of their scale and the fact that sustainable design of high-rise buildings affects so many different elements of a building, such as daylighting, which in turn concerns siting, orientation, building form, facade design, floor-to-floor heights, interior finishes, electric lighting controls, and cooling loads, among other things. Integral design is different than conventional design in its focus on active conceptual design collaboration within a multidisciplinary team.

Design processes can be improved through improving three types of process communication (Senescu et al. 2013; Senescu and Haymaker 2013): understanding, sharing and collaboration. Through visualizing the individual contributions within a design team, morphological overviews based on the individual MologicalCharts stimulate the emergence of solution concepts within design teams. By structuring design (activities) and communication between design team members Integral Design's Morphological Overview forms the basis for reflection on the design results. Through this it helps the design teams come forward with new design propositions. The Morphological Overview supports the communication within the design team and leads to better understanding, sharing and collaboration (Savanović 2009). Although, the proposed model of Integral Design has an implicit proposition which tends to portray it as mere problem solving across various professional domains, is has to be emphasized that the reflection by means of the Morphological Overview enables the introduction of creativity beyond the mere functional, decompositional approach.

As stated by Janet Beckett, director at Carbon Saver a consultant company specialized in Low Carbon Building design and building engineering physics, there could not be a better time than now in time of global change to implement a paradigm shift—we cannot continue in the same vein (Beckett 2012). Earlier dialogue and true cooperation in the project design means it is easier to build on sustainability, and add innovation and engineer-integrated solutions (Beckett 2012).

Designing nZEB requires that architect and engineers overlap their knowledge and skills and share the character of a designer (Brunsgaard et al. 2014). A new kind of architect is needed, who can accept the principles of engineering alongside the building aesthetics, to balance form and function for an optimal sustainable design. A new generation of architects to be inspired by engineering and science, willing not only to listen to concepts and ideas of engineers, but to really truly design together with engineers solutions that can be beautiful, useful as well as sustainable. Also a new kind of engineer is needed, one who is better able to communicate about possible alternative proposals as well as the realities of how engineering services impact on the building and not just solving problems or making calculations.

The challenge is getting synergy between all members of a design team on board with the design process in a sustainable high rise. By exploring the underlying aspirations for building, the team may come to see that the real goal is not the building per se, but the services and benefits it can offer to the client and the community at large.

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Chapter 3
Analysis of Architectural Design Sustainability Issues of Office Towers in Hot Climates: UAE Case

Khaled A. Al-Sallal

1 Introduction

The UAE has been spending billions of dollars to construct new urban developments in order to satisfy the country's fast development, which started since the country was founded in 2 December 1971. The architecture in the major cities such as Abu Dhabi, Dubai, and Sharjah has been shifting into large-scale projects or the so-called mega projects. Such projects typically involve tower architecture. These huge developments are manifested by the continuous vibrant change of the cities' skylines, which sometimes could be noticed easily within a few weeks.

Due to their huge size and external surface area exposed to harsh outdoor conditions (e.g., solar radiation, temperature, and humidity), tower buildings usually consume massive amounts of energy (mainly for cooling and lighting) and water, which makes them among the highest environmental footprint contributors and the largest CO_2 and greenhouse gases emitters. High-energy consumption of office towers as a result of high reliance on inefficient systems and poor lighting design has been witnessed in many buildings like the ones discussed later in this chapter. Many problems emerge from inappropriate design decisions usually made at the early stages of architectural design such as the choice of form configuration and orientation or the depth of floor-plate.

Pressure to slash CO_2 emissions continues to mount with growing levels of legislation and incentives to preserve the environment. To meet these targets, considerable efforts into energy efficiency are underway. In Abu Dhabi, the foundation for Estidama was created in 2007 by the Urban Planning Council (UPC) in the form of Plan Abu Dhabi 2030, which aimed to define how a contemporary, sustainable Arab Capital should look and how it could live (UPC-Estidama 2010). Under the Estidama initiative, a building rating system, called the Pearl Rating System for Estidama,

K.A. Al-Sallal (✉)
Department of Architectural Engineering, UAE University, Abu Dhabi, United Arab Emirates

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was developed and UPC made an announcement of its approval in May 2010. Similar efforts were also made by the Government of Dubai to tackle the increasing environmental issues caused by building constructions in the Dubai Emirate, which lead to the introduction of the Dubai Green Building Regulations implemented in 24 October 2007.

Over the next three decades, the building stock is projected to grow extensively in many parts of the world, which creates an extraordinary opportunity to achieve significant emissions reductions in the building sector. The purpose of this chapter is to analyze current practice of office tower design in the UAE with regard to sustainability issues with emphasis on increased energy consumption. The method used previous research findings as basis for analysis and the derived outcomes are schemed in formats to work as sustainable design guidelines for building designers.

2 Background

2.1 Increasing Electricity Demands in the UAE

In the GCC, Saudi Arabia, UAE, and Kuwait were the only countries that have peak electricity generations greater than 10,000 MW. In the UAE, peak electricity demand in 2007 was 5830 MW for Abu Dhabi, 4730 MW for Dubai, 1557 MW for Sharjah, and 1680 MW for the other emirates (Gulf News 2008). Recent figures in Abu Dhabi showed that peak electricity generation by the Abu Dhabi Water and Electricity Authority (ADWEA) exceeded 10,000 MW for the first time in early July 2012 (ADWEC 2012). It is predicted that Abu Dhabi's electricity demand will rise by an average of almost 13 % per year this decade, a rate that is one-third faster than the increase in power use in the last 5 years (The National 2011). Electricity use in Abu Dhabi and exports to other emirates will rise to 28,188 MW by 2020. In 2008, commercial and residential buildings in Dubai were responsible about 46 and 34 % of total electricity consumption (27,931 GWh), respectively. The remaining 20 % was consumed in industrial and other uses. The forecasted electricity load figures for the year 2020 are more than double this level. According to information from the Dubai Electricity and Water Authority (DEWA) published in *Arabian Business* (2012), power demand in Dubai peaked at 6165 MW in the period April 1–June 30, up from a peak of 5941 MW in the second quarter of 2011; this represents a rise of 3.8 % in the second quarter of 2012, compared to the same period last year.

2.2 Global Building Energy and Greenhouse Gas Emissions

The built environment has been reported at attributing 48 % of all energy consumption in the US with around 75 % of all the electricity produced in the US and 20–40 % of the total energy consumption in Europe and other advanced countries

(Architecture 2030, 2011). Buildings also contribute indirectly to greenhouse gas emissions. The built environment is responsible about half of the greenhouse gas emissions in the U.S. and 30–40 % of the total carbon emissions in the UK. Construction sector in India emits about 22 % of the total annual emission of CO_2 resulting from the Indian economy (Dakwale and Ralegaonkar 2012). Production of construction materials is primarily dependent on conventional energy sources in many parts of the world. Out of the emissions from the construction sector, around 80 % are resulting mainly from the products/industrial processes of energy intensive building materials (i.e., cement, lime, steel, bricks, and aluminum.) (Reddy and Jagadish 2003).

The U.S. Energy Information Administration (EIA) has documented that fossil fuels supply 84 % of total U.S. and 76 % of building sector energy consumption (Architecture 2030, 2011). It is expected to grow by 9.8 % between 2010 and 2030. Building Sector is responsible about 34 % of this growth. The production of carbon dioxide and other greenhouse gasses that are now fueling dangerous climate change is mainly a result of burning fossil fuels to generate energy.

In 2012, the Building Sector was responsible for nearly half (44.7 %) of US CO_2 emissions (Architecture 2030, 2011). By comparison, transportation accounted for 34.3 % of CO_2 emissions and industry just 21.1 %. This makes buildings as the largest Contributor to Climate Change. Many people are surprised to learn this fact as so much attention is given to transportation emissions. Since most of this energy is produced from burning fossil fuels, this makes the building sector the largest emitter of greenhouse gases on earth and the single leading contributor to anthropogenic (human forcing) climate change. By the year 2035, approx. 75 % of the built environment will be either new or renovated. This transformation over the years represents a historic opportunity for the architecture and building community to avoid dangerous climate change.

2.3 Energy in Office Buildings

Office and retail and service buildings consume most of the energy used in buildings because these types of buildings are very common and usually exist in large number and areas. Together, they account for 41 % of all commercial building energy in the US (EIA-CBEC 2003). Office buildings, which have the second largest amount of buildings and floor space in the US, consume most energy of all building types, accounting for 19 % of all commercial energy consumption; i.e., a total of 1.0 quadrillion Btu of combined energy. Lighting accounts for the most use (39 %), followed by space cooling (14 %) and ventilation (9 %) of electricity energy consumption (Btu) by the end use in office buildings in 2003 (Fig. 3.1 and Table 3.1) based on figures by Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey (CBECS). Such important information should be realized by designers in order to give priority when solving the energy problem by design strategies related to daylighting and cooling/ventilation

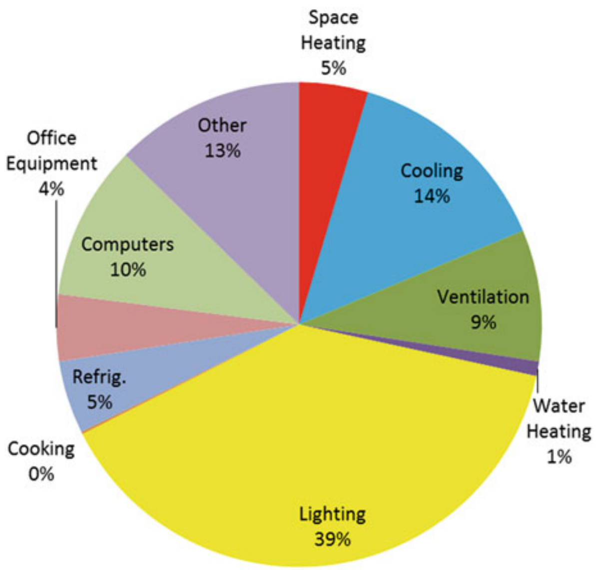


Fig. 3.1 Electricity energy consumption (Btu) by end use in office buildings, 2003

Table 3.1 Electricity energy consumption (Btu) by end use in office buildings

Energy use	Trillion btu	Energy use	Trillion btu
Space heating	33	Cooking	1
Cooling	101	Refrigeration	35
Ventilation	63	Office equipment	32
Water heating	7	Computers	74
Lighting	281	Other	91

Source: Energy Information Administration, 1995 Commercial Buildings Energy Consumption Survey

measures, then replace the residual consumption of energy that will always be there with renewables rather than non-renewables.

2.4 Urban Heat Island Effect

Elevated temperatures from urban heat islands, particularly during the summer, can affect a community's environment and quality of life. The United States Environmental Protection Agency (US EPA 2008) has listed the negative impacts of the urban heat islands as follows:

- Increased energy consumption
- Elevated emissions of air pollutants and greenhouse gases

- Compromised human health and comfort
- Impaired water quality

Heat island effect has a great impact in exacerbating cooling energy requirements in warm to hot climates in summer. Previous research (Akbari et al 1992; US EPA 2008) showed that for US cities with population larger than 100,000, peak urban electric demand increases 1.5–2 % for every 1 °F (0.6 °C) increase in summertime temperature (i.e., 2.5–3.5 % for every °C increase in temperature). Steadily increasing downtown temperatures over the last several decades mean that 5–10 % of community-wide demand for electricity is used to compensate for the heat island effect. During extreme heat events, which are exacerbated by urban heat islands, the resulting high demand for cooling can overload systems and require a utility to introduce extra measures to avoid power outages. The costs for summer heat island were estimated over $1 million per hour, or over $1 billion per year (Akbari et al 1992).

Santamouris et al. (2001) investigated the impact of the urban climate on the energy consumption of buildings in Athens, Greece. The study depended on analysis of weather data retrieved from almost 30 urban and suburban stations and performed specific measurements in ten urban canyons. The findings of the study showed that higher ambient temperatures caused by urban heat island could result in:

- Doubling the cooling load of the urban buildings.
- Tripling the peak electricity load for cooling purposes.
- Decreasing of the COP value for air conditioning (up to 25 %).
- Reducing the airflow rates inside urban canyons up to ten times compared to those when undistributed ambient meteorological data were used.

3 Improving Energy Efficiency and Sustainability in Office Buildings in Hot Climates

3.1 Cooling Energy

To offset the effects of increased energy consumption for cooling in buildings, Santamouris (1999) addressed some significant solutions. These can be outlined as follows:

- Improvement of ambient microclimate in the urban environment—this involves the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies.
- Adaptation of urban buildings to specific environmental conditions—efficiently incorporate energy saving measures and counterbalance major changes of the urban environment including radiative, thermal, moisture, and aerodynamic effects. This incorporates appropriate sizing and placing of the building openings, enhance air flow and natural ventilation, improve daylight availability, and use of passive cooling techniques to decrease cooling energy consumption and improve thermal comfort.

- The use of more efficient advanced air conditioning systems for individual buildings and optimize them to operate in urban conditions. This involves systems with optimized COP curves for the specific temperature and humidity conditions, systems using advanced inverters, intelligent control, etc.
- The use of centralized or semi-centralized production, and management and distribution cooling networks, (district cooling), together with the use of demand side management actions like local or remote cycling.

Lam (2000) has investigated the energy performance of commercial buildings in Hong Kong using computer simulation (DOE-2). The study tested a generic office building that was developed to represent information acquired from a large number of buildings based on a survey. It correlated the overall thermal transfer value (OTTV) concept with other key building design parameters. The findings showed that air-conditioning accounts for 60 % of the total building energy consumption and improving the chiller COP of generic office buildings from 3 to 5 can reduce the total building electricity use by 16 %.

3.2 Lighting Energy

Another important finding by Lam (2000) was the significance of reducing the lighting load in office buildings in Hong Kong, as the study showed that this load has a much higher sensitivity coefficient than the building envelope, indicating greater influences. The total energy consumption went down by 15 % after lowering the lighting load from the 20 to 12.5 W/m^2 with an indoor illuminance of 500 lux. It was recommended to maximize reliance on daylighting as daylight can result in significant energy savings in cooling-dominated commercial buildings in hot climates. That is because: (1) less artificial lighting is used, and (2) daylight has a higher luminous efficacy (110 lumens/W in Hong Kong) than most electric lighting systems (60 lumens/W), thus generating less heat per lighting level provided.

Since lighting control integrated with daylighting is recognized as an important and useful strategy in energy-efficient building design and operation, it is believed that proper daylighting schemes can help reduce the electricity demand and contribute to achieving environmentally sustainable building development. Li and Lam (2001) conducted a study on lighting performance in fully air-conditioned office building facing opposite orientations with daylighting controls in Hong Kong. Electricity consumption by the fluorescent luminaries, indoor illuminance levels, and the room parameters affecting daylighting designs were recorded and analyzed. The results showed substantial lighting energy savings (up to 50 % for the perimeter offices) if proper daylighting schemes are incorporated. Further electricity savings can be realized as a result of the reduction of heat dissipation from artificial lighting, and hence, lower cooling load. The study recommends attending to the subtle interactions of a large number of design features as it could help to improve the quality and quantity of daylight entering into an interior space. To have a more complete picture of the indoor visual environment, more on-site measurement of the actual visual condition is required.

Lighting accounts for the most energy consumption (39 %) in office buildings in the U.S. Reducing artificial lighting loads requires an integrated design approach aiming to optimizing building configuration to admit natural light and using more energy-efficient artificial lighting installations such as efficient low energy lamps, better electronic ballasts, and high quality fittings. Energy-efficient lighting design contributes greatly in improving sustainability levels, especially with regard to energy efficiency and indoor environmental quality. For instance, 75-W incandescent lamp with an 18-W compact fluorescent lamp will avoid emitting the equivalent of 4300 kg of carbon dioxide and about 10 kg of sulphur dioxide from a typical generating plant in the USA (Yeang 1999; MacKenzie 1997; Zeiher 1996). Lighting switching systems can contribute in achieving significant energy savings. This can be coupled with the building management system (BMS), or by using local controls and ambient light sensors to adjust artificial lighting based on the amount of natural light entering the building. An office with simple daylight strategies (such as sidelights and light shelf) and fluorescent lighting system can achieve 60 % total reduction of lighting energy and 51 % annual electric energy savings (Guzowski et al. 1994).

The potential of daylight in saving energy in buildings in the eastern coast of Saudi Arabia was investigated by Alshaibani (2001). The study used a room prototype with certain size and glazing properties (width: 4 m, depth: 5 m, height: 2.8 m, reflectance: 0.47, transmittance: 0.7). The method was based on estimating the percentage of occurrence of the vertical illuminance of 10,638 lux during a full year based on daylight requirement of 500 lux inside the room prototype. The results showed that this requirement of vertical illuminance was available at the four orientations for more than 75 % of the working year; and hence, this indicated a potentiality of 75 % savings in artificial lighting consumption.

4 Passive Cooling Systems

Application of passive cooling techniques in buildings has been proved to be extremely effective and can contribute highly to decrease the cooling load of buildings. (Santamouris and Asimakopoulos 1997). These techniques can be classified as follows:

- *Preventive techniques*—Protection from solar and heat gains should involve the following measures: landscaping, and the use of outdoor and semi outdoor spaces, building form, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains.
- *Modulation of heat gains techniques*—this has to do with the capacity for heat storage in the building structure. This delay strategy depends on decreasing of peaks in cooling load and modulation of internal temperature with heat discharge at a later time.

- *Heat dissipation techniques*—these techniques depend on the potential for disposal of excess heat by natural means. This requires two main conditions: (a) The availability of an appropriate environmental heat sink and (b) The appropriate thermal coupling and sufficient temperature differences for the transfers of heat from indoor spaces to sink. The main processes and heat sinks required can include radiative cooling using the sky, evaporative cooling using air and water, convective cooling, using air, and ground soil.

5 Guidelines for Sustainable Tower Architectural Design

Because of their large scale, tall buildings have greater exposure than other types of buildings to the full impact of the external environmental conditions including air temperatures, humidity, wind, and solar radiation. Also, tall buildings have greater contribution than other forms of buildings to the forming of heat island effect generated in urban environments.

Building operational systems can be categorized by their functions and their relation and impact on natural resources (such as energy and water). Yeang (1999) categorized the building operational systems into the following categories:

1. Passive-Mode Systems,
2. Mixed-Mode Systems,
3. Full-Mode Systems (active systems),
4. Water Conservation Strategy,
5. Wastewater and Sewage Recycling Systems, and
6. Productive Mode Systems.

To create green or environmentally sustainable tall buildings, Yeang (1999) recommended maximizing reliance on passive-mode systems while minimizing reliance on full-mode (or active systems). This could be achieved through appropriate design of the built-form configuration, site layout, façade design, solar-control devices, passive daylight devices, envelope materials, vertical landscaping, and passive cooling.

5.1 Built-Form Configuration

The designer should ensure that the long axis of the built form is oriented east–west so that the long side of the building faces north and south. This allows to place the majority of the windows into the north and south walls and accordingly to reduce solar heat gain. As a general rule of thumb, the optimum aspect ratio of the built form should be 1:2–1:3 for climatic zones nearer to the equatorial zone and lesser at the higher latitudes (Cole et al. 1995; Yeang 1999).

5.2 Arrangement of the Building Masses

The arrangement of the building masses should be considered as a factor in bioclimatic design as its position can help to promote or reduce heat gain. In arid and tropical regions, the service cores of the building should be located on the east and west sides of the building, so as to help shade its form from the low angles of the sun during the major part of the day. Studies show that double-core configuration, with window openings running north and south and cores on the east and west, can achieve significant savings in air-conditioning. The advantage of using this placement is to reduce solar heat gain into the internal user spaces and provides a thermal buffer zone to the hot sides, while at the same time maximizing heat loss away from user spaces. There are several benefits in using the peripheral service core:

- No fire-protection pressurization duct is needed, resulting in lower initial and operating costs,
- Provision of natural ventilation to the lift lobbies and thus further energy savings, solar and wind buffer effects,
- Provision of natural sunlight to the lift and stair lobbies,
- A safer building in event of total power failure or fire,
- Better awareness of the place by providing a view out for users.

5.3 Floor-Plate Design

The floor-plate strategy is about the relationship of the building's floor plate shape, its position on the site, and its orientation to the sun's path and wind direction. In hot arid and tropical climates, the optimum shape is a rectangle that minimizes the length of east and west sides, while maximizes that of north and south sides, to reduce solar insolation on wider sides. The internal spaces arrangement should be planned to reduce solar gain into high occupancy spaces, while service spaces can be used as solar buffers.

5.4 Building Skin Design

A well-designed building envelope will yield significant energy savings. Its permeability to light, heat, and air and its visual transparency must be controlled with flexibility of modification, so that the building can react to changing local climatic conditions. The ideal envelope is the one that is environmentally responsive filter. The green approach does not recommend using hermetically sealed skins. The building skin has to be multi-functional: reduces solar heat gain to the internal space through external shading, maximizes the use of daylighting, provides fresh air ventilation, serves as acoustic barrier, and contributes to the building's esthetics. Double skin façades can provide several benefits: solar control, noise reduction, high-wind reduction, natural ventilation.

5.5 Shading Devices

Regardless of the latitude, some form of solar shading is needed on east, west, and south sides of the building during the overheated period. Solar heat gain through windows can be reduced by sunshades, balconies, deep recesses, or sky-courts. Shading is also needed to reduce glare and direct daylight into deeper reaches of the floor-plate. Fixed shading devices are effective and not costly; yet it can block the sun during times when it is needed as a result of the time shift between the solar year and thermal year. Movable devices can overcome this problem by its flexibility and control to suit outside conditions. Movable louvers can provide additional protection against heat loss in the winter. Depending upon the season and time of the day, the angle control of the louvers achieves optimal daylight incidence in combination with minimal heat gain. Intelligent façades operate with automated angle control, regulated by incident radiation and outside air temperature.

5.6 Glazing Type

Clear glass is often preferred as it gives a more natural light into the inside. Tinted glass cannot be a substitute for sun shading. Tinted glass reduces thermal transmission to 20 %, which is still ineffective in hot climates. It has two negative effects: it conducts heat to inside space after it absorbs it and it reduces daylight significantly. Solar-reflective glass can be used to reduce solar penetration without affecting the view. However, it reduces both short-wave (heat) and long-wave (light) transmission, which results in reducing useful winter heat gain and natural light. It can be used though in climates where heat gain is not desired. Low emissivity glass reduces direct heat gain by transmitting a greater proportion of light than heat. It has the appearance of clear glass and is useful in situations where daylight is desired while solar heat gain should be minimized. It allows the use of larger glazing area for admitting daylight, without necessarily incurring an energy penalty. Other new intelligent glazing systems are currently being researched and some are available today such as photo-chromatics, phase-change materials, holographic, and electrically responsive glass. The green approach tends to encourage the use of clear or low emissivity glass.

5.7 Natural and Artificial Lighting Systems

The objective is to enhance the quality of indoor spaces and cut energy consumption through optimizing the use of daylighting and minimizing the need for artificial lighting. Studies have shown that access to daylight and views provide a feeling of well-being. Adequate daylight can easily be introduced to the depth of inside spaces up to 4.6 m (15 ft) with conventional height window. Other experimental advanced daylight systems can passively redirect sunlight to larger depths (4.6–9.1 m, 15–30 ft) using special technologies such as HOE (i.e., holographic optical elements), articulated light shelves, and light pipes. The advantages of these systems are: (1) to increase the daylight illuminance levels at deeper spaces with minimum solar heat gain, and (2) to improve the uniformity of the daylight luminance distribution across the room under variable solar conditions throughout the year. Narrowing the width of floor plate to approximately 14 m (i.e., external wall to wall width) can help to reduce artificial lighting and optimize natural lighting. A room with a height-to-depth ratio of 1:2 with 20 % glazing of its external wall area allows good light penetration (i.e., 1.5–2 daylight factors) and can be described as cheerfully daylit. In achieving an acceptable comfort level of daylight, one of the discomforts to be recognized and resolved is the problem of glare. Treatment of this problem requires a lighting strategy and has an implication on energy performance.

6 Analysis of Sustainable Tower Architectural Design in the UAE

The issue of high consumption of energy in commercial buildings such as office towers in the UAE and its adverse impact on the environment is alarming and must be considered by decision makers in any future planning. This requires improvement of ambient microclimate in the urban environment, adaptation of urban buildings to passive mode systems for cooling and natural lighting, and using more efficient advanced air conditioning systems.

Improving energy efficiency and sustainability of office buildings must depend on green design guidelines as a basis for generation of design alternatives and concept development analysis. The design issues and determinants for office tower design are outlined in Table 3.2. This table can be used along with the design guidelines shown in Appendix A to help designers generate design concepts of sustainable towers and to evaluate case studies. The guidelines are used here as basis for a wide-range analysis of office towers design in the UAE. Four case studies are used to demonstrate the ideas. The chosen case studies are described below and their design data received from a conducted survey by the author (of three of them) were introduced in Appendix B.

Table 3.2 Design issues and determinants for office tower design in hot climates

Design issue	Design determinants
Built-form configuration	• Orientation of long axis
	• Aspect ratio of the built form
	• Service core configuration
	• Type (central-, split-, end-, and atrium-core)
	• Orientation
Floor plate design	• Floor plate orientation to sun and wind
	• Internal spaces arrangement and the use of solar buffer zones
	• Surface area to volume ratio
	• Plan depth
Façade design	• Building envelope (hermetically sealed versus permeable)
	• Intelligent Façade (double skin versus conventional)
Solar control and shading	• Shading devices (type and orientation)
	• Existence of deep recesses or sky-courts
	• Glazing type (clear, tinted, solar-reflective, low emissivity, other)
Natural and artificial lighting systems	• Type of daylight systems (sidelight, light shelf, top light, etc.)
	• Room proportion for side daylighting (height-to-depth ratio, glazing % of external wall area)
	• Artificial lighting energy consumption
	• Type of artificial lights
	• Energy-saving controls for artificial lighting
	• Artificial lights coupling with BMS

6.1 Design Description

6.1.1 Dubai World Trade Center Tower (DWTC)

The Dubai World Trade Centre Tower (Fig. 3.2) was inaugurated in 1979 and since then has become a prestigious building on Dubai's skyline (DWTC 2004). The Tower stands 184 m high and is one of the tallest buildings in the region. It comprises 39 floors, 28 of them are let commercially with a total net lettable space of approximately 283,000 square feet.

6.1.2 Emirates Towers Office Building (ETOB)

The Emirates Towers complex (Fig. 3.3), located in Dubai, comprises two equilateral triangles containing an office tower and 400 bedroom hotel tower, joined by a central podium containing a selection of shops and restaurants, with covered parking for up to 1800 cars. The office tower is 350 m high; the hotel tower is 305 m high. The ETOB average floor has a net usable area of 810 m^2 with 2.85 m floor-to-ceiling height and is served by 17 elevators. It has 47 floors of lettable space based

Fig. 3.2 Dubai World Trade Centre Tower

Fig. 3.3 Emirates Towers, Dubai—Emirates Towers Office Building (ETOB) is the taller tower

Fig. 3.4 National Bank of Abu Dhabi (NBAD)

on a triangular layout comprising: lobby area and the drum floors (levels 2–8, with 6633–7014 ft^2), the low rise floors (levels 10–20, with 9611 ft^2), the mid rise floors (levels 22–32, with 9611 ft^2), the high rise floors (levels 34–44, with 9611 ft^2), the peak floors (levels 46–51, with 8955 ft^2), the mezzanine (level 52, with 806 ft^2), and other floors designed as transfer floors or for mechanical systems. The total energy consumption of the tower is 560 $KwH/m^2/year$.

6.1.3 National Bank of Abu Dhabi (NBAD)

The NBAD, located in Abu Dhabi, is a double tower structure in pyramidal cross section with inversely reflected triangular peaks (Fig. 3.4). Its gray-colored glass clad gives a touch of formality to its prestigious offices and banking center. The pyramidal form is repeated at ground level with one vertex acting as a support point giving way to a grandiose entrance. Inside this space, there is a four storey atrium that is naturally lit, which in turn allows for exceptional views both to and from the exterior.

Al Bahar Towers

The award-winning Al Bahr Towers in the emirate of Abu Dhabi consists of two 29-storey, 145 m–high towers. Its dynamic façade design, inspired from a traditional Islamic motif, was conceived as a contemporary interpretation of the traditional

Fig. 3.5 Al Bahr Towers, Abu Dhabi

Islamic "mashrabiya"; a popular form of wooden lattice screen found in vernacular Islamic architecture and used as a device for achieving privacy while reducing glare and solar gain (CTBUH 2013). The project brief called for two 29-story towers to create an outstanding landmark that would reflect the region's architectural heritage together with the status of the client's organization while providing a contemporary, sustainable building using modern technology (Fig. 3.5).

6.2 Design Analysis

The analysis of the tower design comprises the following points:

- *Built-form configuration*: According to the rule of thumb for an optimum built-form configuration, it should be a rectangle within an aspect ratio of 1:2–1:3, with long sides oriented to north/south. Yet, when observing the designs of office towers in the UAE, one can easily realize that form configurations of the majority of cases (i.e., their floor plans) are usually square or semi-square (i.e., a rectangle shape with an aspect ratio of less than 1:2). Also the issue of form orientation and how it will affect energy consumption or thermal comfort is not considered at both the city planning and architectural scale. Well-known cases that have this kind of problem are the Dubai World Trade Center (DWTC), the Emirates Tower Office Building (ETOB), and the National Bank of Abu Dhabi (NBAD).

- *Arrangement of the building masses*: Another common issue in the design of office buildings in the UAE is the inappropriate arrangement of building mass and service core configuration. In most cases, the service core is located in the middle of the floor-plan. According to the rule of thumb, the service cores of the building should be located on the east and west sides of the building, so as to help shade its form from the low angles of the sun during the major part of the day. Proper peripheral type core design can work as a thermal buffer zone and improves safety and sense of place. Some good cases with regard to the design of service core configuration can also be found such as the NBAD. Another advantage found in the design of the NBAD is that it utilizes its building mass for thermal storage. Very few office towers have a sky-court or roof garden, a highly recommended design technique to reduce solar heat gain and provide pleasant outdoor space. The NBAD is an example of these few cases.
- *Floor-plate design*: The optimum floor-plate design for the UAE climate is a rectangle that minimizes the length of east and west sides while maximizes that of north and south sides, to reduce solar insolation on wider sides; and the internal spaces arrangement should be planned to reduce solar gain into high occupancy spaces while service spaces can be used as solar buffers. The floor plans of most office towers in the UAE take the shape of a square or other similar shapes that do not give priority for the desirable orientations and avoid the undesirable ones. This issue is evident in the analyzed cases (DWTC, ETOB, and NBAD).
- *Façade Design*: Many commercial buildings in the UAE now are designed with sealed façades including office buildings and towers. The old ones such as the DWTC in Dubai have operable windows; yet it is not integrated with new technologies that help to control ventilation or shading. Newer ones such as the ETOB and the NBAD have hermetically sealed skin, which is not recommended as a green façade approach.
- *Solar shading*: In a harsh climate like the UAE, solar shading must be provided to protect glazed windows or façades during the hot times, especially on the west and east sides where solar radiation comes in low altitude angles. Most of the office towers in the UAE have extensive glazed façades without having any form of solar shading. There are some exceptions though such as the DWTC building built in 1979 and the Abu Dhabi Marine Operating Company (ADMA-OPCO) building built in 1997. These two buildings were designed with recessed windows. The arrangement of the windows in the DWTC tower looks like an egg-crate shading; this type of shading is the best among the fixed shading devices especially for this kind of harsh climate. Another project that has very interesting shading design is Al-Bahr towers in Abu Dhabi built in 2010. The distinguishing feature of these intelligent iconic towers is their protective skin of 2000 umbrella-like glass elements that automatically open and close depending on the intensity of sunlight.
- *Glazing Type*: The optimum approach for the type of glazing is a one that cuts down the transmission of heat while maximizing natural lighting. The low-E glass transmits a greater proportion of light than heat and thus it allows the use of larger glazing area for admitting daylight, without necessarily incurring an

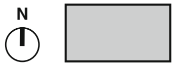
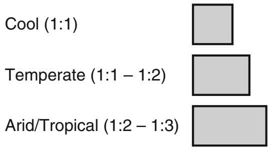
energy penalty. Many office towers in the UAE, especially the recent ones, were built with low-E glass such as the ETOB. Some office towers such as the NBAD were designed with double layered reflective glass. This type of glass reduces both short-wave (heat) and long-wave (light) transmission, which results in reducing useful winter heat gain and natural light. Although many towers are provided with double-glazing windows, none of the analyzed case studies uses double skin façade, a recommended design approach for solar control, noise reduction, and natural ventilation.

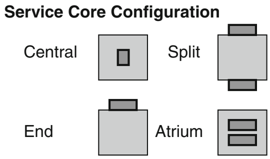
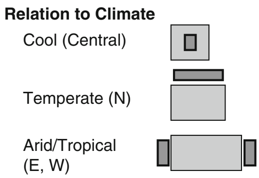
- Among the analyzed cases, only the DWTC was designed to maximize use of daylight. The room height-to-depth ratio is 1:2 with window glazing that is 20 % of the external wall area. All case studies use energy-saving controls for artificial lighting and efficient lighting fixtures. The ETOB has a more sophisticated high-tech lighting systems.

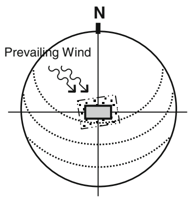
7 Conclusion

It is apparent that large-scale commercial buildings such as office buildings are more exposed than other types of buildings to the full impact of external temperatures, wind, and solar radiation. Also, these buildings have a great effect on heat islands generated in urban environments. Architectural design decisions that have great impact on building energy such as orientation and built form configuration are made at the early stages of the design process. Prioritizing design issues and making the right decisions at this early stage is very crucial. This chapter derived sustainable design guidelines (see Appendix A) from previous published research and used them as basis for analysis and evaluation of existing cases. The guidelines shown in Appendix A should be used in combination with the design issues and determinants shown in Table 3.2.

8 Appendix A: Guidelines for Sustainable Tower Architectural Design

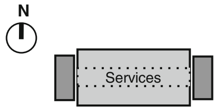
A. Built form configuration	
A1. Orientation	
The long axis of the built form should be oriented east–west so that the long side of the building faces north and south	
This allows to design the majority of the windows into the north and south walls and accordingly to reduce solar heat gain	
A2. Aspect ratio	
As a general rule of thumb, the optimum aspect ratio of the built form should be as 1:2–1:3 for climatic zones nearer to the equatorial zone and lesser at the higher latitudes	

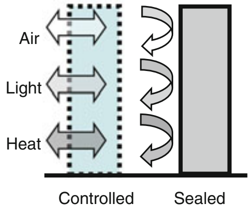
B. Arrangement of the building masses	
In arid and tropical regions, the service cores of the building should be located on the east and west sides of the building, so as to help shade its form from the low angles of the sun during the major part of the day Studies show that double-core configuration, with window openings running north and south and cores on the east and west, can achieve significant savings in air-conditioning The advantage of using this placement is to reduce solar heat gain into the internal user spaces and provides a thermal buffer zone to the hot sides, while at the same time maximizing heat loss away from user spaces	 

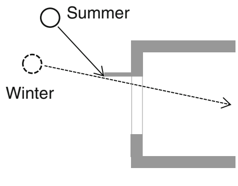
C. Floor-plate design	
C1. Position on the site and relation to sun and wind	
The floor-plate strategy is about the relationship of the building's floor plate shape, its position on the site, and its orientation to the sun's path and wind direction	

(continued)

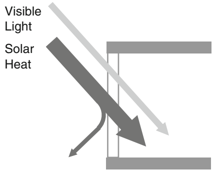
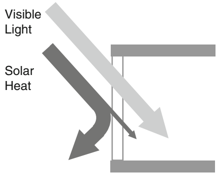
(continued)

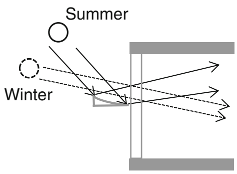
C2. Floor-plate shape	
In hot arid and tropical climates, the optimum shape is a rectangle that minimizes the length of east and west sides while maximizes that of north and south sides, to reduce solar insolation on wider sides	
The internal spaces arrangement should be planned to reduce solar gain into high occupancy spaces while service spaces can be used as solar buffers	

D. Building skin design	
The green approach does not recommend using hermetically sealed skins. The ideal building skin is the one that is environmentally responsive filter, which has to be multi-functional:	
• Reduces solar heat gain to the internal space through external shading	
• Maximizes the use of daylighting, provides fresh air ventilation	
• Serves as acoustic barrier, and contributes to the building's esthetics	
Its permeability to light, heat, and air and its visual transparency must be controlled with flexibility of modification, so that the building can react to changing local climatic conditions	

E. Shading devices	
Solar shading is needed on east, west, and south sides of the building, especially during the overheated period. Shading by light shelves can help to reduce glare and direct sunlight into deeper reaches of the floor-plate	 **Shading by Overhang**
Fixed shading devices are effective and not costly. Movable devices are more expensive, but provide high flexibility and control to suit outside conditions. Depending upon the season and time of the day, the angle control achieves optimal daylight incidence in combination with minimal heat gain	
Intelligent façades operate with automated angle control, regulated by incident radiation and outside air temperature	

(continued)

F. Glazing	
Clear glass is often preferred as it gives a more natural light into the inside. Tinted glass has two negative effects: it conducts heat (approx. 80 %) to inside space after it absorbs it and it reduces daylight significantly	 **Tinted Glass**
Low-e glass reduces direct heat gain by transmitting a greater proportion of light than heat. It has the appearance of clear glass and is useful in situations where daylight is desired, while solar heat gain should be minimized. It allows the use of larger glazing area for admitting daylight, without necessarily incurring an energy penalty. The green approach encourages the use of clear or low emissivity glass	
Other new intelligent glazing systems are currently being researched and some are available today such as photo-chromatics, phase-change materials, holographic, and electrically responsive glass	 **Low-e Glass**

G. Natural and artificial lighting systems	
Objective: to enhance the quality of indoor spaces and cut energy consumption through optimizing the use of daylighting and minimizing the need for artificial lighting	 **Redirection of Sunlight by Articulated Light Shelf**
Adequate daylight can easily be introduced up to 4.6 m (15 ft) with conventional height window. New technologies can passively redirect sunlight to larger depths (4.6–9.1 m, 15–30 ft); i.e., holographic optical elements, articulated light shelves, and light pipes	
Narrowing the width of floor plate to approx. 14 m can help to reduce artificial lighting and optimize natural lighting	

9 Appendix B: Case Studies Data (Based on Data Collection and Survey)

	Dubai World Trade Center (DWTC)	Emirates Towers Office Building (ETOB)	National Bank of Abu Dhabi Headquarter (NBAD)
Basic information			
Client/owner	Dubai Government	HH Sheikh Mohammed bin Rashid Al Makhtoum	NBAD
Location	Sheikh Zayed Road, Dubai	Sheikh Zayed Road, Dubai	Khalifa Street, Abu Dhabi
Architect	John R. Harns	Hazel Wong	Carlos Ott
Other consultants		NORR, Hyder, DSSR	APG
Date completed	1979	Opened April 2000	Feb. 2003
Gross area	46,567 m^2	64,000 m^2	37,000 m^2
Construction cost	N/A	N/A	200,000,000 AED
Energy performance			
Total energy consumption	278 $KwH/m^2/year$	560 $KwH/m^2/year$	N/A
Artificial lighting	40 %	N/A	N/A
Refrigeration cooling	1600 tons	N/A	1500 tons
Mechanical ventilation	20 %	N/A	N/A
Total estimated CO_2 output	700 ppm	Not known	Not known
Energy features			
Natural vent. (% of floor area)	20 %	Nil	Nil
Thermal transmission of building envelope	Not known	Not known	Above standard
Night-time ventilation provision	Forced, through BMS ventilation is provided as per the enthalpy reading	Forced	Forced
Utilization of building mass for thermal storage	No	No	Yes
Solar control systems	External eggcrate shading devices	Only internal blinds	Only internal blinds
Building designed to maximize use of daylight	Yes	No	No
Net floor area %, needing artificial lighting	60 %	100 %	100 %

(continued)

(continued)

	Dubai World Trade Center (DWTC)	Emirates Towers Office Building (ETOB)	National Bank of Abu Dhabi Headquarter (NBAD)
Energy-saving controls for artificial lighting	Building management system	Computer-based centralized lighting control system	Lighting control system, access control system
Use of energy-efficient lighting fixtures	Reflective type diffusers	Modular and compact fluorescent luminaries, each light fixture is attached to a lighting control module which supplies power and enables independent or group dimming and on/off switching	Task-oriented fluorescent fixtures with electronic transformer starters saving energy consump. up to 20 % and expand tube life up to 30 %

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Chapter 4
Indoor Environment and Assessment

Baizhan Li and Runming Yao

1 Introduction

High-rise buildings became popular due to increasing urbanization and land prices combined with advances in structure and construction technologies. By the mid-twentieth century, high-rise buildings featuring steel structural frames and glass exterior sheathing had become a standard feature of the architectural landscape in most countries worldwide (Encyclopædia 2013).

The birth of high-rise building in China dates back to the 1920s and 1930s. The rapid urbanization and large population lead to a high demand for the construction of high-rise buildings; in 2014, 60 % of new over 200 m buildings within global range were completed in China (CTBUH 2015). Figure 4.1 shows the distribution of super high-rise buildings more than 250 m high in China.

1.1 Indoor Environment Quality

The indoor environmental quality (IEQ) is considered to be one of the most important health concerns since people spend over 90 % of their time indoors. The air quality and pollution are the most important environmental factors related to symptoms of Sick Building Syndrome (SBS) in offices (Li 1998). Besides the health concern, the indoor environment has a considerable impact on workplace productivity and occupant well-being. It is essential to understand the criteria for assessing IEQ. Five key factors have been identified as indicators for IEQ assessment based on a broad literature review, namely acoustic, thermal comfort, indoor air quality, visual and electromagnet field (Yao et al. 2008).

B. Li (✉) • R. Yao
Chongqing University, Chongqing, China
e-mail: r.yao@reading.ac.uk

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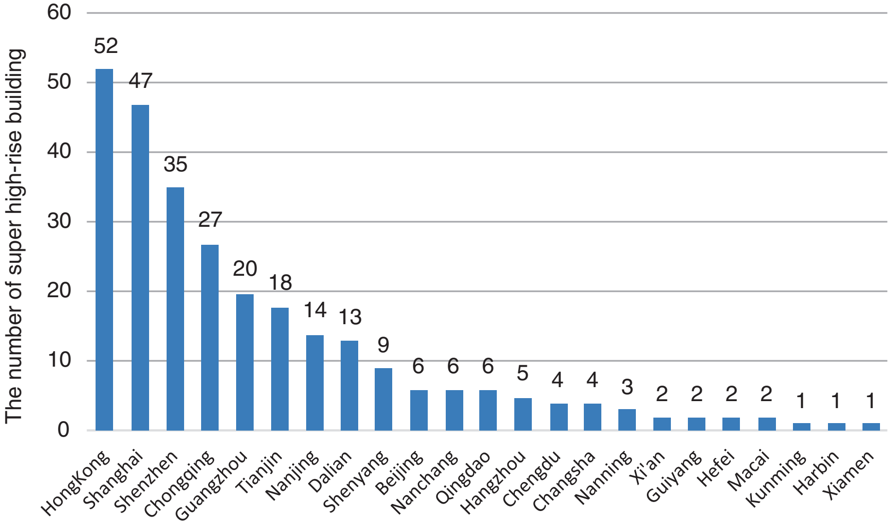

Fig. 4.1 Distribution of super high-rise building more than 250 m in China

While the aim of indoor environment design in high-rise is the same as for other types of building—to maintain a comfortable and healthy indoor environment for occupants to work and rest—due to their height and high population density, the indoor environment in high-rise buildings has specific requirements. The study about super-tall residential buildings in Korea reveals that health, including physical health and mental health, is the most influential index for resident well-being, followed by safety and security (Lee et al. 2011). In order to maintain the well-being of occupants, a safe and comfortable indoor environment should be preserved.

2 Acoustic

Environmental noise is unwanted or harmful sound. This is commonly caused by human activities including road traffic, railways, air transport, industry, recreation and construction; and perceived in the near domestic environment such as residential areas, public spaces and community environments like schools (Kang 2013). Emitted noise in high-rise buildings could come from elevators, public facilities, sanitary system pipework, pressurized water supply and drainage systems. Though measures such as vibration damping and sound insulation have been attempted, a noisy indoor environment is still prominent in many high-rise buildings.

Outdoor noise could be the issue affecting the indoor acoustic environment. For example, opened windows can transfer outdoor noise into buildings. In naturally ventilated high-rise buildings, the sound pressure level increases with the floor level due to wind and air temperature influences (Dahlan 2009). Studies reveal that the

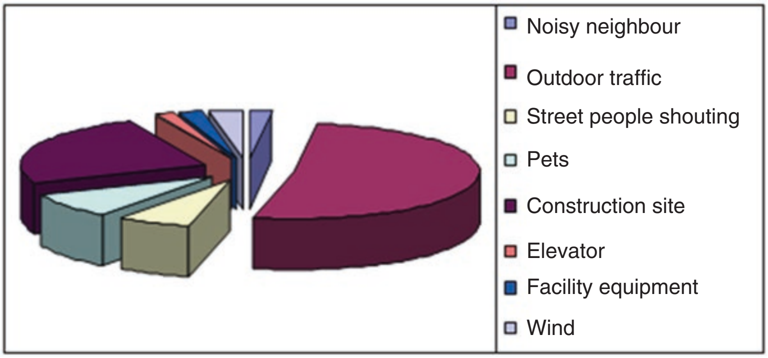

Fig. 4.2 The noise sources in high-rise buildings in China (Wang et al. 2012)

higher the level of the building, the level of noise received indoors increases (Liu et al. 2009). The high density of high-rise buildings magnifies the effect of noise and extends the time over which it is suffered. This phenomenon may be caused by the repeated reflection of sound waves between buildings (Wu 2007).

A survey from Wang et al. (2012) shows the main source of the noise in high-rise buildings (see Fig. 4.2).

From the figure we can see that eight sources have been regarded. Among that, outdoor traffic noise is regarded as the main source, which accounts for more than 50 %, followed by the on-site construction noise due to the urbanizations. Other noise sources include noisy neighbours, pets and facility systems.

The low-frequency noise will affect occupants' working productivity and even health. The sound pressure level of low-frequency noise is much higher than that of high-frequency noise in the facilities room, and the attenuation performance of low-frequency noise is weaker than that of high-frequency noise in occupied rooms (Xu 2006).

Throughout the various physical layers of urban society, acoustics, or urban *soundscapes*, can impact on people's physiological and psychological well-being. Undesirable noise can seriously degrade the experience of occupants living in problem locations or conversely, a well-designed urban environment that has considered its acoustic impact can bolster work productivity and general well-being through understanding the physical properties of form (Kang 2013).

Proper control over the noise and maintaining a comfortable acoustic environment is very important for occupants' well-being in high-rise buildings. The noise control measures can be focused on buildings and service systems. Controlling noise in buildings includes façade acoustic isolation, floor impact isolation, the design of party walls, waste pipes, entrance doors, in-sink garbage disposal units, road traffic and aircraft noise and pools above sensitive areas. Control over service systems includes mechanical plant, duct-generated noise, heat exchange pump rooms, fan-assisted variable air volume boxes, pool filtration plant, condensers and chilled water pipe systems, lift motor rooms, lifts travelling in lift shafts, garbage chutes, water supply pumps, standby power plant, SPA baths and pool vacuum cleaning systems (Palmer 2008).

3 Lighting

Lighting systems will influence the indoor visual comfort and the work productivity. The use of glass curtain walls in high-rise buildings modifies the building outlook and transmits more daylight to reduce the electricity load for illumination. However, this could lead to light pollution in the urban area when the glazing reflects direct sunlight within the urban area. Consequently, pedestrians will suffer from the light pollution. In addition, the energy demand for cooling will significantly increase with a large glazing ratio. The high density of high-rise buildings in urban areas affects the indoor daylight level of the lower floors. Wang et al. (2012) conducted a questionnaire survey in residential buildings in China. It was revealed that, in general, the people living in the higher levels (above the 18th floor) feel that their rooms are brighter.

People have a right to have access to daylight in a building according to the property laws, so reasonable planning is very important for the construction of high-rise buildings to confirm a good natural light visual environment for lower floor residents (Gou et al. 2010). Apart from reasonable landscape planning, artificial light systems should also be applied to supply additional luminosity when natural lighting is not sufficient.

4 Thermal Comfort

High-rise buildings also bring high occupancy density. In residential buildings, the heat released into rooms is from domestic appliances including cooking, kettles, entertainment, lighting and occupants' activities. In office buildings, the heat is released from office equipment including computers, printers, artificial lighting and human activities. Due to the excessive use of glass external façades, solar radiation significantly increases the solar gains in summer thereby causing thermal discomfort.

There are various definitions of thermal comfort. In heat balance theory, Fanger defines thermal comfort as a status where 'people would feel neither cold nor hot' (Fanger 1972). A person's thermal sensation is affected by the physical environment and personal factors. The physical environment includes parameters of air temperature, mean radiant temperature, relative air velocity and water vapour pressure in ambient air (humidity). The personal factors include metabolic rate (heat production in the body) and clothing level. Thus, there are both physical and non-physical factors influencing the thermal comfort of subjects. In addition to the physical environmental factors and personal factors, some other factors, e.g. anthropological and psychological factors, could also affect thermal sensations. These include age, gender, lighting and the occupant's state of health.

According to the thermal comfort survey in high-rise residential buildings in Chongqing and Shanghai, China, it is revealed that there were no significant discrepancies of the occupant thermal comfort satisfaction in summer among the residents living in lower, middle and higher levels of the building. This is because air conditioning is popularly used in this area in summer regardless of the number of floors (Shi et al. 2007; Wang et al. 2012).

4.1 Recommendations for Office Environments

Fanger (1972) describes a method for the use of the PMV (*Predicted Mean Vote*) and PPD (*Predicted Percentage Dissatisfied*) in practical applications.

Table 4.1 lists the recommended indoor thermal comfort criteria for offices.

As demonstrated in Table 4.1, the indoor climates are classified in terms of either temperature or PMV–PPD ranges, such as categories A, B and C in ISO7730 and categories I, II and III in EN15251 and the Chinese standard. These standards can be used to assess the indoor thermal environment via dynamic thermal simulation by counting the number of hours that are within the thermal comfort zone according to the different standards.

5 Air Quality

The existence of high-rise buildings will influence the microclimate of their neighbouring area. They act as obstacles to, and pathways for, the wind, allowing streets with taller buildings to capture more fresh air (Hang et al. 2012). At the same time, some air pollutants will be discharged into the atmospheric environment from high-rise buildings. They include lampblack from kitchens, exhaust gas from toilets, hot air from air condensing units, exhaust gases from underground garages and bad smells from refuse storage areas. The degree of air pollution usually intensifies in the morning and evening rush hours. It is difficult for air pollutants to dilute and diffuse in the area with a high density of buildings, especially for large-scale blocks of high-rise buildings.

Some tests have been conducted in Zhengzhou to explore the characteristics of the vertical distribution of particulate matter (Liu et al. 2009). As for TSP and PM10, the concentration declines with the elevation until the height reaches around 60 m, then the concentration increases with the elevation. As for PM2.5 and PM1, the concentration increases with the elevation. On lower stories, the concentration levels are mainly subject to gravity; however, on the higher stories, the concentration levels are mainly subject to atmospheric turbulence (see Fig. 4.3).

Table 4.1 Thermal comfort criteria for offices

Thermal comfort standard	Recommended values		
ASHRAE Standard 55	80 % Criteria (PPD ≤ 20 %; −0.85 < PMV < +0.85)	$T_c = 0.31T_{out} \pm 17.8 \pm 3.5$	
	90 % Criteria (PPD ≤ 10 %; −0.5 < PMV < +0.5)	$T_c = 0.31T_{out} \pm 17.8 \pm 2.5$	
ISO 7730	Category	Summer (°C)	Winter (°C)
	A (PPD < 6 %; −0.2 < PMV < +0.2)	24.5 ± 1.0	22.0 ± 1.0
	B (PPD < 10 %; −0.5 < PMV < +0.5)	24.5 ± 1.5	22.0 ± 2.0
	C (PPD < 15 %; −0.7 < PMV < +0.7)	24.5 ± 2.5	22.0 ± 3.0
EN15251	I (PPD < 6 %; −0.2 < PMV < +0.2)	$T_c = 0.31T_{out} \pm 17.8 \pm 2.5$	
	II (PPD < 10 %; −0.5 < PMV < +0.5)	$T_c = 0.31T_{out} \pm 17.8 \pm 3.5$	
	III (PPD < 15 %;-0.7 < PMV < +0.7)	$T_c = 0.31T_{out} \pm 17.8 \pm 4.2$	
CIBSE Guide A	Air-conditioned (PPD < 10 %; −0.5 < PMV < +0.5)	Summer (°C)	22–24
		Winter (°C)	21–23
	Non-air-conditioned (PPD < 10 %; −0.5 < PMV < +0.5)	Free-running	$T_c = 0.33T_{rm} \pm 18.8 \pm 2$
		Heated or cooling	$T_c = 0.09T_{rm} \pm 22.6 \pm 2$
China standard	For heated and cooled buildings		
	I	PPD ≤ 10 %	−0.5 ≤ PMV ≤ +0.5
	II	10 % < PPD ≤ 25 %	−1 ≤ PMV < −0.5 or +0.5 < PMV ≤ +1
	III	PPD > 25 %	PMV < −1 or PMV > +1

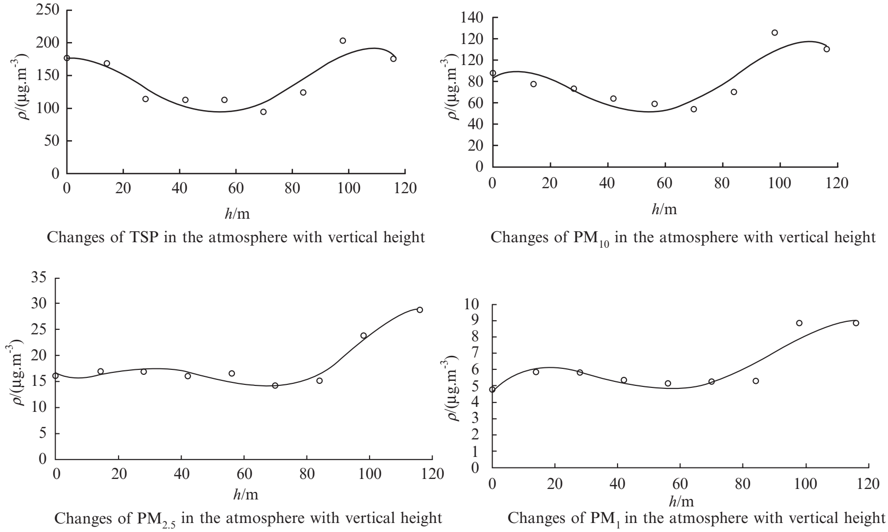

Fig. 4.3 Vertical distribution of particle pollution in the atmosphere (Liu et al. 2009)

Natural ventilation is widely promoted in high-rise buildings for its energy-saving potential with its effect being mainly influenced by wind speed, direction and architectural composition (Cui et al. 2012). As shown in Fig. 4.4, during the natural ventilation process, the exhaust air of one flat may become the intake of the adjacent upper flat, and vertical upward transport of contaminants between flats in high-rise residential buildings with natural ventilation will cause problems for the airborne transmission of infection (Gao et al. 2008a). According to tests and simulation work carried out in Hong Kong, in a high-rise building, normally 5 % of the exhaust air will enter the room upstairs due to buoyancy lift (Gao et al. 2008b). Studies have proved that the stack effect plays a very important role in indoor airborne virus transmission from lower floors to higher floors in high-rise hospital buildings (Lim et al. 2011). While wind tunnel tests on a 1:30 scale model of a 10-story residential building illustrated that pollutants can not only spread both upward and downward in the vertical direction, but also in horizontal directions (Liu et al. 2010).

In the buildings with an atrium, the concentration of pollutants in the atrium is higher than that in the surrounding areas with more contaminants being found on higher floors than on lower floors. The same tendency appears in the buildings with long corridors (Zhou 2006).

Mobile-source-related pollutants CO and PM10, as well as volatile organic compounds (VOCs), have been studied in high-rise apartment buildings. The outdoor air concentrations of CO and PM10 are much lower in higher-floor apartments compared to those on lower floors. Also, their concentrations were significantly higher in the winter and summer. But the difference of indoor CO and PM10 concentrations between the lower-floor and higher-floor apartments varies with season. Closing a major roadway will lead to a significantly higher PM10 concentration both indoors and outdoors. While CO indoor and outdoor concentrations did not

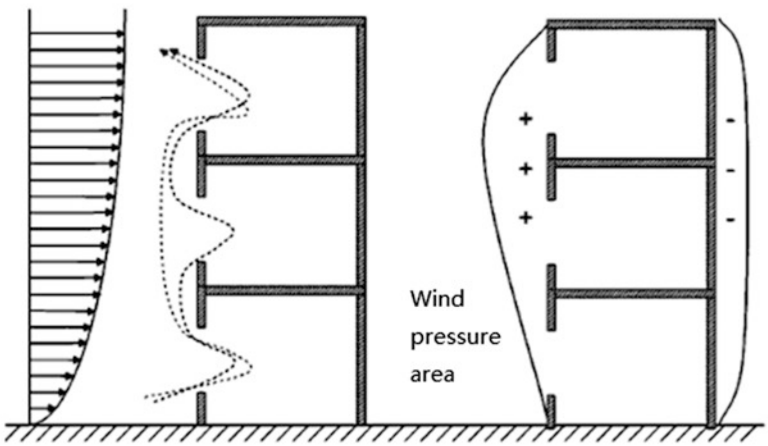

Fig. 4.4 An illustration of air pollutant cascade transfer under natural ventilation (Gao et al. 2008a, b)

vary much according to the distances from major roadways (Jo and Lee 2006). When considering VOCs, their ambient concentrations are much higher in summer for both low and high floors (Jo and Kim 2002).

6 Assessment Method

The indoor environmental quality (IEQ) assessment is complicated as it should concern multiple factors such as acoustics, illumination, thermal comfort and indoor air quality (IAQ). Most conventional studies on the indoor environment address each category separately. For example, many studies focus on a single category such as indoor air quality, indoor thermal comfort and indoor daylight environment. There is little information about a comprehensive assessment method considering multiple criteria which would affect indoor environmental quality. Some identified factors of indoor environment quality assessment are qualitative in nature and can only be assessed on the basis of human perception. Therefore, there is a demand to develop a holistic assessment method to assess indoor environmental quality.

Yao et al. (Yao et al. 2008) developed a holistic approach to evaluate indoor environmental quality. The recursive algorithm of the Evidential Reasoning (ER) approach has been used to aggregate multiple indoor environmental indicators, resulting in an aggregated distributed assessment for indoor environmental quality. The ER approach is an innovation method which is developed based upon the Dempster–Shafer (DS) theory. The ER approach is different from the conventional methods of multiple criteria decision-making (MCDM), because it uses a belief structure to describe the attribute of an alternative. One of the advantages of the ER approach is that it is capable of modelling precise data whilst capturing various types of uncertainties as well as the incomplete information.

Figure 4.5 shows the framework of indoor environment assessment criteria including the indicators of acoustic, thermal comfort, indoor air quality, illuminance and electromagnetic field in the upper level. Each indicator includes sub-indicators represented as E_1—Equalized sound pressure level in 24 h, E_2—Indoor temperature, E_3—Indoor humidity, E_4— Indoor air velocity, E_5—Predicted Mean Vote (PMV), E_6—Suspended particle, E_7—Carbon monoxide, E_8—Carbon dioxide, E_9—Formaldehyde, E_{10}—Volatile organic compounds (VOCs), E_{11}—Average illuminance of the area, E_{12}—Uniformity ratio of illuminance at the targeted surface, E_{13}—Ratio of daylight usage, E_{14}—electric field intensity of extremely low frequency (ELF) and E_{15}—Magnetic flux of extremely low frequency (ELF).

As one of the classic methods that handle uncertain information, so far the DS theory has found successful applications in many areas such as pattern recognition, information fusion, database and knowledge discovery, multiple attribute decision analysis or decisions and expert systems.

The model for assessment of IEQ is illustrated in Fig. 4.6. It is assumed that there are number of L indicators for IEQ assessment, and the indicators of IEQ are described as E_1, E_2, …, E_L. In addition, in order to apply the DS theory to assess

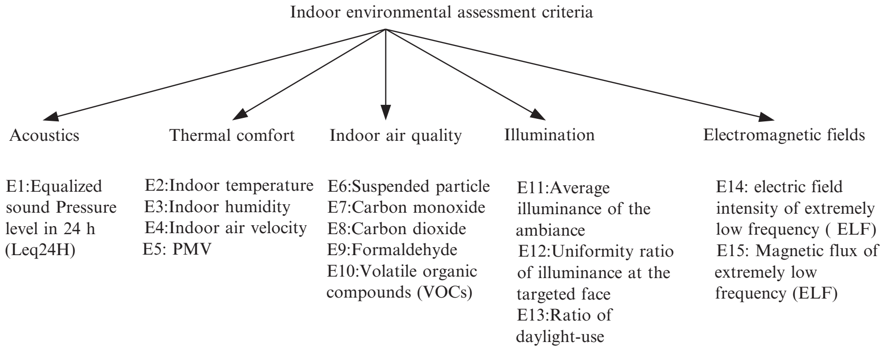

Fig. 4.5 Framework of indoor environmental assessment criteria (Yao et al. 2008)

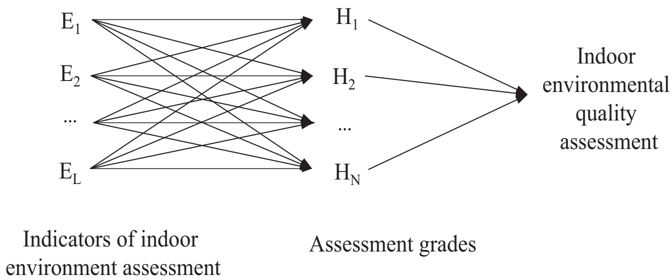

Fig. 4.6 The model of indoor environmental quality assessment

IEQ, it is assumed that these indicators are independent of each other. There are N assessment grades for each indicator, which are also the grades used to assess the overall IEQ. The assessment grades are described by $H_1, H_2, \ldots, H_N$. $H=\{H_1, H_2, \ldots, H_N\}$ is assumed to be a collectively exhaustive and mutually exclusive set and is considered as the frame of discernment of the theory of evidence, with each assessment of IEQ on each indicator being considered as a piece of evidence for the overall assessment of IEQ. There are L pieces of evidence sources for the overall assessment of IEQ in total. The ER approach is used to combine the L pieces of evidence sources to form an aggregated result for the assessment of IEQ in this model. As is mentioned above, in order to use the DS theory and ER approach to assess the IEQ, two assumptions are required. However, this method retains the generality of assessment of IEQ.

There are three key steps for implementing the above model to assess the IEQ.

Step 1: Identification of the indicators of IEQ. Identification of the assessment grades for the overall IEQ, which are also the assessment grades for each of the indicators of IEQ.

Step 2: IEQ is assessed on each indicator and each grade. On some factors, the IEQ is evaluated to one of the grades with certainty. On some other indicators, the IEQ is evaluated to more than one grade with a degree of belief, which describes the strength with which the IEQ is assessed to a particular grade on a particular indicator.

Step 3: The recursive ER algorithm is used to aggregate the assessment on each indicator, resulting in an aggregated result, which contains the overall degree of belief with which IEQ is assessed for each grade.

Step 4: IEQ is assigned to a certain assessment grade based on the analysis of the overall degree of belief for the IEQ.

The ER approach uses belief structure to capture the precise and the uncertain or incomplete original assessment information. As mentioned in the assessment model of IEQ, there are L indicators and N assessment grades for the assessment of IEQ. It is supposed that the relative weights of the L indicators of IEQ are given by $W=(\omega_1, \ldots, \omega_L)$, which is normalized to satisfy the following condition:

$$\sum_{i=1} \omega_i = 1 \quad \text{and} \quad \omega_i \geq 0, \ i=1,\ldots,L.$$

While IEQ is assessed on an indicator E_j to a grade H_n with a degree of belief of $\beta_{n,j}(n=1, \ldots N; j=1, \ldots L)$, for each indicator of IEQ, $\beta_{n,j}$ satisfies:

$$\beta_{n,j} \geq 0 \quad \text{and} \quad \sum_{n=1}^{N} \beta_{n,j} \leq 1 \quad j=1,\ldots N$$

Table 4.2 illustrates the belief degree structure of the IEQ assessment.

It is necessary to determine the weights of each indicator when applying DS theory and the ER approach. In this study, the weights of each physical category are achieved by the Analytical Hierarchy Process (AHP) method and the related survey. Table 4.3 shows the weights of the categories and Table 4.4 lists the weights of indicators from an indoor environmental quality survey in China in 2007.

Table 4.2 The belief degree structure of the IEQ assessment

Indicators of IEQ	Weights	Assessment grades $H_1, H_2 \ldots, H_n$
E_1	ω_1	$\beta_{1,1}\ \beta_{1,2} \ldots \beta_{1,n}$
E_2	ω_2	$\beta_{2,1}\ \beta_{2,2} \ldots \beta_{2,n}$
…	…	… … … …
E_L	ω_L	$\beta_{L,1}\ \beta_{L,2} \ldots \beta_{L,n}$

Table 4.3 Weights of categories

Category	Weights
Acoustics	0.203
Thermal comfort	0.208
Indoor air quality	0.290
Illumination	0.164
Electromagnetic fields	0.135

Table 4.4 Weights of indicators

Indicators	Weights
E_1: Equalized sound pressure level in 24 h (L_{eq}24H)	0.203
E_2: Indoor temperature	0.052
E_3: Indoor humidity	0.052
E_4: Indoor air velocity	0.052
E_5: PMV	0.050
E_6: Suspended particles, PM_{10}	0.050
E_7: Carbon monoxide (CO)	0.058
E_8: Carbon dioxide (CO_2)	0.058
E_9: Formaldehyde (HCHO)	0.058
E_{10}: Volatile organic compounds (VOCs)	0.058
E_{11}: Average illuminance of the ambiance	0.041
E_{12}: Uniformity ratio of illuminance at the targeted surface	0.041
E_{13}: Ratio of daylight-use	0.041
E_{14}: Electric field intensity of extremely low frequency (ELF)	0.067
E_{15}: Magnetic flux of extremely low frequency (ELF)	0.067

A case study has been presented in this chapter to demonstrate the results of the developed IEQ assessment model. In this example, it is assumed that there are five assessment grades for the assessment of IEQ. The assessment grades are described as H_1, H_2, H_3, H_4 and H_5. H_1 is the best performance while H_5 is the worst performance of IEQ. Table 4.5 shows the results of the case study.

Through a complicated calculation process, aggregated results from the programme will be produced (see Fig. 4.7). From Fig. 4.7, we can see that the grade of H_3 overwhelms the other grades. The degree of ignorance is 0.014. That means the ignorance of this assessment is within an accepted range. So the IEQ in the example is assessed to grade H_3.

The case study has demonstrated the implementation of this method. In each individual case, the weights of indicators and the rule of the IEQ assessed to each grade on each indicator need to be investigated based on the individual situation.

7 Summary

The shortage of land and the explosion of population lead to the growth of high-rise buildings in urban areas. While the land shortage problem will be ongoing in most countries throughout the world, there is an inevitable and constant trend favouring the growth in high-rise buildings due to the advantages of compact public facilities and transportation systems. The question about how to create a comfortable and healthy indoor environment should be considered in the process of planning and

Table 4.5 The belief degree in a case study

Indicators (weights)	H_1	H_2	H_3	H_4	H_5
E_1 (0.203)			0.9	0.1	
E_2 (0.052)		0.6	0.4		
E_3 (0.052)			0.7	0.3	
E_4 (0.052)			0.5	0.4	
E_5 (0.052)		0.3	0.5	0.2	
E_6 (0.058)		0.1	0.8		
E_7 (0.058)			0.1	0.3	0.6
E_8 (0.058)	0.2	0.3	0.5		
E_9 (0.058)		0.5	0.5		
E_{10} (0.058)			0.7	0.2	
E_{11} (0.041)		0.6	0.4		
E_{12} (0.041)		0.1	0.5	0.4	
E_{13} (0.041)		0.9	0.1		
E_{14} (0.067)		0.8	0.2		
E_{15} (0.067)		0.3	0.7		

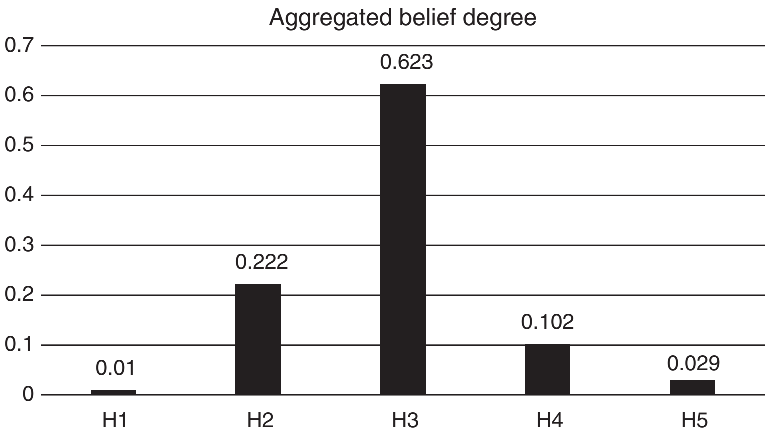

Fig. 4.7 The aggregated belief degree for each assessment grade

construction of a high-rise building. This chapter presents a method of assessing indoor environmental quality of a high-rise building in China applying DS theory and the ER approach. An example of implementation of the method is demonstrated. The method can be applied to any other cases with modification.

Comprehensive analysis and evaluation of the indoor environmental quality in high-rise buildings should be considered at the stages of planning and post occupant. Taking full account of the indoor environment quality, a series of measures to improve the acoustic environment, light environment, thermal environment, air environment, air pollution and other related issues should be developed. Accordingly, the legislations of indoor environmental quality should be established.

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. High-rise buildings need to emphasize the connection with the environment and people through ideas about occupant health and well-being.

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Chapter 5
The Increasing Demand on High-Rise Buildings and Their History

Manuel Correia Guedes and Gustavo Cantuária

1 Introduction

Large-scale urban centres have entered the twenty-first century with a paradox to discuss. As the cities touch the skies with their growing skyscrapers, they also reach out to attract and embrace as many people as possible. Aiming to become an important financial, commercial, cultural, technological, or touristic place, and therefore attract investments, they need to grow. The more the cities grow, more people are needed to make it grow. With more people, more infrastructures are necessary. In this on-going trend, tall buildings appear both as protagonists and antagonists.

On the positive side, tall buildings may claim to be environmentally friendly in the process of urban densification, as they take up minimum space (on the urban plan), help mobility due to proximity to public transportation, and maximise the potential use of building installations. On the other hand, they also raise suspicion because of characteristics such as deep plan, lack of natural ventilation, urban shadows, sealed glass facades, solar reflection, and glare. In addition, arguably the biggest dispute is overcoming the perception of being vanity icons, driven by power and greed—into a more humane view, based on sustainable habitats. Shifting values is indeed the essence and core of the urban agenda of this new millennium.

Tall buildings traditionally resonate with domination, individualism, self-centredness, and egocentricity. That is *passé, démodé*, and *cliché*. This new era is not one of looking solely within, but soulfully outwards. The ultimate challenge of tall buildings is one of collaboration. It's a symbiotic relationship, one of integrating the

M.C. Guedes (✉)
Departamento de Engenharia Civil e Arquitectura,
Instituto Superior Técnico - Universidade de Lisboa,
Gabinete 2.67, Av. Rovisco Pais, Lisbon 1049-001, Portugal
e-mail: manuel.guedes@tecnico.ulisboa.pt

G. Cantuária
Faculdade de Arquitectura, Universidade de Brasilia, Brasil

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natural environment with the built environment in the most thoughtful and responsible manner. A genuine sustainable agenda.

2 Sustainability

Due to the fast deterioration of quality of life, seen in a massive scale in the slums and favelas all over the developing world, man is in a desperate quest to revert this degrading path. Like most of the issues in modern society, architecture too seems to have been stricken by the influence of the 'globalization' process, where local cultural identity gives way to the language of ignorance and law of the strongest. Importing the architectural ideas and concepts of foreign countries, whose geography, environment, and climate are totally different from that of origin, has led to improper, often catastrophic, architectural solutions and typologies, especially in developing countries. Furthermore, any interesting lessons of what were once the most sensible ways of building, according to culture and climate, are still being ignored and forgotten.

When money and resources are abundant, how, where, and when one builds is frequently overlooked. It is important, not to say essential, that one makes the most benefit of its living environment, in an intelligent and sustainable manner. The appropriateness of one solution for one community is not necessarily appropriate for another. There are a variety of problems in big urban centres; therefore, there should be a variety of solutions. Ideas should be abundant and appropriate to each context, and knowledge never ignored, always feeding back to past experiences and ancestors. Consequently cultural values, tradition, and historic memory, all that makes people and cities diverse, interesting, and unique, will be preserved.

As we move through a new century and a new millennium with an absurd increase in population, increase in hunger, and more astonishingly an increase in social differences, sustainable development is no longer an option but a requirement. It should no longer be theoretical, but practical. In the 1987 United Nations Conference entitled 'Our Common Future', it was defined that "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Architecture plays a major role in making this development possible.

The urban centres are one of the most important works produced by humanity, and undoubtedly the one that has caused most environmental damage. Deforestation, heat island effect, and climatic changes are examples that blame the rapid growth of the industrialised city. The exaggerated use of natural resources and energy has also been a major concern. In most big cities, around one third (33 %) of the final consumption is related to the buildings.

Sustainability in developing countries, which hold 75 % of the world's population, is a bigger challenge. They have only "17 % of the world's gross national product, 5 % of science and technology, 15 % of energy consumption, 30 % of the food grains, 11 % of the education spending, and 6 % of the health expenditure" (Rice and Rasmusson 1992).

According to last Revision of the official United Nations population estimates and projections about 54 % of the world's population currently lives in urban areas, and this proportion is expected to increase to 66 % by 2050. Projections also show that urbanization combined with the overall growth of the world's population could add another 2.5 billion people to urban populations by 2050, a total of 9.8 billion people, with close to 90 % of the increase concentrated in Asia and Africa.

In 1990, there were ten 'mega-cities' with ten million inhabitants or more, which were home to 153 million people, or slightly less than 7 % of the global urban population at that time. This has increased to 28 mega-cities worldwide in 2014, home to 453 million people or about 12 % of the world's urban dwellers. Of these 28 mega-cities, 16 are located in Asia, 4 in Latin America, 3 in Africa and Europe, and 2 in Northern America. By 2030, the world is projected to have 41 mega-cities with ten million inhabitants or more.

The first thing to be aware is that natural resources are limited, especially in a world of fast increasing population. Manmade fuels and electricity are costly, inaccessible to poorer nations. Energy systems cannot cope with the exaggerated demands. The more we use today, the less future generations can also rely on them. This opposes any logical idea of sustainability. Generally, design is not taught in most places in the context of its social and ecological impact. Mackenzie (1991) in his approach to green design suggests the approach of "eco-efficiency, which means the delivery of the maximum benefit to the user, with the minimum use of resources and the least possible environment damage."

There is today a vast body of knowledge on how to design buildings, including skyscrapers, in a sustainable and affordable way, through the use of bioclimatic, low energy strategies. There are even (a few) examples of low-energy (more sustainable) skyscrapers that could be followed, such as Norman Foster's Commerzbank building in Frankfurt, Ken Yang's Bioclimatic skyscrapers, or, on a smaller scale, the more recent wooden London's Stadthaus, the Forte Building in Melbourne, or Michael Greene's 'Plyscraper' in Vancouver. Unfortunately, this knowledge is not being put to practice, being replaced by 'status' driven typologies—deep plan buildings, with all-glazed facades, which are highly energy consuming and naturally damaging to the environment. For example, about one-sixth of all electricity generated in the United States is used for air conditioning in buildings—as a result of poor design and unrealistic comfort standards. That is about 40 billion dollars (Fig. 5.1).

3 Brief Historical Overview of Tall Buildings

In different periods of the history of architecture, man has incessantly challenged heights in construction, being limited only by its technological capacity. Naturally, what could be called as a tall building has changed dramatically over the years. Verticality has always been a symbol of superiority and power. In medieval times, San

Fig. 5.1 A 'glass tower', recently built in Cascais, Portugal. Unfortunately, Glass Architecture is today fashionable, symbolizing economic status. It leads to excessive energy consumption (e.g., due to air conditioning), poor comfort levels, and damage to the environment. It is in flagrant contradiction with a truly sustainable design practice

Gimignano in Italy was considered the Manhattan of its era. Cathedrals lashed up in the sky during the Gothic age in a symbolic attempt to bridge the mundane life on earth with heaven. The vast interiors reminded the religious community of their smallness in relation to the Almighty, and at the same time imposed respect towards the Holy.

Literature has it that the term 'skyscraper' was used to classify tall buildings by the end of the nineteenth century, and beginning of the twentieth. In modern times, it is widely accepted that in the 1920s and 1930s the tall building typology was already an architectural force. The United States is considered the birthplace of high-rise buildings in our contemporary society. The American cities of New York and Chicago began competing for the world's tallest building. Buildings in Chicago like the Tribune Tower (1925) at 141 m were promptly beaten by buildings in New York such as the Chrysler Building (1930) at 319 m and the Empire State Building (1932) at 381 m high. Engineering seemed to have no constraints, and technology was pushed to its limits. "This was a period of fascination with the tall building, its iconic forces and its dazzling views from unimaginable heights. Buildings of that time are still recognized today as some of the most spectacular and grandiose worldwide—the Empire State Building representing one of the last models of the art-nouveau and art-deco periods, the so-called 'golden age of the skyscrapers'" (Gonçalves 2010).

In Europe, leading the modernist concept of 'form follows function' and 'less is more', Mies Van der Rohe proposed 'glass' skyscrapers for Berlin, responding to the need for modern office buildings. Another building designed by Mies and Philip Johnson in 1958, the Seagram Building in New York City, became an icon of the International Style. The Seagram Building is a clear expression of functionality in line with construction rationalization in tall buildings, making it lighter and cheaper than any other at the time. During the same period, Walter Gropius also contributed with innovations, proposing designs for the first residential buildings in the European continent. Le Corbusier was another modernist involved in new aspirations for tall buildings, proposing in 1923 the idea of the City of Towers, where he idealises the future city dependant on high-rise buildings, housing 4000 people each. Other utopian designs appeared around that time. Russians had some proposals, but probably the most far-fetched example came from Frank Lloyd Wright in 1956, with his 1600 m high design for a building in Illinois.

It is interesting to notice that although air conditioning already existed by then, the buildings from the first half of the twentieth century relied on natural ventilation for cooling. Its internal environment was dependent on its relation to the external environment. Therefore the benefits of daylight, passive cooling, and acoustic comfort were based on the interaction of the building design and its fabric with the exterior.

The post-war period saw the spreading of the International Style, where tall buildings increased the size of their (deep) plans, leading to the excessive use of artificial lighting and air conditioning. The extensive repetition and banalisation of the design guidelines from the International Style in the United States and elsewhere resulted in a building model of poor contextual relationships with urban culture, climate, and urban design. This was a rupture of designing with the climate, and the beginning of a vicious cycle of buildings was totally dependent on artificial energy sources for lighting and cooling.

During the 1960s and 1970s, the industrial business in the United States was booming, which led to another race for the world's tallest building. This was a statement of power and wealth. One of the two main buildings, which resulted from this period, was the World Trade Centre in New York in 1972, with 417 m, and which was eventually destroyed in a terrorist attack on September 11th 2001. The other iconic building of this period is the Sears Tower, built in 1973, 442 m high.

Soon after, in 1973, there was an economic turnaround and a world energetic problem with the oil crisis that halted the skyscraper race. For the first time, people's attention was directed to the fragility of our natural resources and our deep need of its preservation. The rational use of fossil fuels and the environmental quality in spaces in tall buildings were beginning to be discussed. The profound dependency on air conditioning also brought an increase in health problems, and awareness of the sick building syndrome (SBS), caused by its poor air quality. Consequently, the 1980s saw the first moves to a more environmentally friendly design for tall buildings, and the publication of the Brundtland Report (1987), addressing the issues and concepts of sustainability. This report was eventually followed by a green agenda, officially known as Agenda 21, resulting from the UN summit in Rio, in 1992.

The 1990s saw a spread of the phenomenon of globalization and the economic pressures resulting from it. New financial centres were booming around the planet, especially in big urban cities of developing countries like Taipei, Singapore, Shanghai, Beijing, and Dubai. This led to a great demand for office and commercial buildings, rapidly transforming the urban grid of already densified cities. The capitalist transformation and consequent economic development forced a vertical building boom in places of Southeast Asia and the Middle East. The most representative building of this period is the Petronas Tower, built in the capital city of Malaysia, Kuala Lumpur, in 1997. Its 452 m beat the Sears Tower as the tallest building on the planet, until then.

In a different direction, tall buildings in Europe were being discussed in the light of environmental awareness. High-rise buildings with sustainable concepts were appearing, such as Norman Foster's headquarters of the Commerzbank in Frankfurt in 1998. Its design included passive strategies for cooling, daylighting, and heating. Sky gardens and a central atrium were also incorporated. It is said that for over 80 % of the year the building is naturally ventilated. The Commerzbank is acknowledged as the first and one of the most important environmental tall buildings in Europe. The recognition of the importance of sustainability and environmentally responsible buildings led to the introduction of rating systems such as BREEAM, which assesses how 'green' is a building.

Since the late 1990s and throughout this young twenty-first century, there has been another, yet much greater, race for the world's tallest building. Countries like Dubai and Abu Dhabi have with incredible speed completely transformed their natural environment into a sea of tall glass buildings, totally disconnected to their climate and completely unaware of their energetic cost and environmental damage. This trend is not stopping so soon, as there is a new 'generation' of buildings planned, and others already being built, over the next decade.

There is no doubt that tall buildings play a significant role in today's society. It expresses wealth, power, status, economic capacity, and technological accomplishment. Nevertheless, concerns regarding environmental performance, public welfare, and sustainable development are not a choice anymore, but a necessity.

4 Greenery and High-Rise Buildings

Recently, there has been a spate of interest in how to combine the stressing demands of modern life and society with a healthy natural environment. Applied researchers have become increasingly interested in how to benefit the most out of natural elements and resources such as sun, wind, and vegetation. The possibility that man can benefit from natural cooling and evapotranspiration from vegetation instead of artificial air conditioning, humidifiers, or any other energy-consuming device has generated interest in the development of passive cooling environments.

Two negative aspects of great urban societies are the overheating of a city, a process commonly known as the heat island effect, and pollution. The main reasons for these major threats are firstly the highly successful economic strategy of the wealthiest nations, backed as it is by technological innovation. Secondly is the accelerated rate in which the world's population is growing. The bigger the city, the bigger these problems are. Vegetation in its various forms has been said and known as being able to diminish these negative aspects. Greenery has long been known for its cooling effects and improving unfavourable microclimatic conditions around buildings, and consequently ameliorating the quality of life of its users.

To create comfortable indoor and outdoor living environments, or to reduce cooling loads, solar control is the most basic construction method of building in the low latitudes. Nevertheless, "it is widely admitted that plants around buildings alter the adverse microclimates and make the thermal environment more pleasant and liveable. Planting for solar control or wind protection is a good practical example" (Hoyano 1988).

Nevertheless, architecture is the form of art with most impact on people and their perceptions. "Architecture reflects, materializes and eternalizes ideas and images of ideal life. Buildings and towns enable us to structure, understand and remember the shapeless flow of reality and, ultimately, to recognise and remember who we are" (Pallasmaa 1996). Our living environment "strengthens the existential experience, one's sense of being in the world, essentially giving rise to a strengthened experience of self" (Pallasmaa 1996). The closer we bring nature to our habitats, the better use we can make of it, gaining in physiological and psychological aspects.

Trees and landscape are not only scenery, but linked with physical, biological, and cultural features. They include the entire community of all living and lifeless things, and depend on the relationships and forces of both the biotic and abiotic world. Man being an inseparable part of this system is in a position to modify it, to exclude, introduce, or change natural and unnatural elements in his surroundings. The quality of interference will define the extension and quality of sustainability.

To minimize the impact of external factors, especially wind, high-rise buildings are mostly built with sealed facades, neglecting any possibility of cooling through natural ventilation. The relentless use of central and mechanical air conditioning leads to an excessive and even unnecessary use of energy. Sometimes, a natural and comfortable external temperature of 26 °C is transformed into an unpleasant 18 °C due to air conditioning. Bigger problems such as overloading energy peaks and sick building syndrome come into question. "A vicious circle is created because waste heat from air-conditioning units to cool buildings dries up the city temperature which then requires larger cooling load for the buildings" (Takakura et al. 2000). Sick building syndrome is manifested as diffuse reactions to airborne compounds, aerosols, and other particulates, commonly found in poorly maintained air conditioners. Some reactions can be itchy eyes, dry mucous membranes, abnormal fatigue, headache, or other psychosomatic reactions (Ryd 1991).

Direct solar radiation impacting on walls and windows is the primary source of heat gain, but two other factors are also important: heat from ambient air, and

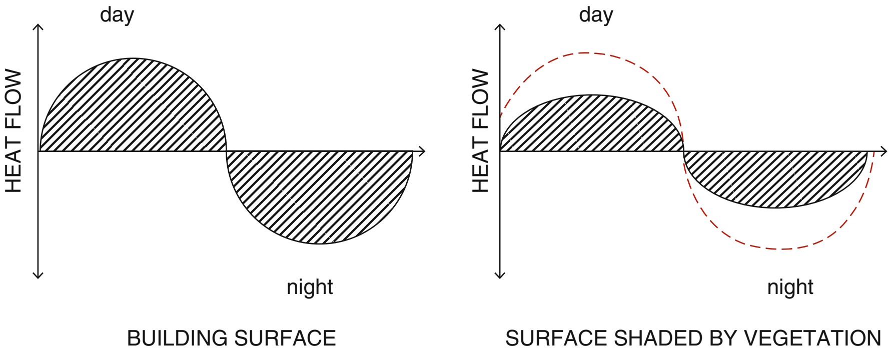

Fig. 5.2 Effects of vegetation on a surface (after Oke 1990)

indirect, long wave radiation from the immediate surroundings. All three of these factors can be moderated by vegetation growing close to a building's surface. The greenery works like a second skin to roofs and walls, acting as insulation. Figure 5.2 describes the effect.

Rooftops with vegetation can also decrease the heat flux through the rooftop slab. In urbanized areas during the summer, the vegetation system can be successfully applied to reduce the thermal load on buildings and to moderate hotter and drier climates. Studies by Harazono et al. (1990) indicate that the absolute humidity in the surrounding air increased and the air temperature in the room below decreased with the rooftop vegetation in summer. Investigations show that changes in plant activities cause seasonal variations in the effects of vegetation. During the summer for example, the transpiration of plants is more vigorous and plants and deciduous trees have leaves, which interrupt solar radiation and then shade building surfaces. Harazono states: "If we were able to grow plants and trees on unused surfaces without the need for any additional reinforcement, for example, rooftops or other open spaces, then we could obtain a more beautiful neighbourhood, a moderate microclimate, and a decrement in the thermal load on the air-conditioning of buildings."

Vegetation also interferes directly with air quality. The pollutants can be diluted or transformed into harmless substance before reaching their targets, which can be plant, animal, human being, or inanimate structure. Vegetation can act as an effective sink for airborne pollutants. They may intercept or absorb pollutants, which are then combined with plant tissue and are effectively removed from their pathway. Carbon dioxide is an essential part of the food making process of plants, photosynthesis. They absorb this pollution and it is then assimilated as carbon within the vegetation, with the by-product oxygen released into the atmosphere. Carbon dioxide is absorbed by the leaf surface through stomata. Once the pollutants are absorbed, they are diffused into intercellular spaces or dissipated by water films.

The inherent characteristics of vegetation such as evapotranspiration, dust retention, and shading indicate the enormous potential of working with the urban fabric and ameliorating the environmental performance of tall buildings. Ken Yeang, an architect from Malaysia, has embraced the idea of bioclimatic skyscrapers, linking different forms of greenery to his tall building designs. For the past three decades, he has taken the challenge of designing 'green' buildings, integrating the building with its natural environment, mainly in the tropics. The use of vegetation as a building element and fabric has allowed a very distinct architecture. Although there is not much data on the building's environmental performance, there is no doubt of its impact on public awareness towards an ecological approach. On the contrary of being a limitation, the environmental agenda allows for creative possibilities, inventiveness, and opportunities for sustainable expression, along with responsible ethics.

5 Conclusions

Growing cities are facing a troubling scenario. Population is rising at worrying speed, road networks expanding, suburbs spreading incessantly, increasing numbers of vehicles and pollution, great areas being abused, harming plants and man's life. The environment and human pride is being destroyed, leaving the city in a shameful state of landscape decomposition. The rural society has been overwhelmed by the urban, obfuscating cultural values and confusing collective instincts. Huxley described the uncontrollable urban colonisation as chaotic 30 years ago, and since then it has not gone any better: "Man is at last pressing hard on his spatial environment. There is little leeway left for his colonisation of new areas of the world surface. He is pressing hard on his resources, notably non-renewable resources. In fact, we are well on our way to ruining our material habitat. But we are beginning to ruin our spiritual, cultural and emotional habitat also. We are spreading great masses of human habitation over the face of the land, neither cities nor suburbs nor towns nor villages, just a vast mass of urban sprawl or sub utopia. And to escape this, people are spilling out farther and farther into the wilder parts and so destroying them. And we are making our cities so big as to be monstrous, so big that they are becoming impossible to live in." The survival of the urban areas depends on the city and nature being a single design.

With the impossibility to continue to spread outwards, tall buildings can be part of the solution and literally rise to the occasion. A responsible, sustainable, and creative design, one which relates to its natural environment, will be the stepping stone for a new paradigm in city planning.

Prof. Manuel Correia Guedes	Prof. Gustavo Cantuária
Instituto Superior Técnico	Faculty of Architecture
University of Lisbon, Portugal	University of Brasília, Brazil

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Chapter 6
The Sustainable High-Rise Building Renewables and Public Perceptions

Neveen Hamza

1 Introduction

This chapter looks into how users and the public perceive the efforts in achieving sustainable buildings and the inclusion of renewable energy technologies. It is acknowledged that social acceptance underpins the interaction between policy-makers, the public as community groups, and developers. Acceptance is usually based on perceptions gained from personal experiences, the media, personal information exchanges, and education. Wüstenhagen et al. (2007) break down the concept of social acceptance into three interchanging levels; sociopolitical acceptance, market acceptance, and community acceptance. The sociopolitical nexus influences government policies for incentivization schemes, distinctions between permissible planning, or the need for full planning approval applications. Case studies show how community acceptance plays a significant role in promoting failures and successes achieved when using passive architectural design as opposed to the inclusion of various renewables technological in high-rise public. Renewable technologies are more scrutinized by the public as a perception of the technologies' maturity, reliability, and their perceived visual intrusion in urban areas.

Key sustainable high-rise buildings achieving high sustainability accolades are chosen as case studies, with a professional understanding of the efforts needed to meet the strenuous criteria of BREEAM and LEED. In the UK, the voluntary code 'Building Research Establishment Environmental Assessment Method' 'BREEAM' (http://www.breeam.com/why-breeam) consists of a set of strategic principles and requirements which define an integrated approach to the design, construction, management, evaluation and certification of the environmental, and social and economic

N. Hamza (✉)
School of Architecture, Planning and landscape, Newcastle University,
Newcastle upon Tyne, Tyne and Wear, UK
e-mail: neveen.hamza@newcastle.ac.uk

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impacts across the full life cycle of the built environment. It is not publicized as a mechanism to boost public perception of sustainable buildings. Contrary to BREEAM, the Leadership in Energy and Environmental Design (LEED) in the USA, state on their home webpage that gaining a LEED award publicizes sustainability and boosts public appreciation of Green Buildings as a rating system. LEED advocates its impact on public perception leading to the encouragement and acceleration of global adoption of sustainable green building and development practices through the creation and implementation of universally understood, accepted tools and performance criteria. It is changing the way we think about how buildings and communities are planned, constructed, maintained, and operated. (http://www.usgbc.org/leed. An analysis of newspaper articles, social media, and tweets is used to identify shifting public attitudes to these structures and their objectives. This chapter contests that not all buildings meeting these high standards have been appreciated by the public. Diverse case studies such as the Federal building in San Francisco by Metamorphosis-2008, the Lion House in Northumberland England, Strada in London, and the green building in Temple Bar-Dublin are considered as examples of technical achievements of sustainable design but tepid public enthusiasm. This chapter considers the varying public responses to passive architectural solutions and renewable energy technologies of greater and lesser intrusive visual natures. Those that are more visually intrusive include those technologies with moving parts; those that demand substantial need for structural interventions and alterations, and with less evidence of their efficiency, such as urban wind turbines.

2 Incentivizing Sustainability and Public Acceptance

In the UK, support for and regulation to incentivize the take up of renewable energy generation faced major changes in 2015. Until then, there were major attempts to tighten targets for reducing energy consumption, carbon dioxide emissions and the impact of buildings on local ecology sustainable building regulations and voluntary codes were seen. These regulations had a particular backing during the UK coalition government, in which the minority Coalition party, the Liberal Democrats, had a clear policy mandate to promote sustainability and renewable energy (2010–2015). With an emphasis on the household level and public interest in green ideas, the major mechanism to achieve higher standards of sustainability in the UK building stock has been to incentivize increasing insulation levels and the inclusion of renewable technologies. The Feed-in Tariff scheme was the primary support mechanism introduced by this government to incentivize deployment of small- and medium-scale (<5 MW) renewable energy generation in the UK. The less intrusive static renewable technologies such as PV and solar thermal heating received a higher level of support through planning permissions and regulations compared to other technologies that might be described as more intrusive such as urban wind turbines. The scheme was launched in April 2010, and a review referred to as ‘Phase 2B’ came into effect in December 2012. This review implemented significant changes to tariffs and structures for non-PV technologies such as wind, hydro, and anaerobic digestion. It introduced lowered tariff levels for wind generation; amalgamated the tariff bracket for all turbines under 100 kW; and introduced a capacity-driven digression mechanism effective from April 2014.

The growth experienced by the small wind market sector in previous years has been dramatically reversed throughout 2013 and 2014. The Renewable UK report points out that this decline in the market is due to the implementation of Phase 2B of the Feed-in Tariff in December 2012; the deployed capacity of turbines within the sub-100 kW sector decreased over 2013 by a combined total of almost 55 % compared with 2012. When broken down, this represents a 49 % capacity decrease in the 15–100 kW bracket; a 72 % capacity decrease in the 1.5–15 kW bracket; and a 33 % capacity decrease in the 0–1.5 kW bracket. (small and medium wind UK market report, Renewable UK, March 2015, www.renewableUK.com.)

At the higher level of new buildings and commercial buildings, developers and architects alike would argue that regulatory compliance for sustainable buildings, and more so of buildings including renewables, needed a longer lead time for project approval and an increase in initial project costs. They would also concur that there were benefits that pushed the UK construction industry to think about energy demand and well-being in the design phase (Hamza and Greenwood 2008). Again, while it can be argued that the abolition of sustainability codes by the Conservative government in 2015 was a backward step away from agreed climate change targets, underpinned by a hope that a more educated and accepting public might now inform a demand-led paradigm shift demanding an uptake of renewables in urban area. It also seems that companies eager to 'promote sustainability' as part of their corporate values still seek to develop sustainable buildings and strategies as means to improve productivity, worker well-being while also reducing their energy demand (Hamza 2013). However, these matters are far from simple. For example, in high-rise buildings, due to the larger floor plates, occupancy levels, and internal heat gains, it is acknowledged that grid supply will always be needed due to the high power demand to operate these buildings. It is difficult to provide the required energy levels from passive design principles even if these are combined with a number of renewable energy generation technologies. It is prudent to review these high-rise sustainable buildings as major architectural and technical endeavours with their attempts to maximize the benefit of designing within local climatic contexts, with available natural resources, within specific cultural norms (Hamza 2013).

3 Public Perceptions and Visibility of Renewables

With major UK policy changes after the localism agenda was introduced in planning by the Coalition Government in 2010, planners were left more uncertain about how to progress projects that involve large-scale adoption of renewable resources of energy. In the case of on shore wind energy, the preferred development site needs to be identified in the local or neighbourhood plan as suitable. Public consultation needs to demonstrate that the impacts of the development have been fully addressed to the satisfaction and subsequent approval to develop by the community. Given the sensitivity of issues such as perceived negative impact on land and property values, these consents are far from assured. Only then will planning permission be granted.

Devine-Wright (2012) and IEA Wind Task 28 (2013) report that Adopting Decentralized Energy Systems, for those societies driven by a rejection for construction of nuclear plants, will lead to more societal engagement as it:

- Encourages energy citizenship
- Encourages engagement with energy systems
- Altruistic values of carrying about climate change will increase the appeal of engaging with microgeneration
- That societies are less individualistic, lazy, and passive and seek to be engaged and are socially motivated to deal with the microgeneration systems
- And would allocate the necessary time to familiarize with the technology and be able to run it properly

Contrary to these altruistic aspirations, West et al. (2010) interviewed a sample of residents in the South West of England, where the largest proportion of renewable energy projects was executed. Narratives were dominated by discussions of visual impact of renewable energy technologies often generating emotional responses and ways to minimize visual impacts. These narratives suggested that knowing something is efficient and well-designed might make it visually pleasing. Renewable energy technologies installations were nevertheless seen as both inefficient and visually intrusive in unacceptable ways. The sample interviewed was divided into 'Hierarchist' narratives who opted to minimize visual impacts, suggesting an inclination towards converting traditional buildings (e.g. derelict tin mines in Cornwall), or developing out to sea, where it is '*out of sight, out of mind*', while the 'Egalitarians' stated that renewable energy makes a positive statement about energy self-sufficiency and should be a landscape feature.

Post 2015, it is interesting to note how the planning system (https://www.planningportal.co.uk/info/200130/common_projects/52/solar_panels_non_domestic/2 accessed 10/5/2016) allows for 'permissible development' without the need to apply for planning permissions and the public consultation. Any such building must meet all the following criteria without exception.

- Equipment should be sited, so far as is practicable, to minimize the effect on the external appearance of the building and the amenity of the area.
- When no longer needed, the equipment should be removed as soon as reasonably practicable.

All the following limits must be met:

- Solar panels installed on a wall or a pitched roof should project no more than 200 mm from the wall surface or roof slope.
- Where panels are installed on a flat roof, the highest part of the equipment should not be more than one metre above the highest part of the roof (excluding the chimney).

- Equipment mounted on a roof must not be within one metre of the external edge of the roof.
- Equipment mounted on a wall must not be within one metre of a junction of that wall with another wall or with the roof of the building.
- The panels [renewables] must not be installed on a listed building or on a building that is within the grounds of a listed building, or on a site designated as a scheduled monument.
- If the equipment is on the roof of the building, the capacity for generation of electricity across the whole of the site cannot exceed 1 MW.
- Other than microgeneration solar thermal equipment or microgeneration solar PV equipment, if there is to be any other solar PV equipment installed on the roof of a building then the Prior Approval (56 days) of the Local Planning Authority is required. This will assess the design and external appearance of the development, particularly in respect of the impact of glare on occupiers of neighbouring land.
- Source:

The list highlights very strong underlying public perceptions about what is aesthetically acceptable, with a strong mandate to hide rather than showcase these arguably ‘ugly features of energy generation that should be must *should not project from pitched roofs to be noticed and must be functional with minimal external appearance*!.

Although this is the level of social acceptance from which the term NIMBY (‘not in my backyard’) has emerged, research has demonstrated that community acceptance of sustainable high-rise projects cannot be reduced to simple NIMBYism but is actually a complex and dynamic social phenomena, influenced by an array of factors, including perceptions of justice and trust, and fear of losing property market value. In the UK context, where urban areas are a mix of high-rise public use buildings and residential buildings, there is a normative expectation of owner occupation based on rising financial returns. Anticipated rise in values of residential properties may be used to seed new business, to help children onto the property ladder, or to fund care in later life. In the face of lessening public resources from the state, the extent of an individuals’ personal wealth is a significant issue in determining choices. The fear then of falling values or negative equity if visually intrusive renewables are included are installed is very real.

3.1 Public Perceptions to Different Sustainable Architecture Propositions

Public perception is influenced by the maturity of technologies and both experienced and published experiences of these buildings. The following case studies of the federal building in San Francisco and the Lion House in Alnwick, UK, demonstrate how these highly sophisticated attempts towards achieving sustainable building status were received by the public. These examples show varying levels of integration of passive and renewable energy features.

Case Study 1 The Federal Building in San Francisco by Morphosis (2008)

The building was constructed on a brownfield site, with the architects ideas to *'work in response to performance'* at various levels. In an interview, Thom Main states that the *'Aesthetics is a response to various forces'* naming environmental design principles as leading factors in the decisions behind the glass fins on facades, and the mesh as shading systems on the south orientation. Although the building was not designed originally to meet LEED credentials, it was assessed post-construction at a 'Silver' level. The building was designed with various environmental aspects to reduce energy demand.

4 Energy-Saving Features

- Building passively designed, narrow shape, and orientation to maximize natural ventilation and daylight. Design intentions to save 26 % of electrical lighting consumption (not achieved)
- Green materials include:
- Floor to ceiling glass to maximize daylight—scrutinized by occupants for glare
- 50 % Mix of slag in concrete to increase durability of concrete and less pollutant for the environment
- Low or zero toxicity material for finishes
- 10 % of waste during construction to landfills
- 87 % of all building materials are recyclable
- Embedded sensors in the building to automate temperature and light adjustments
- Facade sensors for night time ventilation
- Occupancy and daylight sensors
- Glass find on North elevation to direct air into a gap where it would rise and cool in summer before entering the air-conditioning system
- Perforated steel panels serves as a light screen and a natural ventilation system
- These open to allow natural ventilation to the top 13 floors that do not have any air-conditioning systems
- Elevators open every third floor to prompt occupants to walk up and down for well-being—disabled lifts open on every floor ended up being congested with able-bodied people!
- Underground parking to allow for a Plaza for public use…this ended up as socially unsustainable!

4.1 What the Public say

Fowler et al. (2010) were commissioned by the General Services Administration to survey employee workplace satisfaction in 22 federal buildings nationwide, Employee satisfaction varied wildly between a low of 13 and a high of 98 % while

17 of the 22 scored above 50 %. While incorporating many green concepts more aggressively than other buildings, the lowest ranked building for employee satisfaction was the San Francisco Federal Building, with a rating of just 13 %. The San Francisco building scored well below the median in the categories of thermal comfort, lighting, and acoustics.

> Kane (2011) in his article "S.F. federal building plaza draws neighbors' ire. Urban blight Condo dwellers: Homeless take over after hours" highlighted issues of unintended failures 'Social services building people waiting to be served in windowless rooms, occupants of the office building suffer from glare and sometimes use umbrellas inside their cubicles, natural ventilation introduces very high wind velocities making the paper fly, the lifts that open on every third floor haven't really been operated as expected as able-bodied people tend to use the disabled lifts that open on every floor, the piazza is occupied by the homeless after working hours.'

Case study 2 The Lion House in Northumberland England

How much do the public really want to engage with the display of sustainability and its supporting technologies?

In The Lion House designed by Gibberd architects and completed in 2008 in Alnwick, a historic market town in Northumberland UK was first hailed as a sustainable building with its integration of PV and three stand-alone wind turbines on site.

Evaluated under BREAM in 2008, the building was judged as outstanding. The brief for this scheme was to create a building which was an exemplary precedent for sustainability within the UK. It included a plethora of sustainability performance to aid the passive solar design such as:

- Biomass boiler
- Integrated PV panels
- Evacuated tube solar thermal collectors
- Three 15 kW wind turbines.
- Enhanced thermal performance building fabric
- Mechanical Ventilation with Heat recovery (MVHR)
- Rainwater harvesting technology
- Low water consumption fittings

It is interesting to note that it was the wind turbines, arguably the most intrusive feature, that attracted the most criticism and attention from locals.

4.2 What the Public say

After its competition, the local community complained about the visual appearance of the wind turbines and expressed their disappointment that they stood idle in the landscape. © Jane Coltman, Northumberland Gazette, 12th of January Saturday 11 February, 2012 http://www.windbyte.co.uk/northumberland.html and Northumberland Gazette.

Fig. 6.1 Photomontage of public's perception on the usefulness of building-integrated wind turbines

'Much-criticized wind turbines on the edge of Alnwick have been out of action for almost half the time they have been installed, according to figures released following a Freedom of Information Act request by the Gazette. The statistics provided by the Department for Environment, Food and Rural Affairs (DEFRA) show that the three generators at its flagship Lion House were offline for a total of 494 days since they went live on March 2, 2009. By comparison, they were working for 581 days during the same period'.

'The problems arose after a worldwide recall by the turbine manufacturer, Proven Energy, which discovered a fault with its P-35 model in 2009. Proven finally went bust last September, but was sold by receiver KPMG to Irish renewables firm Kingspan Wind'.

The photomontage in Fig. 6.1 is the image appearing on the local gazette website suggesting that the wind turbines have as much utility as sandcastles.

Wind turbines standing idle FROM 2005 TO 2010. Finally has been approved with the guarantee they will not interfere with the radar signals in the area.

It took DEFRA two years to find a company to repair the turbines, but interestingly the then town counsellor wrote what reflects the communities sentiment of support for renewables but the lack of trust in the durability and efficiency of the technologies: '*It seemed absolutely pointless to me to put turbines up then let them stand still*'. '*I am pleased but I still have my doubts about turbines because their efficiency levels are so low*'. This building has PV cells and interestingly no evaluation of their performance could be found in the public domain. This reflects how the static aesthetic technology generated less controversy than what was perceived as visually intrusive technologies with its moving parts.

http://www.northumberlandgazette.co.uk/news/local-news/after-two-years-off-wind-turbines-are-on-the-move-again-1-5679999#ixzz48wQ5z6bk

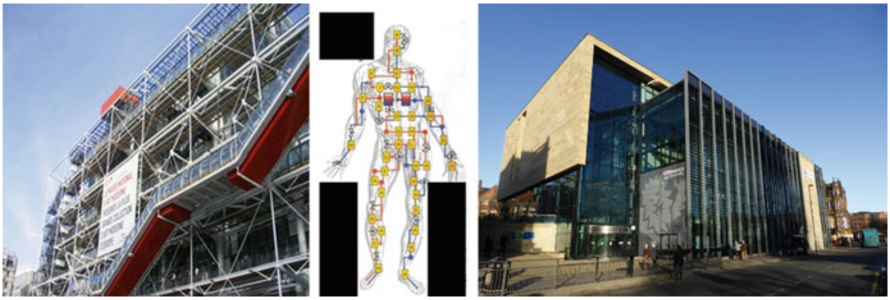

Fig. 6.2 Centre Pompidou with its exposed building services (*left*), the analogy of a human as a set of building services mechanisms (*middle*) and the King's Gate building, Newcastle University (*right*)

4.3 Public Perceptions and Driving the Visibility of Renewables on High-Rise Buildings

It seems wind turbines are the most controversial when testing perceptions of the public on renewables. The following section will focus on how this particular technology has been more negatively affected by failing examples of their integration on high-rise buildings.

While ethical theories of public participation and awareness (Devine-Wright 2009) point out to strategies that may improve engagement with microgeneration such as citizen ship, appropriate sitting and operation, local management, the main issue still remains. As opposed to passive measures of 'static and quiet', renewable microgeneration systems in reducing the carbon footprint of the urban environment, the tolerance for the length of visual and noise exposure to urban wind turbines remains unanswered. Figure 6.2, draws on the analogy of exposing building services in architecture to demonstrate what is vital but hidden in the same way as we might visualize our own human body as a set of exposed pipework and systems. To what extent do we want to be challenged in this way or do we refer to acknowledge but not see?

While exposing the building services as a 'high-tech' style was hailed by the architecture community, there is no evidence that this style gained any universal acceptance. Building services with their rotating fans for mechanical ventilation remained hidden. In fact, in some cases vistual effect very important. such as the main university student services' Fig. 6.2 Centre Pompidou with its exposed building services (left), King's Gate, Fig. 6.2, building in Newcastle University, planning permission was only granted when architects agreed to house the ugly building services on the underground floor to avoid visual pollution to the councillors and staff offices in the city council building was located directly opposite.

Why would urban wind turbines be dealt with differently? There needs to be social studies at this micro level and whether housing wind turbines as an unseen element and part of the building configuration paves the way to public acceptance.

It can be argued that about a decade after Bahrain's World Trade Centre Three exposed wind turbines, the latest form of building-integrated wind turbines in the Skidmore, Owings & Merrill's (SOM) Pearl River Tower, opted for vertical-axis turbines to minimize noise and vibration but still located them in unoccupied 'technical floors' to isolate them from occupants in the building. Whether this will be the trend remains to be seen.

Building-integrated wind turbines are expected to take advantage of the building height as a mast towards less turbulent flows at lower urban levels. Although the building-integrated wind turbines may yield more power than the building-mounted wind turbines, the cost per kilowatt tends to be relatively high. Compared to medium-/large-scale wind turbines, the integrated and mounted wind turbines have to invest in required foundations, tower, and cabling. According to the WINEUR (2005), for building-mounted wind turbines to be successful in generating electricity, the average wind speed should not be less than 5.5 m/s. According to Bahaj et al. (2007), Müller et al. (2009) and (Abohela et al. 2013) high-rise buildings have the largest potential for wind turbine integration when compared to low-rise structures. In locating the building wind turbine, the building roof should be approximately 50 % higher than its surroundings, and the turbine located near the centre of the roof on the most common wind direction for the location, with the lowest position of the rotor at least 30 % of the building height above the roof level.

The Warwick Wind Trials Project states that the poor sites for mounting wind turbines are single-storey buildings while good sites are 45 m-tall exposed flats in isolated settings on hilltops (Encraft 2009). Wind flow within the built environment depends on the exact geometry of all buildings on site. Integrating and positioning wind turbines on roofs need to consider roof construction materials. Turbulent flow creates stresses on the drive gear in a turbine, creating vibrations. These vibrations can, in turn, create harmonic resonances within a building structure. Metal roof decks made from thin roll-formed steel sheet, common in commercial buildings, can act like drumheads and amplify these resonances. Buildings then become musical instruments. AeroVironment, the building-integrated wind energy company, suggests in its sales literature that their turbines are only appropriate for buildings constructed of concrete. http://www.avinc.com/engineering/architecturalwind1 accessed 10/5/2016.

Abohela et al. 2011 (reviewed a number of wind integrated projects and contrasted published data on their performance. Figure 6.4 demonstrates two case studies highlighting the limitations of this integration method.

Anderson et al. (2008) studied the Green Building in Temple Bar, Dublin, as an earlier attempt for mounting three small horizontal-axis wind turbines combined with solar hot water and photovoltaic collectors (Fig. 6.3). The application resulted in excessive noise, vibration, and eventual cracking of the turbine blades. The wind turbines were determined to be uneconomical and were eventually replaced by photovoltaic cells. Another example is the Kirklees council building (civic centre 3) in the town centre of Huddersfield, UK that was retrofitted to house a large array (143 m^2) of solar photovoltaic panels and two 6 kW wind turbines to generate electricity and a set of solar energy collectors (48 m^2) to heat the building's water (Fig. 6.3). Kirklees council spent £15,000 on preparing the roof to take the structural

Fig. 6.3 (*Left*) The Green Building in Temple Bar, Dublin. (*Right*) The Kirklees council building (civic centre 3) in the town centre of Huddersfield, UK

Fig. 6.4 From left Integrated wind turbine in Pearl River Tower (courtesy SOM), Pearl River Tower in China (courtesy SOM), Strata SE1 project in London

load, vibration and improve the insulation of the roof. The Council wanted to demonstrate leadership through targeting a reduction in its building's carbon footprint by around 8 % (15 tonnes of Carbon dioxide/annum) and reduce dependency on grid-generated electricity.

It is interesting to note that the average electricity generated from the photovoltaic array and the wind turbine was 5 % of the total electricity demand. However, similar to the Green Building in Temple Bar, the wind turbines failed to generate a reliable electricity supply and were eventually disconnected from the grid and left to promote a demonstration of good intentions. Wind-mounted turbines in both cases were seen as an Urban Wind Turbines Integration in the Built Form and Environment. It left the public with a perception that this is an expensive add on (Kirklees Environment Unit 2006).

The Warwick Wind Trials Project in the UK measured turbine performance of 26 building-mounted wind turbines from October 2007 through October 2008 and found an average capacity factor of 0.85 %. All were very small ('microwind', defined as less than 2 kW) turbines, including the Ampair 600 (600 W), Zephyr Air Dolphin (1000 W), Eclectic D400 StealthGen (400 W), and Windsave WS1000 (1000 W). For each installation, measured electricity production was compared with predicted production based on the manufacturers' supplied power curves and both predicted and measured wind speeds. The study found that predicted performance exceeded actual performance by a factor of 15–17. With the worst-performing systems, the electricity required to run the electronics exceeded the electricity production, so the wind turbines were net consumers of electricity!

Building augmented wind turbines, is a form of integration when the building is sculpted based on aerodynamic principles to harness wind to be driven towards a turbine. In this case, the building form acts as the structural support for wind turbines. For example, Fig. 6.4 includes Pearl River Tower in China and the Strata SE1 building in London. However, Müller et al. (2009) noted that unless the inclusion of this technology in the building is perceived as adding value, it can't be assumed that such projects will become the norm as urban wind turbines may not always be visually accepted.

The Strata was then voted 'Britain's ugliest new building' by readers of Building Design magazine (and thus the holder of the 2010 Carbuncle Cup), Local press expressed the dismay of having to endure the ugliness of the building in addition to its rarely rotating three wind turbines. A symbol that hanged over the London horizon to remind Londoners of the failing technology performance.

> It seems that the posh folks living in the upper floor penthouses objected to the noise and vibration of the spinning blades, prompting project director Ian Bogle to suggest that they should be turned off between 11 p.m. and 7 a.m. each night (Londonist, March 2010).

Although local press blamed it on the vibration, Tom Hawkins commented (http://www.urban75.org/blog/)

> It's not so much the noise or vibration that has shut the turbines off, more like the £54,000 + vat a year maintenance costs for generating hardly anything that is the real factor. I know, I was involved in the second year budget for that building.

5 Conclusions

This chapter argues that the societal acceptance of urban wind generation has been affected by experience and media coverage. Although research suggests that public perceptions and acceptance of micro wind generation may be supported by value beliefs and excitement in participation in new forms of technology, there is no evidence found that this is the case on the ground for high-rise public buildings.

Public perceptions and their engagement with the market dictate growth patterns and can underpin incentivization schemes and government policy. Similarly, this also affects building regulations.

Architectural styles and the integration of renewables are directly affected by all of the above factors. It is interesting to see the discourse on how much of micro renewable energy should be seen and heard by the public. This in its wake will lead to raising questions on how to advance other forms of microgeneration such as the ducted systems and the possible involvement of artists to improve the aesthetic of these systems. In conclusion, this chapter argues that unless success stories are found, scepticism of the public of these technologies microgeneration will remain.

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Chapter 7
Environmentally Performative Design for High-Rise Buildings in North America

Mona Azarbayjani

Due to current rise of environmental concerns, and interest in high-performance and energy-efficient buildings, the question of "what is sustainable high-rise building" has been raised. Increase of the number of tall buildings worldwide and relatively high energy consumption in building operation create a significant impact of high-rise buildings on overall targets set by the environmental agenda.

The growth of cities increases. It is estimated that by the year 2050 almost 70 % of world's population will live in urban areas and cities. Buildings are responsible for 40 % of energy consumption, and 33 % of global CO_2 emissions. In the United States, from that 40 % energy consumption, 46 % of energy and around 35.4 % of electricity generation[1] go into commercial buildings (Fig. 7.1).

However, the real problem is not the energy consumption of the buildings but the nonrenewable energy consumption and the emission of CO_2 as by-products. Therefore, the challenge is to reduce the energy consumption while the renewable energies are integrated into the building.

By definition, high-rise buildings are not mainly sustainable. Most of the high-rise buildings follow a standard plan form without considering the context and environmental relationship to the places where they are located.

The arguments are also related to high-energy operation and its impact on the environment and infrastructure. The problems of tall buildings with large quantities of glazing experience heat losses in the winter and overheat of excess solar gain in the summer. Therefore, the idea of high-performance high-rise buildings has been created by measures on integrating water, light, and passive energies and further to relate those to local climate. There are wide differences in the areas of energy consumption due to climatic regions. Though the majority of energy consumption in

[1] *Source*: U.S. Energy Information Administration (EIA), Electric Power Monthly, Table 5.1, September 2012. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_01

M. Azarbayjani (✉)
School of Architecture at the University of North Carolina at Charlotte, Charlotte, NC, USA
e-mail: mazarbay@uncc.edu

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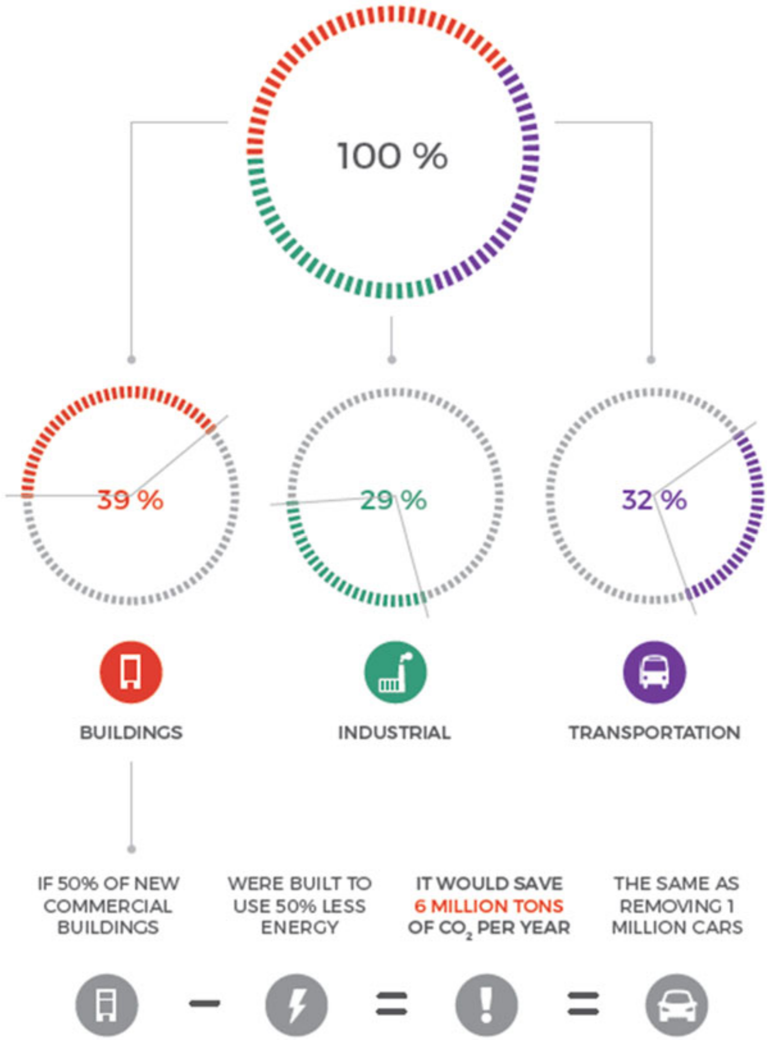

Fig. 7.1 Energy consumption in three sectors with associated CO_2 emissions

building operation goes into internal environmental control systems and artificial lighting, the key to improve the energy performance also lies under the use of strategies to take those loads off the building's portfolio.

It must be noted that the design of environmentally performative high-rise buildings required deep understanding of climatic context potential and constraints. The year 1990 marked the beginning of more environmentally performative high-rise buildings (Fig. 7.2).

Due to many environmental concerns related to high-rise buildings, the sustainable high-rise includes architectural, engineering, and contextual issues related to

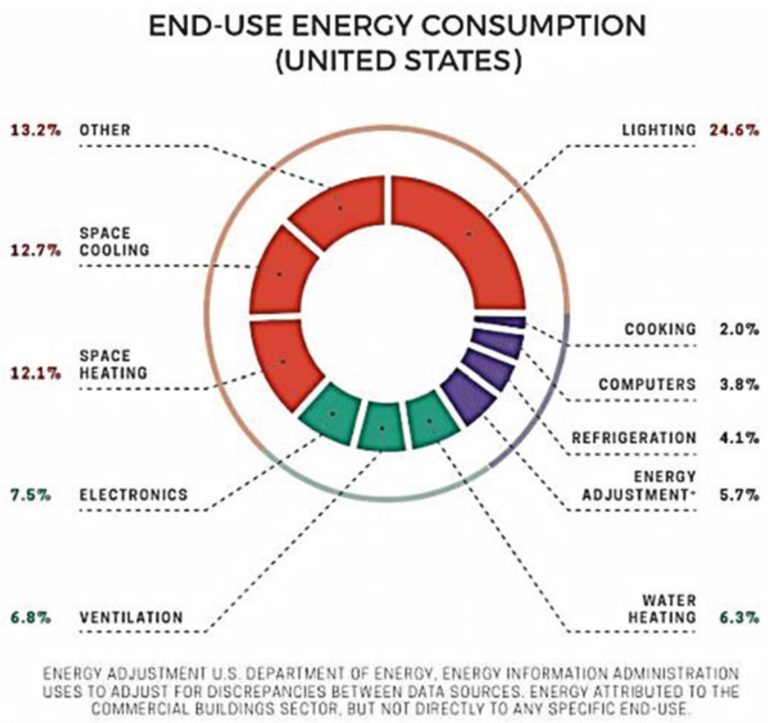

Fig. 7.2 2009 Building energy data book US Department of Energy, http://buildingsdatabook.eere.energy.gov/doct/xls_pdf/314.pdf

building and environmental performance. In regard to the impacts on the performance, the basic strategies are to reduce the demands for energy and water considering the context of the building.

Mainly the lessons learned from vernacular architecture such as daylighting, increasing of thermal mass, and using natural ventilation can be translated easily into smaller-scale buildings, while integration of those strategies into larger-scale buildings are more complex. Due to higher wind velocity in tall buildings, opening windows for natural ventilation on the top levels can be complicated and not doable. That is why mostly larger buildings rely on mechanical ventilation equipment.

The designer of the Galleria Vittorio Emanuele II (1877) Giuseppe Mengoni, developed a labyrinth, which was pulling the air into underground chambers to be cooled by the earth and returned through vents in the floor as needed. This idea has been more developed and used in current buildings such as Manitoba Hydro.[2] As Yeang mentioned, “passive design is essentially low-energy design achieved by the building’s particular morphological organization” (Yeang 1999). In addition, integration of advanced façade technology with HVAC systems results in optimizing energy efficiency and thermal comfort of the occupants. Many high-rise buildings

[2] Solar Power: The Evolution of Sustainable Architecture, Behling Sophia and Stefan, 2000.

also use mechanical environmental systems to achieve thermal comfort for the occupants. Incorporating sustainability can mean integration of passive systems into design of those systems. So the idea is to maximize the Passive strategies for heating and cooling. This is the best way to reduce energy consumption.

The interest in being sustainable has created several misinterpretations around the design of *high-rises resulted in adverse impact on environmental performance. The use of green labels cannot justify the vagueness of actual performance. A distinctive example of this is incorporating highly glazed façades with no appropriate shadings that create overheating and discomfort while increasing the cooling loads. The use of green labels should be demonstrated by the actual performance of the building rather than just implementation of the strategies and no data to support the claims.

The performative building should operate toward zero CO_2 emissions. A comprehensive study done by NREL on a large number of building models from 2003 CBECS (Commercial Building Energy Consumption Surveys) found out 62 % of buildings can reach net zero energy by integration of current technologies.

The definition of Net Zero energy building is to use renewable energy sources to provide the amount of energy the building consumes, or to use off-site renewable energy resources that are transported to the site. As discussed above, high-rise buildings always consumed more energy that they can generate on the site, due to limited amount of their roof and site area. The exposure of high-rise buildings to sun and wind provides the possibility of catching solar radiation or harvest winds and as the case studies have shown, these strategies can be effective. Though as a result of many possible combinations of technological solution, there is no formula to determine the final design; however, the guidelines of strategies can provide a platform for architects to make better decisions to explore the potentials and environmental compositions.

Being viewed as a major energy consumer, high-rise buildings are integrating new technologies to be more energy efficient. In this chapter, the technological system and design strategies of two US environmentally sensitive buildings are examined. These buildings are responsive to their climate and using cutting-edge environmental systems while introducing renewable energy generation coupled with passive solutions. The buildings strategies are introduced in four steps of reduction, integration, reclamation, and production.

1 Integrated Design Sustainable Skyscraper: The Design Factors, Sustainability Credentials

There is no doubt that integration of appropriate vernacular and sustainable strategies can reduce the high-rise building's energy consumption significantly.

As Bachman listed the types of integration,[3] Performance integration means to share the functions of the two elements without actually combining the pieces. For instance in a direct-gain passive solar heating system, the floor of the sunlit

[3] "Integrated Buildings: The Systems Basis of Architecture" in 2002.

space can share the thermal work of the envelope and the mechanical heating systems by providing thermal mass and storage.

If the HVAC and the facade systems are well integrated, the operating and initial cost will be reduced and also the occupants comfort will be improved. When decisively considering environmental performative design, very little to almost no data is available to compare the improvements compared to the conventional designs.

The design of high-performance tall buildings requires the integration of components and systems. It is crucial to holistically combine the strategies to achieve high-performance energy goals. There are four independent steps to lead into the net zero energy introduced by SOM:

- Reduction: The first step to a high-performance building is to find the possibilities to reduce the energy consumption. Most of the energy goes into HVAC and lighting systems. The reduction strategies need to target those areas.
- Integration: The second step is to include strategies to take advantages of passive resources and integrate them in building envelopes.
- Reclamation: The third step is to harvest the energy that has been once used in the buildings and recover it to be reused.
- Production: This step incorporates the technology to produce renewable energies efficiently.

The concept of environmental performative high-rise building should include a critical overview of its actual performance. The claims of performative design should be based on the comparison of the building's real performance to the conventional model.

This chapter discusses the two case studies in regard to integration of the systems with special emphasis on sustainable buildings. Many projects can demonstrate the ideas and principles behind performative design. Two of those are analyzed and introduced below. First is the Manitoba hydro tower by KPMB Architect completed in 2009 and the second is the One Bryant Park by COOKFOX Architect in 2010. The first is an example of integration of passive strategies while the second incorporates site-renewable energy generation.

2 Performative Design Examples

2.1 Manitoba Hydro, Canada

In sustainable skyscrapers, priority has been given to passive systems of heating and cooling over active- and mixed-mode systems because it consumes lowest energy from renewable resources. The Manitoba Hydro tower is 18-story office building, which will feature "bioclimatic" design adapted for the Canadian climate.

Manitoba Hydro, Canada, was completed in 2009 (see Fig. 7.3). It is the primary energy utility in the providence of Manitoba, the fourth largest energy utility in Canada, and it offers one of the lowest electricity rates in the world.

Fig. 7.3 Manitoba Hydro Tower, © photo by Terri Boake

2.1.1 Site

The site was specifically chosen because of its closeness to public transportation routes and the untapped opportunities to design a building to harvest passive solar heating and daylighting. The orientation and massing strategies were carefully analyzed to optimize the potentials of the site (Fig. 7.4).

2.1.2 Climate

Manitoba Hydro is located in Winnipeg Manitoba, which is one of the coldest cities in the world. The climate and temperature of Winnipeg is extreme and fluctuates dramatically over the year. Winter temperatures average around −35 °C, increasing to +34 °C by the summer time. The severe climate of Winnipeg has 8.9 m/s winds in the wintertime but also it is very sunny during cold season that results in an opportunity to incorporate passive solar heating and daylighting which reduces the lighting loads and creates hybrid ventilation (Fig. 7.5).

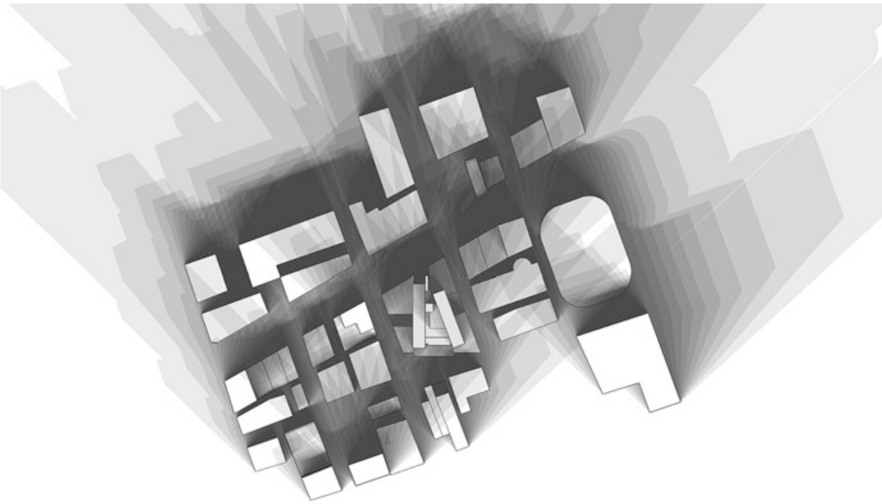

Fig. 7.4 Butterfly shadow site plan, © M. Keramati

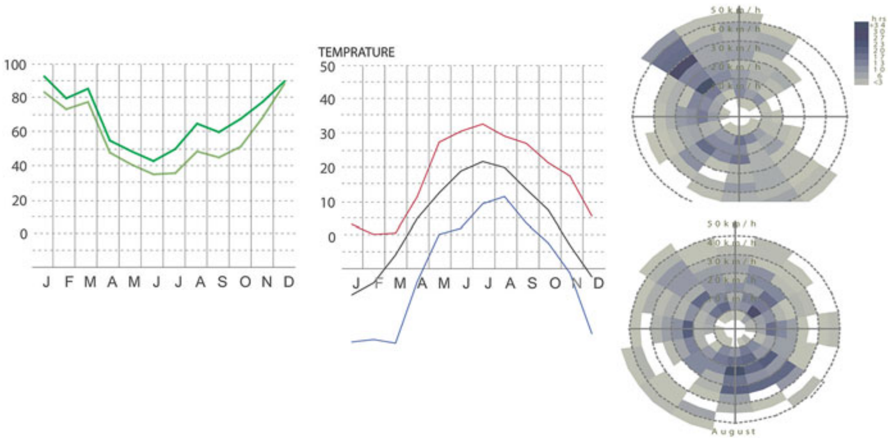

Fig. 7.5 Climatic data of Winnipeg: monthly relative humidity and temperature, January and August wind roses, © M. Keramati

2.1.3 Design Intent and Sustainable Strategies

The Tower's form consists of two 18-story twin office towers resting on a stepped 3-story public arcade that includes commercial space. The towers converge at the north side and open to south for capturing maximum sunlight and winds. The towers with narrow floor plates and floor-to-ceiling glazing let the daylight to enter the

Fig. 7.6 Manitoba hydro tower *Left*: top of the chimney, *Right*: double-skin façade and chimney, © photos by Terri Boake

space deep. Every six floors of the towers open to south-facing winter gardens with waterfalls to humidify and dehumidify the air entering the offices (Fig. 7.6).

A 115-m tall solar chimney is located on the north side of the building. It rises above the towers and is a key element for the passive ventilation system. It works with winter gardens that extend through a number of floors with mechanical louvers at each end of the atrium and enables the space to be closed or opened according to weather conditions, ventilating the air using the stack effect in solar chimney.

Solar chimney, during the summer month and shoulder season, draws the exhausted air out of the building. In winter months, the heat recovered at the chimney is brought to the bottom to preheat the air inlets.

The building consumes 80 kWh/m^2 per year which is 66 % more efficient than the model national energy code for buildings. Beyond being a high-performance building, it also provides 100 % fresh air, which results in a healthy environment. The building uses a holistic approach to be Gold LEED rating building. The sustainable features to achieve the results are:

- Passive strategies: thermal mass, daylighting, geothermal, natural ventilation, solar chimney, winter gardens, water features.
- Mechanical strategies: radiant heating and cooling, displacement ventilation, and double-skin facades.

Thermal Mass

The structure of the building is made of concrete and it was left exposed to create thermal mass to moderate the temperature fluctuations. The structure creates radiant slabs to exchange the heat with the offices (Fig. 7.7).

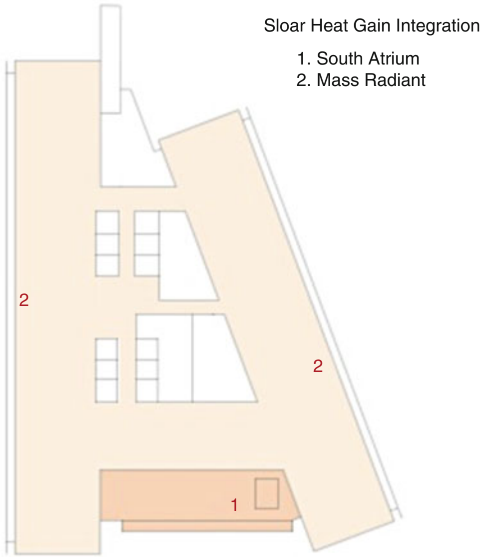

Fig. 7.7 Solar Heat Gain Integration—Plan diagram, © M. Keramati

Daylighting

Majority of energy consumption of the building goes into the lighting system, providing daylight not just as a means of energy efficiency but also health and well-being of the occupants, provided by narrow floor plates of the towers. The twin office towers are oriented toward west and northeast. All floor-to-ceiling glazing and ceiling height of 3.3 m and double-skin façade provide daylighting with motorized windows and large automated louvers minimize solar heat gain and glare. Louver blades act as a light shelf at the top and penetrate the light deeper inside the room by reflecting light on to the white ceiling. The floor plates are narrow so no employees are more than 9 m from the window. The integrated shading systems are perforated to allow transparency and penetration of the daylighting on the east and west orientation while blocking the solar heat gain and glare (Fig. 7.8).

Natural Ventilation Strategy

From the onset of planning, Manitoba Hydro is providing 100 % fresh air in contrast to North American office building that recirculates the air. The building is oriented toward south so the prevailing wind can naturally ventilate the structure. The building provides direct outside air regardless of the season as well as the individual control for the occupants.

The interior of curtain wall is manually operable and allows occupants to control their environment while the exterior has automated wall vents to adjust the temperature and airflow.

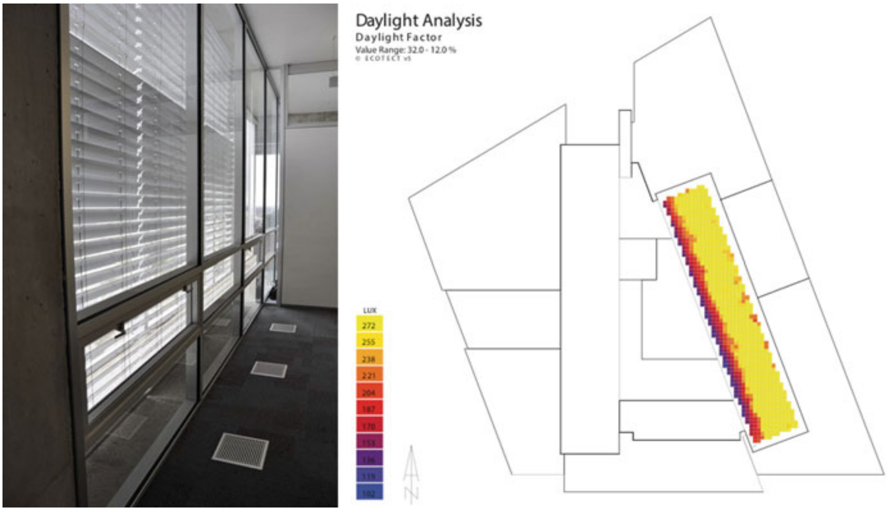

Fig. 7.8 *Left*: shading strategies: double-skin facade with motorized shade, © photo by Terri Boake, *Right*: daylight analysis of the offices, © M. Keramati

The natural ventilation strategy of the building is provided by a double-skin façade system, which supplies air to the offices, and a series of six-story winter gardens. They draw the air and precondition it before it enters the office spaces through vents in the raised floor. The 115-m tall solar chimney on the north side exhausts the returning air rising from the occupants and other sources in the offices. In winter, the solar chimney draws exhaust air down to heat the parking and pre-heat incoming cold air from the winter gardens.

In the shoulder seasons, the building only provides fresh outdoor air through the use of automatic and manually operated windows (Fig. 7.9).

Winter Gardens

On north and south side of the winter gardens, there are interconnecting stairs that provide opportunities for physical activity and interactions among employees.

Winter gardens act as the “lungs” of the building; they feature 24-m tall water curtain that will humidify the air during the winter month. The louvers in the south-facing double wall let the fresh air enter the winter garden and via the 280 tensioned mylar ribbons extended from ceiling to floor, the incoming air can be heated by the sun and humidified by the water. During the summer time, this water that goes down the ribbons is chill and can dehumidify the air that enters the atria (Fig. 7.10).

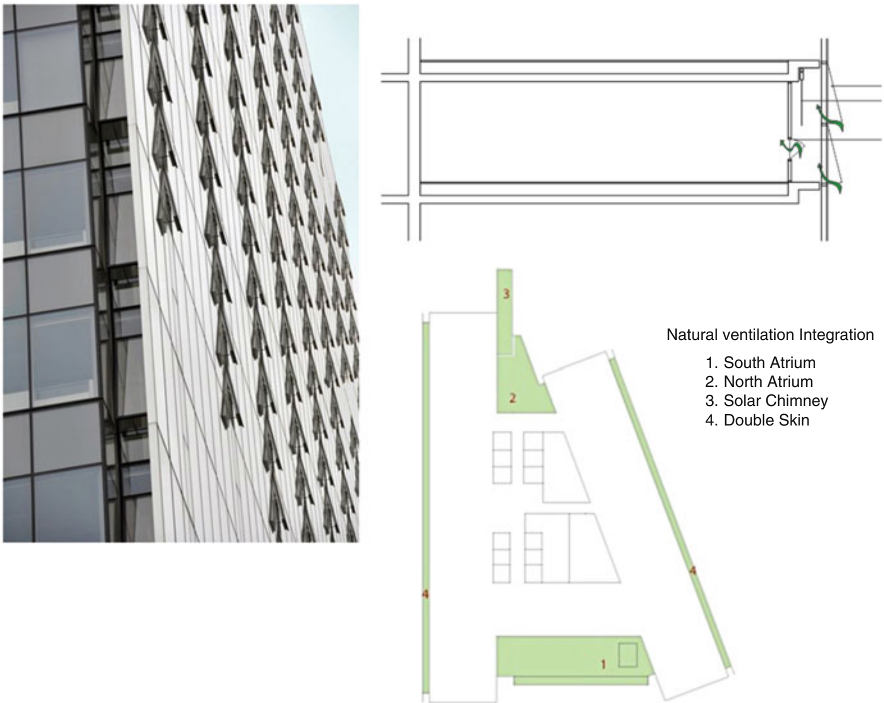

Fig. 7.9 Natural ventilation—double-skin façade, © photo by Terri Boake, *Right*: natural ventilation strategy atrium, section and plan view, © M. Keramati

Fig. 7.10 *Left*: tall water curtain wall, *Middle*: water ribbons, *Right*: winter garden atrium space, © photos by Terri Boake

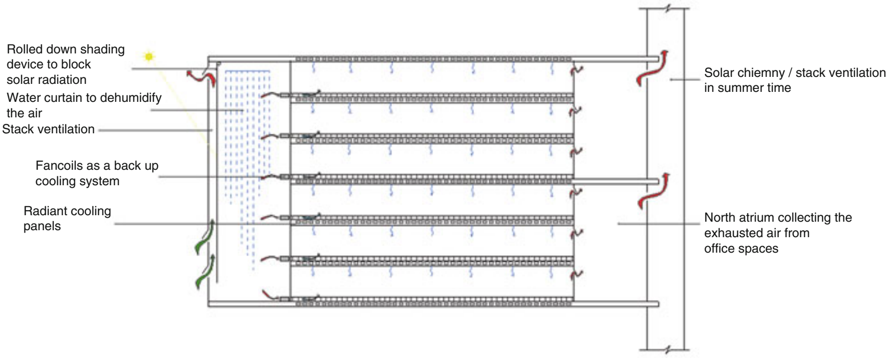

Fig. 7.11 Cooling system diagram, © M. Keramati

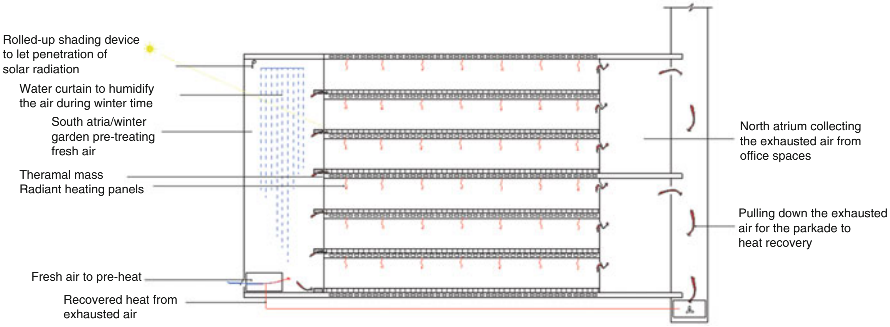

Fig. 7.12 Heating system diagram, © M. Keramati

2.1.4 Heating and Cooling System

Hundred percent of cooling load and 50 % of heating load are covered by geothermal heat pump system. The main heating and cooling source of the Manitoba hydro building is exposed radiant concrete ceiling slabs. The water pumped in the tubes that are embedded in the concrete floor slab heats and cools the spaces by thermal radiation. This water system provides better comfort and uses less energy in comparison with air heating system.

The radiant heating and cooling slabs are located in the office space. However, the excess energy can run through the water gardens and the buffer zone in the double-skin façade to maintain temperature and reduce the heat loss (Figs. 7.11 and 7.12).

Geothermal System

There is a closed loop system consisting of 280 boreholes, 6 in. in diameter, 400 ft deep, spread between the building's foundation piles and caissons. Each bar hole contains glycol that extracts the heat from the building and returns it to the ground during the summer time and the flow is reverse during the winter season.

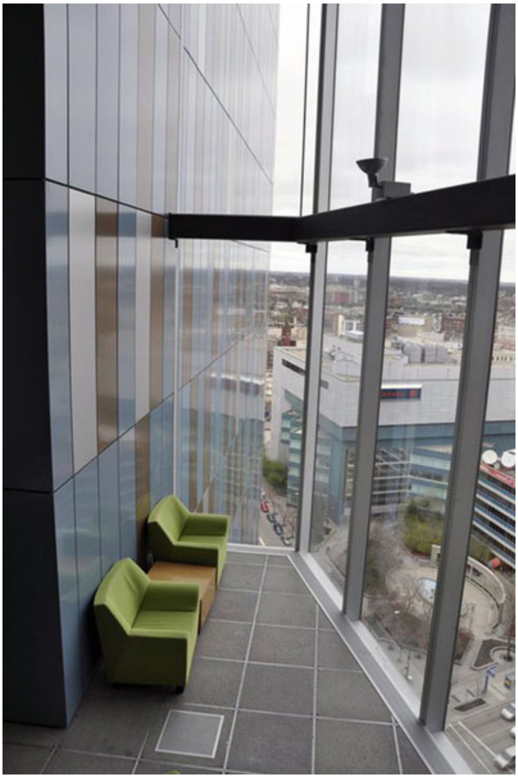

Fig. 7.13 Displacement ventilation, © photo by Terri Boake

Conditioned water is circulated in tubes in radiant cooling slabs, providing 100 % of the temperature conditioning. Through this radiant heating system, the geothermal installation provides approximately 60 % of the heating in the radiant slabs.

Displacement Ventilation

Displacement ventilation introduces air at very low velocity at floor level via raised floor system. Air rises and moves gradually as it warms up by the internal loads (i.e. occupants and office equipment). This system is more efficient than over head mechanical system as it only provides air at the level of the occupants. In this system the conventional ducts under the ceiling can be eliminated (Fig. 7.13).

2.1.5 Performance Analysis

Energy consumption analysis of the building was compared to similar energy benchmark. This comparison shows that the building's projected performance surpasses those benchmarks. The total annual thermal energy consumption ranges between 105 and 128 kWh/m^2. It is important to mention that these figures fall

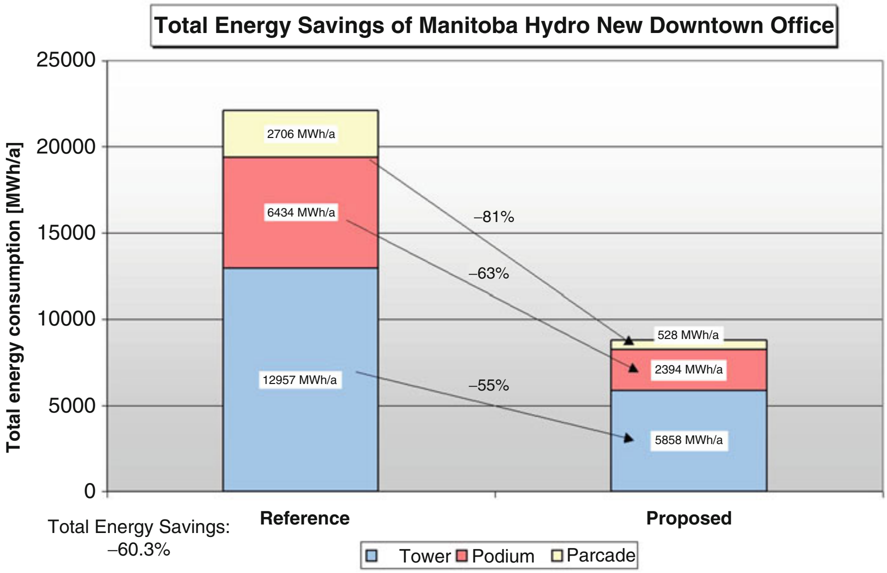

Fig. 7.14 Performative analysis by KPMB

below all benchmarks including fully air-conditioned offices (190 kWh/m^2), offices mechanically ventilated and heated but not cooled (160 kWh/m^2), and most surprisingly naturally ventilated office buildings (135 kWh/m^2) (Gonçalves 2010).

Two years of optimization of energy performance led to an unexpected result considering the extreme climatic conditions. All the optimization strategies resulted in reduction on energy loads. The first year operation cost was 161 kWh/m^2 and that reduced to 85 going beyond the target of 120, which in comparison with the benchmarks is 70 % better (Fig. 7.14).

2.2 One Bryant Park, New York

The One Bryant Park in midtown New York designed by Cook + Fox Architects is the first commercial high-rise to achieve LEED Platinum certification.

It is one of the first environmentally sensitive high-rises that emphasizes daylight, fresh air, and high-performance systems. The building has 55-story in a dense context (Fig. 7.15).

2.2.1 Site

The building is located in the heart of the midtown and the decision was to build higher square feet and a high efficiency from the start. The midtown in New York City has intensely dense area and as it is shown in the butterfly shadow image, the

Fig. 7.15 One Bryant Park building, © photo by the author

building had to rise above the adjacent buildings to create solar access for the offices. The building is located on the same block as two subway stations that linked under the tower with access to 17 lines. Grand Central Station sits only two blocks away to create great access to the rest of the city and beyond (Fig. 7.16).

2.2.2 Design Intent and Sustainable Strategies

In regard to the four sustainable steps, the One Bryant Park uses strategies including the following for:

Reduction

- The use of a high-performance façade reduces air infiltration. Double-lite insulated units with low emissivity glass and a ceramic frit that covers 60 % of the glass reduce solar heat gain.
- A decoupled ventilation system delivered via a raised access floor.
- Floor-by-floor air handling units provide more even, efficient, and healthy cooling and fresh air.
- LED lighting, IO lighting, low-energy high-efficient lighting system.

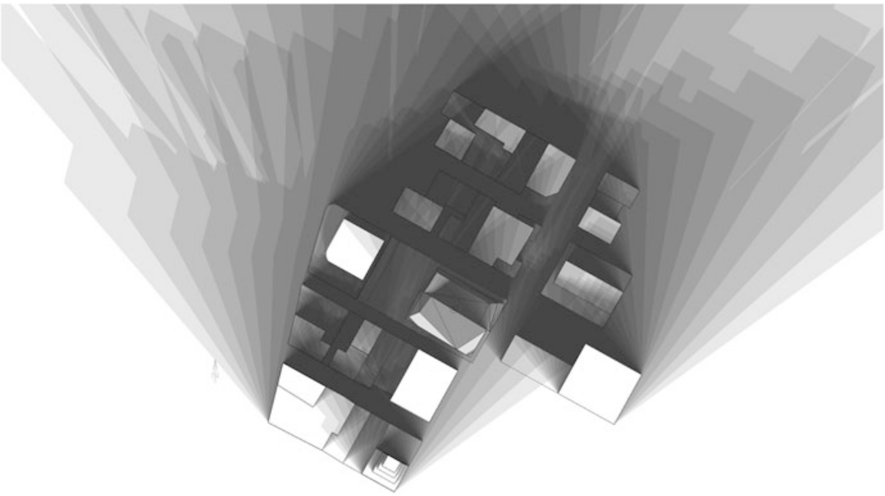

Fig. 7.16 Butterfly shadow, © M. Keramati

Integration

These strategies that take advantage of passive and natural energy resources include:

- Daylight harvesting using daylight responsive controls integrated with the automated blinds.

Reclamation

- Building collects all the rainwater that falls on the site, which is 48 in. (120 cm) per year. The collection tanks can store the water to be used for irrigation and flushing the toilets.
- The gray water treatment system on the site takes the water and treats it to be used for the cooling tower. The water then will return back to the atmosphere in the form of vapor.
- The waste heat from cogeneration provides heat in winter and cooling in summer through an absorption chiller.

Production

The One Bryant Park incorporated the use of 4.6 MW on-site cogeneration technology. This system provides about 65 % of building's annual electricity requirements and reduces the peak demand. This system generates most of the heating energy system more efficiently than what the city's grid is capable of. A typical electric power gird is less than 30–35 % efficient by the time energy is transformed from the plan generator. The on-site generation will generate energy more efficiently.

Fig. 7.17 Control system, © photo by the author

Ice storage system provides approx. 25 % of the building's annual cooling requirements, reducing daytime peak loads on city's electricity grid. At night, excess electricity from cogeneration system is used to produce ice, which is melted during the day to supplement the cooling system.

Water Usage

One Bryant Park collects every drop of rainwater that falls on its site, nearly 48 in. per year. A series of collection tanks distributed throughout the floors can store over 329,000 gal of water that is used for irrigating plants and flushing the building's toilets. But it does not end there. Gray water treatment on the site takes water from the building and treats it for use in the cooling towers that returns water back to the atmosphere in the form of vapor—essentially completing a cycle back to nature. Water consumption is reduced in half, by employing low-flow lavatory sinks and waterless urinals.

The environmental features of this building include automated shading and perimeter daylight dimming, under floor air distribution systems, ice storage, and cooling tower optimization (Fig. 7.17).

Degeneration

The buildings also move toward a decentralized power grid. One Bryant Park has a 4.6-MW natural gas-fired cogeneration plant providing two thirds of the buildings' electrical demand and is expected to reach 77 % efficiency (zero transmission) (Fig. 7.18).

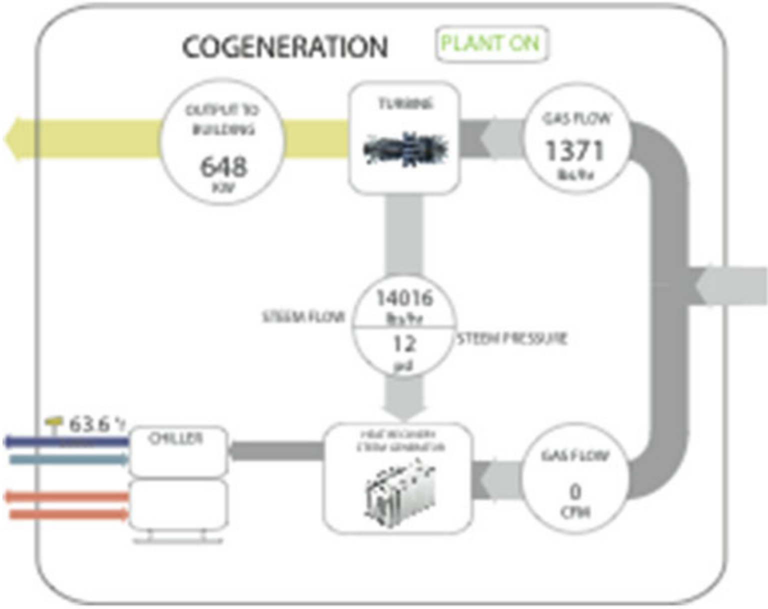

Fig. 7.18 Degeneration diagram, © M. Keramati

2.2.3 Cooling

At night, while demand in the building is low, the power will be used to make ice in 44 storage tanks in the basement of the building. During the day, this ice is allowed to melt and is used to cool the air of the building, drastically lowering its energy consumption during peak hours (Fig. 7.19).

Displacement ventilation is used through the facility to minimize the volume of air to be cooled. The air distribution is under the floor to eliminate ductwork and to bring air in a higher temperature and lower speed so the energy loss will be minimized and the entire height of the room does not need to be cooed by blowing the air down (Fig. 7.20).

2.2.4 Daylighting

One Bryant Park chose to tap into more daylight for workspaces, evident by its clear exterior. By using baked frit to reflect light outside of the main vision plane, each floor has floor-to-ceiling glass that allows light to penetrate deeper into spaces, minimizing the need of interior lighting and providing views of the city (Fig. 7.21).

The tower's exterior curtain wall is made up of floor-to-ceiling, double-lite insulated units of low-iron glass. To help control heat gain and glare, the units include a low-e coating as well as a ceramic frit that covers 60 % of the glass where the curtain wall meets the floor and the ceiling. The pattern gradually decreases in density toward the vision portion of each panel. Nonmetallic spacers in the aluminum mullion system and

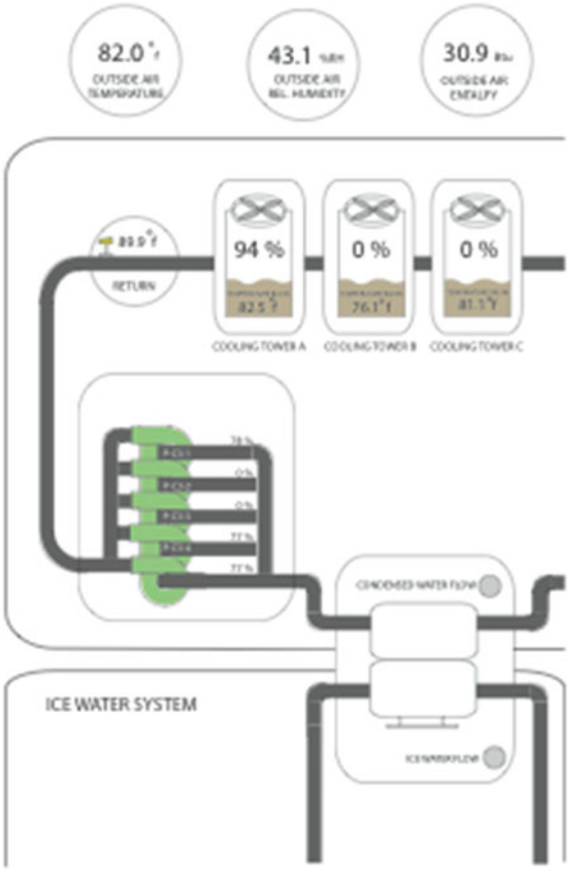

Fig. 7.19 Ice storage tank diagram, © M. Keramati

extra mineral wool insulation at the floor slabs help achieve a U value for the assembly of 0.38—a thermal resistance that is better than most glass towers built in New York City over the last decade, but still below prescriptive code requirements.

The glass panels used in the facade have a light dotted pattern printed on them, invisible to naked eye from a distance, which restricts the infra-red heat radiations of sun while allowing visible light to enter, thus cutting daytime lighting expenses. Further, the building is designed in such a manner that no dark corners are left in it (Fig. 7.22).

2.3 Performance Analysis

The trading activities are conducted in One Bryant park. The related floors are draped in video screens to stream financial information which results in higher energy consumption. The all glazing facade also results in significant heat losses. By incorporating the combined heat and power plant (CHP) capable of generating 70 % of the building electricity and an absorption chiller powered by waste heat

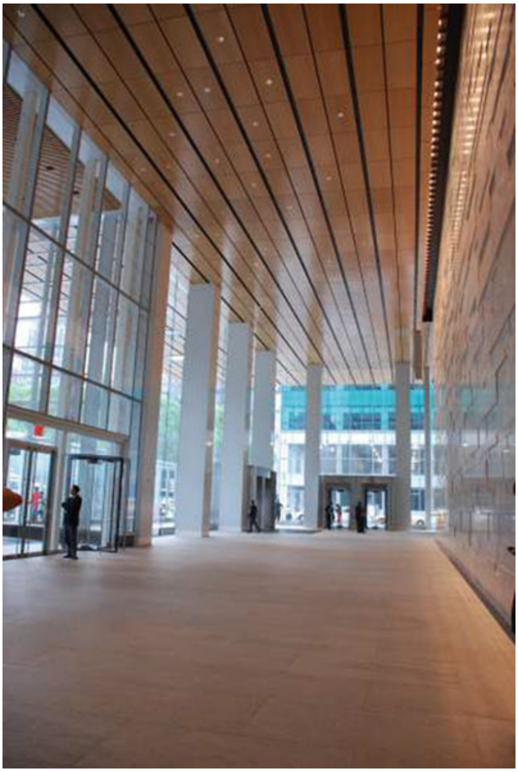

Fig. 7.20 Displacement ventilation in the lobby, © photo by the author

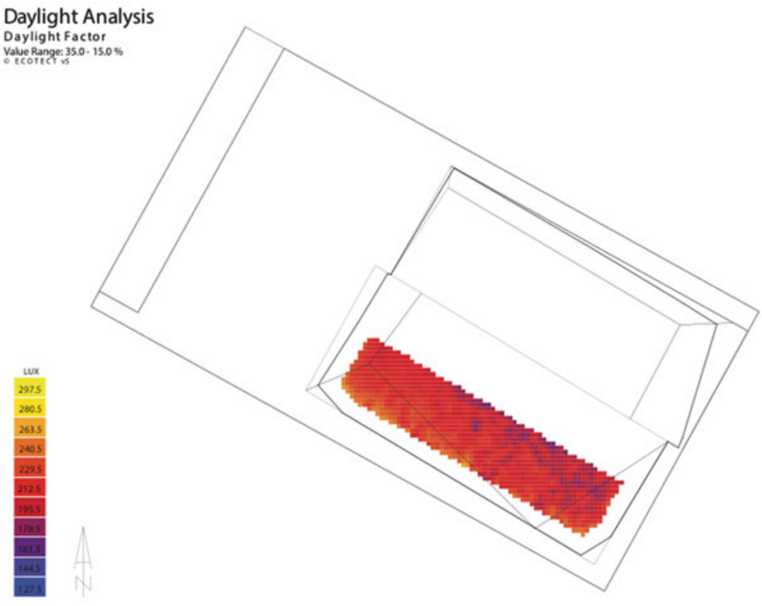

Fig. 7.21 Daylighting analysis of one of the offices, © M. Keramati

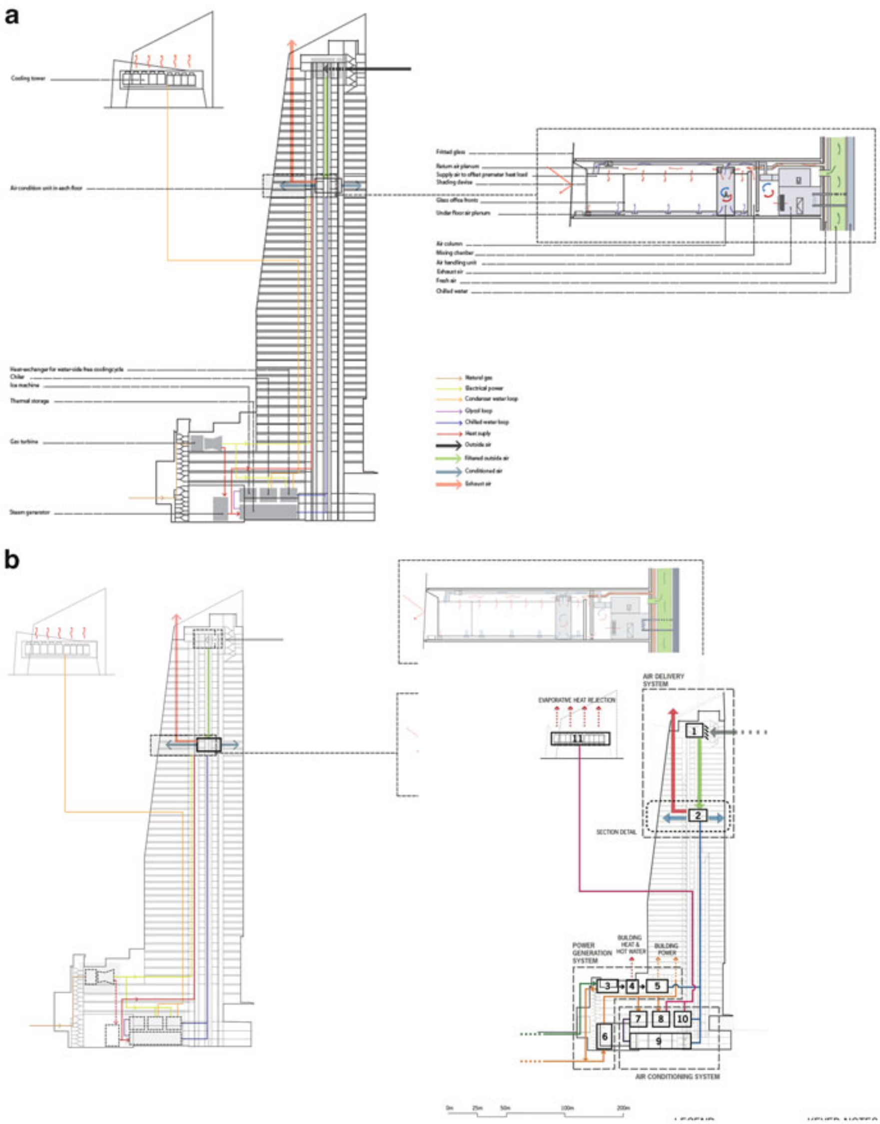

Fig. 7.22 Cross section of building, (a) cooling strategies, © M. Keramati; (b) cogeneration strategies

from CHP plant and ice storage, the building can achieve energy improvements over the ASHRAE 90.1-2204 baseline. The debate is ongoing on the principle of energy-efficient design, which basically starts with minimizing the loads and then investing on the systems to serve the loads. This building invested on the technologies is opposed to the envelope upgrades (Fig. 7.23).

Actual energy consumption at One Bryant Park is 12.7 % lower than predicted at design. The energy-efficient HVAC systems, demand control ventilation with

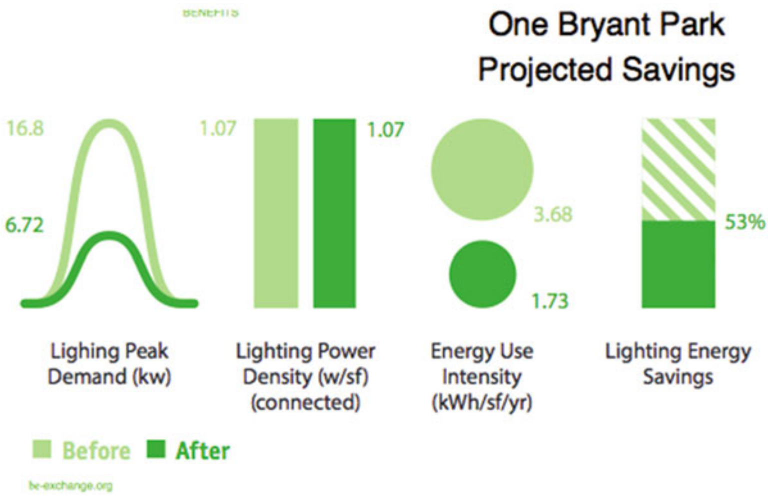

Fig. 7.23 Projected saving by Living Lab NYC May 6, 2015

4.6 MW gas turbine cogeneration systems, and chilled water plant with waste heat absorption and ice production reduce the building's electric demand and offset the energy needs. However, still the source EUI of the building is 336 kBtu/ft^2 in 2013 that exceeded the expectations of the design which shows the saving is 9.9 % better than 90.2-2004 ASHRAE standard.

3 Conclusion

The two examples introduced here were the two sides of energy-efficient design arguments. In Energy-efficient skyscrapers, sustainability means to reduce the energy loads by integrated passive systems of heating and cooling in addition to the mixed-mode mechanical systems as the backup plan. However, as observed in the One Bryant Park, the common principle has not been followed and instead the building was invested in the building systems to generate the loads that were created by the design.

Sustainable high-rise buildings can operate at optimum efficiency and reduce their environmental impact. The key is the importance of constantly exploring how to improve the operation of the building to achieve high efficiency. The resources such as sunlight and rainwater harvesting can be deployed as means of reduction in resources.

Acknowledgement I would like to thank my graduate research assistant, Maryam Keramati who was instrumental in execution of this project. I would like to recognize her drawings in all the diagrams and her analysis in this chapter. I also would like to acknowledge my undergraduate assistant, Victoria Pike for drawing the first two diagrams in this chapter. I am grateful for the support provided by the school of architecture at University of North Carolina at Charlotte.

Chapter 8
Assessing the Myths on Energy Efficiency When Retrofitting Multifamily Buildings in a Northern Region

Jan Akander, Mathias Cehlin, and Bahram Moshfegh

1 Introduction

1.1 National Goals

In light of EU's requirements on achieving major cuts in energy use by 2050, Sweden has similar targets. The built environment must by 2020 reduce energy use by 20 and 50 % by 2050. While the size of the future building stock will increase—and independently of how energy efficient each future new building will be—the energy performance of the old stock must be improved in order to reach those goals. Buildings in Sweden consume almost 39 % of all demand side energy, of which most is for space and domestic hot water (DHW) heating (SEA 2013). The building sector has the best potential to reduce energy use by 50 % in 2050 compared to the energy use during 1995 (Boverket 2007). A step in that direction is to diminish energy use by 20 % in 2020 and that 50 % of all energy should come from renewable sources. The latter goal was achieved in 2012 at 51 % (Eurostat 2014), but the former goal is more difficult to reach. In four major renovation projects in Sweden that involved retrofitting of multifamily building blocks in large cities, more than 50 % reduction was achieved and in two of the cases, the energy conservation measures (EMCs) were considered profitable (Byman and Jernelius 2012).

J. Akander (✉) • M. Cehlin
Department of Building, Energy and Environmental Engineering, Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, Sweden
e-mail: jan.akander@hig.se; mathias.cehlin@hig.se

B. Moshfegh
Department of Management and Engineering, Division of Energy Systems, Linköping University, Linköping, Sweden
e-mail: bahram.moshfegh@liu.se

A. Sayigh (ed.), *Sustainable High Rise Buildings in Urban Zones*,
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CO_2-eq emissions from the building stock are relatively low. On a national basis, electricity is mainly produced by hydro (48 %), nuclear (38 %) and wind power (4 %) and the remaining 10 % is combustion-based production (SEA 2013). Buildings account for lower than 15 % of Sweden's CO_2-eq emissions.

1.2 Gävleborg Region

Gävleborg is a sparse forestry region with many smaller urban areas and composed of totally ten municipalities. Situated just below the geometric center of Sweden (see Fig. 8.1), the mean annual outdoor temperature is approximately 4 °C, occasionally plummeting to −30 °C. Global solar radiation is 950–1000 kWh/(m² year), mainly concentrated to the non-heating season (Hydrological Institute 2014).

Unemployment is the highest in the country. Also, there are substantially more persons leaving (retiring) than entering the workforce. Only three of the ten municipalities do not have a decreasing population (Akander et al. 2012).

Among the total of 140,000 dwellings, 65,800 are apartments in multifamily buildings. Three municipalities have excess housing; two have a lack and the rest have a balanced housing situation (Akander et al. 2012). Energy for space and DWH heating of multifamily buildings in the region is supplied with the following shares: District heating 92 %, resistive electricity and heat pumps 2 %, others (biofuels and combinations of the above) 5 % and oil 1 %, respectively (Akander et al. 2012).

1.3 EKG-f

The National Statistics Bureau published a report (SCB 2009) that stated that the average multifamily building in Sweden used 154 kWh/(m² year) during the years 2006 and 2007 (the value is not normalized to weather). The corresponding value for Gävleborg indicate 164 kWh/(m² year). These statistics triggered the EKG-f project which actually was not focused on why the statistics looked this way; it was more-so about what to do about it in view of Sweden's national goals. EKG-f was a regional project (Akander et al. 2012) aimed to:

- Increase the region's knowledge on the thermal performance of the multifamily building stock and which measures are economical in energy-efficient retrofitting.
- Spread information on best practice and good examples to meet forthcoming national targets on reducing energy use and CO_2-eq emissions.
- Investigate the region's potentials of reducing energy use in buildings with 50 % and CO_2-eq by 75 % without jeopardizing indoor climate.

The strategy was to choose at least one real multifamily building in each of the ten municipalities and use these buildings to explore the energy savings obtained

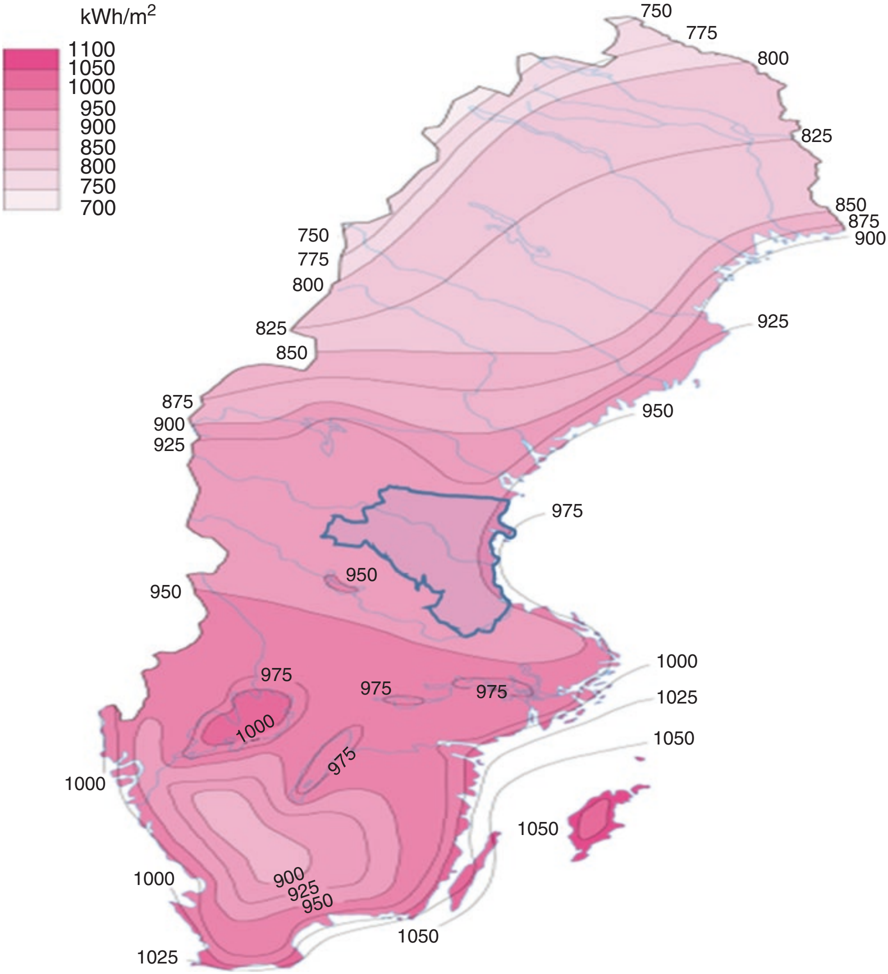

Fig. 8.1 Map of Sweden with solar radiation (Hydrological Institute 2014) and the region marked in *blue*

from various retrofitting alternatives by means of building energy simulations (BES). Cost estimates of the retrofitting alternatives were assessed and the profitability was evaluated using life cycle cost analysis (LCC). A major part was to investigate if deep energy retrofitting is economical, i.e., if the energy savings would in the long run compensate investment costs and to what extent it would do so.

The studied buildings and main features are listed, in Table 8.1. A requirement was that the building owners intend to retrofit in the near future. The buildings are not statistically representative for the population in any way. These are more-so chosen to have a variation in building types, systems, location, and other characteristics, having in common the aspect of needing renovation to some extent. However,

Table 8.1 Studied buildings in the project

No	Municipality, town—address, ownership (site location)	Year	Area [m^2], Apts [no.]	Load-bearing structure, mean U-value [W/(m^2 K)]	Vent-sys	Heat sys.	Efficiency [–]	Energy use [kWh/m^2 year]		
								Total	DHW	Facil. El.
1	Ljusdal—Ringvägen 18, private (urban)	1962	721, 7	Aerated concrete, 0.794	Nat	DH	0.95	181	32	18
2	Hudiksvall, Delsbo—Smedjeg. 4, municipal (urban)	1970	1221, 10	Wood/concrete, 0.780	Nat	DH	0.95	138	28	1
3	Sandviken—Polhemsg. 9, Co-op (urban)	1950	1378, 18	Aerated concrete, 0.830	Nat	DH	0.95	176	28	5
4	Gävle, Sätra—Ulvsätersg. 14, private (urban)	1973	2581, 27	Aerated concrete, 0.708	Exh	DH	0.95	119	30	2
5	Gävle, City—Staketgatan 9, Co-op (urban)	1899	3000, 24	Brick, 0.790	Exh	DH	0.95	123	22	9
6	Bollnäs, Segersta—Stora v. 33, private (rural)	1955	589, 6	Aerated concrete, 0.776	Nat	Pellet boiler	0.90	162	27	12
7	Söderhamn, Ljusne—Bruksg. 6, private (rural)	1950	607, 8	Timber frame, 0.823	Nat	Pellet boiler	0.85	183	26	12
8	Hudiksvall, Hallstaåsv. 40, private (rural)	1880	402, 5	Wood frame, 0.571	Exh	Oil boiler	0.81	213	30	17
9	Sandviken, Gästr. H-by—Allén 5, private (rural)	1966	190, 4	Aerated concrete, 0.830	Nat	GSHP	2.8	88	42	4
10	Nordanstig, Ilsbo-Bäcken 17, municipal (rural)	1971	292, 4	Wood frame, 0.456	Nat	Electr.	1.00	171	24	0
11	Ockelbo—Marstrandsv. 68, municipal (rural)	1977	364, 5	Wood frame, 0.631	Exh	Electr.	1.00	195	36	0

Area is the heated floor area, and Apts denote the number of apartments. The presented energy use (total) does not include household electricity. The mean U-value of the building includes thermal bridges. (*Nat* natural, *Exh* exhaust, *GSHP* ground source heat pump, *DH* district heating.) The buildings are listed in the order of heat source and with increasing floor area note that all buildings are quite small in size and amount of apartments. The reason is due to that cities and towns in the region are relatively small and quite many buildings are situated in rural context.

The metrics for energy use in Sweden is to divide the annual value by the floor area of spaces which are heated to at least 10 °C. The so-called specific energy use is defined as the sum of energy for space heating and cooling, heating of DHW and facility electricity (i.e., energy for operating the building, such as electricity for fans, pumps, and lighting in common spaces) divided by the floor area. The values shown in Table 8.1 are weather-normalized specific energy use based on bills supplied by the owners. For privacy reasons, household electricity was not investigated and was set in calculations with a default value of 30 kWh/(m^2 year) (SVEBY 2009). Notably, household electricity is not included in the definition of specific energy use according to Swedish building regulations.

1.4 Aim and Scope

This chapter presents some of the findings from the EKG-f project in terms of what is profitable for property owners when improving the energy efficiency of a multifamily building during renovation. The study investigates whether or not the investment cost of retrofitting alternatives can be recovered on basis of energy savings to avoid increases in rent—especially in view of the housing situation in the region. Focus is primarily on thermal energy savings but issues on indoor climate and building regulation enforcement are considered. Based on the findings, a concluding discussion is made on whether or not some myths on energy use and retrofitting are true.

2 Methods

A crucial part of the project was to base the work on real buildings and to assess actual performance characteristics and energy use. Audits and measurements were conducted at site. Audits included inspections of the design, types, and condition of building components and systems. Instantaneous and 2-week measurements were made on building and component dimensions, indoor temperatures, ventilation rates, and air tightness of one apartment per building. Together with design drawings (if available), energy bills, energy performance certificates, and mandatory ventilation inspection protocols, these data were used for models in BES programs BV2 (Nilsson 1997) or IDA-ICE (Sahlin et al. 2004). The base models of the buildings were validated to give annual energy use as close as possible to collected (billed) energy. Having this done, the next step was to test various ECM alternatives to quantify energy savings, reduced CO_2-eq emissions and life cycle costs.

2.1 Assessment Description

2.1.1 Are Statistics Correct?

In the first part of the project, energy use of the Gävleborg multifamily building stock was analyzed by means of statistics from the National Statistics Bureau (SBC) reports and a register where energy use is recorded from Energy Performance Certificates (EPC), called Gripen and administered by Boverket (the National Board of Housing, Building, and Planning). Gripen is trusted to have more reliable statistics on energy use than SCB, since a certified auditor has been at site to collect information (building drawings, energy bills, etc.) compared with sampled telephone inquiries made by SCB. According to law, all multifamily buildings should have valid EPCs since 2008. However, an assumption on that this has been done to 100 % is not reasonable, though the majority of the stock should have this done. Moreover, several inaccuracies in Gripen have for example been investigated by Mangold et al. (2015), in terms of how the definition of floor area and default conversion values influence the performance statistics of individual or clusters of buildings.

2.1.2 Selection of Buildings

The strategy to select buildings was to involve property owners who had thoughts on renovating their buildings and at the same time make these more energy efficient. News about the project and the search of property owners was communicated by means of the local radio, newspapers, and the Internet. Interested owners were informed that there were some mandatory lectures on energy performance, meetings, ambitions, and planning of building inspections and outcomes. This was the only commitment that owners had. Property janitors/managers also participated in lectures and meetings. Lectures on know-how and best practice were presented by involved personnel working within this project together with invited best practice experts and companies that offer energy-saving services and products.

Initially, the plan was to have at least one participating building per municipality of totally ten. However, there were no interested/qualified stakeholders in two of the municipalities. Therefore, three municipalities have two buildings thus amounting to a total of 11 buildings. Among the candidate buildings, the choices were based on obtaining a wide variety in terms of types of ownership, localization, building size and frame, type of ventilation and heating system, age and degree of listing (heritage protection). The choices did not reflect on representing the regional stock (which for example has a share of heating by 92 % with district heating).

2.1.3 Assessment of Energy Use and Building Performance

The first step was to gather various documents that give information on the building. These are, if available, building design drawings and description, energy performance certificates (EPC), mandatory ventilation inspection (OVK) and energy bills.

In order to have more reliable input for the BES, the premises were visited by project personnel. Audits were carried out by inspection of the composition and condition of constructions and systems, power of building services and other electric components, set-points, and control settings.

Measurements made at site were:

- Temperature in zones and outdoor air.
- Temperature readings of installations, especially of supply temperature to radiators and domestic hot water circulation system (DHWC) inlet and outlet temperatures.
- In common spaces, lighting power and controls was assessed.
- Pictures were taken of the facades to ensure window and external wall areas.

At each site, an apartment was chosen to perform the following investigations/measurements:

- Apartment room temperatures during the visit.
- Measurement of room and building dimensions.
- Assessment of window sizes and types.
- Estimation and prediction of material types and thicknesses in constructions (especially thermal insulation in walls).
- Readings of installation system gauges were made.
- Measurement of air flow rates in the ventilation terminals in the apartment (especially for the mechanically ventilated buildings).
- Blower door measurement for air tightness.

There were two types of longer term measurements:

- A temperature logger was left in the apartment to record the indoor temperature for at least 2 weeks and also one outdoors. This was to capture the long-term values more reliably.
- In apartments with natural ventilation, a tracer gas method was used to assess the overtime rate of air change; for at least 2 weeks.

2.1.4 Building Energy Simulation of ECMs Impact on Energy Use and Costs

There are many BES programs available for the purpose of simulating EMCs. According to Kalema et al. (2008), the results from using a BES program are affected by;

- How experienced and skilled the user is at translating realty into a numerical model.
- The quality of input data (for example areas, values on material parameters and heat transfer coefficients).
- Numerical solver methods.

The first two points give larger result deviations than the last point and simpler (single zone models) give approximately the same results as more complex multizone models. With this as basis and that the personnel's experience of using various BES programs, the two that were chosen are dynamic simulation programs—BV2, a single zone model (Nilsson 1997) and IDA –ICE, a multizone model (Sahlin et al. 2004).

Due to Data Protection Act, the use of electricity of the occupants cannot be assessed (for privacy and that the metering is within each apartment). Swedish BES standards SVEBY (2009) sets a default value corresponding to 30 kWh/(m^2 year). DHW is also uncertain, even though the total cold water consumption of the building is known. The method used for estimating DHW heating energy is based on a fixed water quantity (12 m^3 water per apartment) and per tenant (18 m^3 per person) and year (Aton Teknikkonsult 2007).

2.2 Retrofitting Alternatives

Buildings commonly have to be renovated every 40th year (SABO 2009) and when doing so, it is practical and economical to include EMCs. In the building envelope, thermal performance can be improved by the following means: additional insulation in the attic, external and/or basement walls, and the ground slab, replacement of old windows with new or by mounting extra panes, new doors and by assembling new balconies that reduced the effects of thermal bridges. These measures reduce heat losses and thereby supplied energy.

Heating, ventilation and air conditioning systems (HVAC) can be retrofitted or changed, often resulting in lower heat losses and in many cases by directly reducing supplied energy. Investigated alternatives include mounting of photovoltaics (PV) or solar thermal panels on available roof surfaces, heat exchange and recovery ventilation system of the balanced type (HRX), heat recovery from shower water, adjustment/tuning of the heating system, and also the use of low-flow faucets.

Though mostly related to user habits, studies were performed on energy savings due to lower indoor temperature by 1 °C, individual measurement and debit, energy-efficient lights in stairwells and use of presence control systems. Change in household electricity and its influence on the energy balance of the building was not studied.

At initial stages, the profitability of individual ECMs was investigated. Depending on the extent of energy savings, two ECM packages which are composed of various ECMs, are suggested to reach approximately 50 % cuts in energy use. The packages are not in any way optimized; these are proposed on basis of the building's needs, condition and what measure practically is possible to achieve. For example, building No. 4 already has windows with up-to-date performance, *U*-values equal to 1.3 W/(m^2 K), and are also in good condition (Table 8.2).

Table 8.2 Packages 1 and 2 are combinations of ECMs with the objective to reduce today's energy use with 50 %

Building no.	1	2	3	4	5	6	7	8	9	10	11
Package 1											
Attic: additional insulation (mm)	200		200						200		
External wall: additional insulation (mm)	100	100	200	100	40	100	100	100	100	100	100
Basement floor: additional insulation (mm)						100					
Basement wall: drainage/ insulation (mm)		100	100								
New windows: U (W/m^2 K)		1.8	0.85		1.30	1.30	1.30	0.85	1.30	1.30	1.30
New doors: U (W/m^2 K)									0.90	0.90	
HRX ventilation: thermal efficiency (%)	85			85	85			85			
Shower HRX: recovery part of DHW: (%)	20	20									
Low-flow faucets		✓									
PV: A (m^2), P (kWt)									70, 10		
Solar thermal panel: A (m^2)			39			15	15			9	15
Lower indoor air temperature by 1 °C			✓		✓		✓	✓		✓	✓
Adjustment of the heating system		✓	✓						✓	✓	
Package 2											
Attic: additional insulation (mm)	200		200	400							
External wall: additional insulation (mm)	100	100	200			100		100	100	100	100
Basement wall: additional insulation (mm)	50							100			
New windows: U (W/m^2 K)		0.85	0.85			1.3	0.85		0.85	0.85	0.85
New doors: U (W/m^2 K)										0.9	

(continued)

Table 8.2 (continued)

Building no.	1	2	3	4	5	6	7	8	9	10	11
HRX ventilation: thermal efficiency (%)		85	85			85			85	85	85
Shower HRX: recovery part of DHW: (%)				20	20	20	20	20			
Low-flow faucets		✓	✓								
PV: A (m^2), P (kWt)			50, 8		50, 8				70, 10		70, 10
LED lights in stairwells with presence control					✓						
Solar thermal panel: A (m^2)	25	21		60				15		9	
Lower indoor air temperature by 1 °C	✓				✓		✓			✓	
Night setback temperature by 3 °C								✓			
Adjustment of the heating system		✓	✓	✓							
Individual measurement and debit			✓								
Package 3											
Attic: additional insulation (mm)			200					200	200		
External wall: additional insulation (mm)	100								100		
Basement wall: drainage/insulation (mm)			100								
New windows: U (W/m^2 K)						1.3			1.3		
Extra pane on old windows: U (W/m^2 K)								1.8			1.8
New balcony: reduced thermal bridges	✓		✓			✓					
New balcony door						✓					
HRX ventilation: thermal efficiency (%)				85							
Shower HRX: recovery part of DHW: (%)								20			

(continued)

Table 8.2 (continued)

Building no.	1	2	3	4	5	6	7	8	9	10	11
Low-flow faucets	✓					✓		✓			
PV: A (m^2), P (kWt)										70, 5	70, 10
Solar thermal panel: A (m^2)										9	
LED lights in stairwells with presence control				✓							
Air to air heat pump COP (–)											3
Lower indoor temperature by 1 °C					✓						
Adjustment of the heating system	✓				✓				✓		
Individual measurement and debit				✓							

The ECMs are not optimized in any way: these show how the reduction can practically be achieved, i.e., depending on the conditions and circumstances for implementing an ECM in each building. Package 3 is ECMs that the property owner has proposed and has ambitions of carrying out

2.3 Life Cycle Cost

In this study, LCC was used to investigate the profitability of an investment made to save energy. For a building component or system that has a service life of n years, costs that are evenly distributed during the service lifetime can be added up and evaluated in net present value (NPV) form; see Eqs. (8.1), (8.2), (8.3), and (8.4). The total LCC is the sum of investment cost and annual energy and maintenance costs which depend on energy prices and energy use (Abel et al. 2012):

$$\mathrm{LCC}_{\mathrm{tot}} = \mathrm{C}_{\mathrm{investment}} + \mathrm{LCC}_{\mathrm{energy}} + \mathrm{LCC}_{\mathrm{maintenance}} + \mathrm{LCC}_{\mathrm{residual}} \tag{8.1}$$

$$\mathrm{LCC}_{\mathrm{energy}} = \mathrm{NPV}\ \mathrm{P}_{\mathrm{energyprice}}\ \mathrm{E}_{\mathrm{energyuse}} \tag{8.2}$$

$$\mathrm{LCC}_{\mathrm{maintenance}} = \mathrm{NPV}\ \mathrm{C}_{\mathrm{maintenance}} \tag{8.3}$$

$$\mathrm{LCC}_{\mathrm{residual}} = \frac{1}{\left(1+f\right)^{n}} \mathrm{C}_{\mathrm{residual}} \tag{8.4}$$

NPV is dependent on the net discount rate r and the estimated net increase rate of energy prices p; both exclude inflation. An adjusted net discount rate f as expressed in Eq. (8.5) gives NPV in Eq. (8.6) (Abel et al. 2012):

$$f = \frac{\left(r-p\right)}{\left(1+p\right)} \tag{8.5}$$

$$\text{NPV} = \frac{(1+f)^n - 1}{f*(1+f)^n} \tag{8.6}$$

For small p-values, the adjusted net discount rate in Eq. (8.5) is approximately $f = r - p$

The lowest LCC_{tot} is the most profitable. These equations are used for individual retrofitting measures. However, it is common that multiple measures are performed during a renovation occasion and for this purpose a tool called Belok Totalverktyg (Abel et al. 2012) has been utilized (which in turn is based on Eqs. (8.1), (8.2), (8.3), (8.4), (8.5), and (8.6)).

Retrofitting costs are estimated by using a calculation tool used by building sector professionals, Wikells Sektionsdata ROT2011 (Wikells Byggberäkningar 2013). Furthermore, assumptions are made that the increase of energy prices is 3 % for DH and pellets, 5 % for electricity and with a discount rate at 6 %. Prices for electricity, oil, and pellets are assumed to be 0.092, 0.120, and 0.046 €/kWh, respectively (SEA 2013; SPBI 2013) whereas district heating depends on the building's location, 0.057 ~ 0.068 €/kWh (Nils Holgersson Group 2013).

2.4 Primary Energy and CO_2-eq Emission

When primary energy sources are converted to energy carriers and distributed to the demand side, energy is lost. The end customers purchase the carrier energy that is supplied to the building, i.e., the energy use of the building. Primary energy is quantified with the help of primary energy factors that are specific for fuel types, distribution and conversion processes. The factors used in this project are based on Swedish average values much owing to that the buildings are distributed among eight municipalities—all with different suppliers. Primary energy factors are in this project, for electricity, set to be 2.5 (Nordic marginal value) and 1.5 (national mix average value), district heating 0.9, whereas oil and wood pellets both set to 1.2, respectively (SOU 2008).

Emissions of CO_2-eq are linked to the use of primary energy. Emissions used in this project are 400 and 85 CO_2-eq (g/kWh) for marginal and average electricity production, 74 g/kWh for district heating (average Swedish mix value), and 300 and 10 g/kWh for oil and pellets, respectively (SOU 2008).

3 Results

3.1 Statistics on the National vs Regional Level

The energy use (excluding facility electricity) was during 2006 and 2007 for the nation 154 kWh/(m^2 year) and for Gävleborg 164 kWh/(m^2 year), not normalized for weather (SCB 2009). These two figures were one of the reasons for starting this

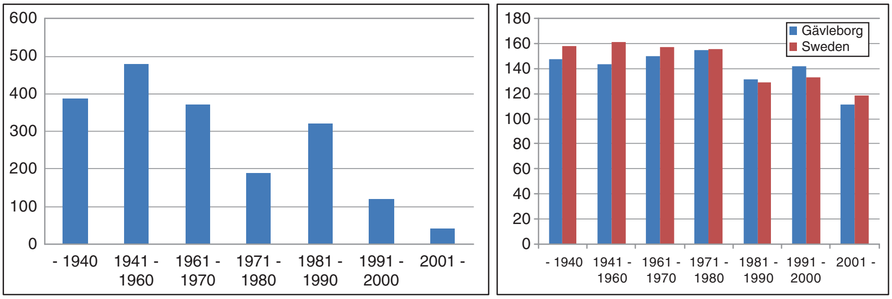

Fig. 8.2 To the *left*: number of multifamily buildings distributed according to the year of erection. To the *right*: specific energy use [kWh/(m^2 year)] by year of erection for Gävleborg and Sweden

project. When investigating newer statistics from various sources, contradictory information was found, especially when comparing results from the National Statistics Bureau and the EPC register Gripen. For the year 2011, the national normalized value was 151 kWh/(m^2 year) (SEA 2012) whereas the database Gripen indicates that Gävleborg on an average has a lower specific energy use for multifamily buildings, namely 145 kWh/(m^2 year). Figure 8.2 shows information on Gävleborgs multifamily building stock concerning when buildings were erected and how the distribution of specific energy use looks.

The statistics indicate the following:

- 20 % of Gävleborgs buildings were erected before 1941 and more that 65 % are older than 40 years.
- By October 2012 there are 1903 EPCs in the region, corresponding to 2 149 430 m^2. The average building has a heated floor area 1129 m^2.
- Buildings from 1971 to 1980 have the highest energy use and the lowest is found in new buildings (2001 and onward). Also buildings erected during the years 1981–1990 show better performance than buildings from the period 1991–2000.
- There were few multifamily buildings erected during the 1970s and has remained low since the 1990s.

Some statics that is not shown in Fig. 8.2 are:

- The oldest buildings have the lowest share of district heating whilst newest buildings have the highest.
- Of the 2 % of the buildings that are heated with oil, more than half of these are built before 1941. Only 4 % of the buildings have resistive electric heating and 6 % use ground source heat pumps.

An interesting aspect is that buildings erected before the 1970s on an average have better energy performance than those of the 1970s. A reason may be that it is the buildings of the 1970s that soon require major renovation (every 40th year) whereas older building to a larger extent have been retrofitted. Another interesting fact is that energy requirement in building regulation became more strict after the oil crisis in 1973, already introduced in late 70s. Since then, energy use has decreased except during the 90s, showing that legislature did not work well. Building codes allowed a new multifamily building (not heated by electricity) in 2014 to have a maximum energy use of 110 kWh/(m^2 year).

3.2 Investigation of EPC, Ventilation, and Indoor Temperatures

Aside from energy matters, the investigation gave insights in several other aspects that are linked with indoor climate and how well laws are followed. In terms of law, every multifamily building in Sweden should have:

- A valid EPC certificate that shows the performance of the building and has suggestions on how this can be improved. The performance is usually based on energy bills and an audit. All buildings should have the certificate since 2011.
- A valid certificate from a mandatory ventilation inspection (OVK) where ventilation flows and function is checked. The law was enforced in 1992 after that a large investigation of the building stock showed that residences in general had too small ventilation rates, thereby creating a poor indoor air quality.
- Building codes have for decades stated that residences must be ventilated with fresh air corresponding to at least 0.5 ACH.

According to the top left display in Fig. 8.3, one of the 11 buildings does not have a valid EPC. Moreover, only five buildings have approved OVK. This may have consequences for ventilation statistics.

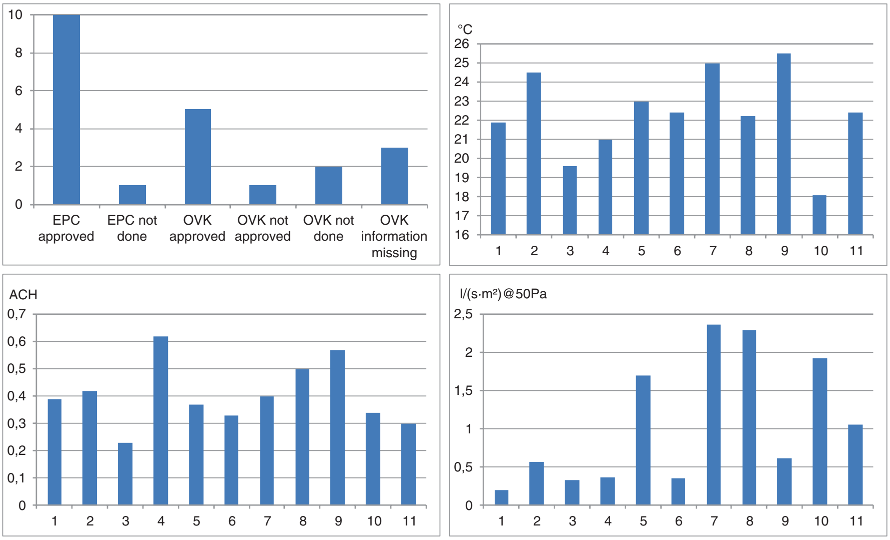

Fig. 8.3 *Top left*: number of approved EPC and OVK certificates for the 11 buildings. *Top right*: indoor temperatures measured for 2 weeks in an apartment of each building. *Bottom left*: measured air change rates per hour (ACH) in each apartment. *Bottom right*: measured air tightness—the unit is the air flow (liter per second) through the envelope area at 50 Pa pressure difference

Assessment of ventilation, temperature, and air tightness results in Fig. 8.3 indicates:

- Ventilation rates are often too low in apartments, on an average 0.41 ACH.
- Mean indoor temperatures are within authority (Public Health Agency) recommended ranges (20–24 °C) (2005) but can for various buildings be reduced since the mean value for all is 22.3 °C. A comment on building 10—the tenant was visiting the hospital for a longer period and lowered the indoor temperature when away.
- Air tightness of envelopes is dependent on construction type, with wood/timber frames being most leaky. As a reference value, older building codes had requirements on maximum 0.8 l/(s m^2). Buildings with masonry or concrete frames (0.8 l/(s m^2)) are more airtight than buildings with timer or wood frames (1.9 l/(s m^2)). However, there is no clear correspondence between ventilation rates and envelope air tightness in Fig. 8.3.

3.3 Influence of Individual EMCs

Results for individual measures in terms of reduction of energy use in comparison with today's consumption are displayed in Table 8.3. In some cases, values are not presented since practical implementation of the ECM is not possible. For example, building No. 5 is a historical building for which external wall insulation is not allowed and there is no space for additional insulation in the attic of building No. 10. Results on other types and combination of measures can be found in (Akander et al. 2012).

HVAC retrofitting and improvements, with exception of ventilation systems (HRX), generally indicate that those measures are more profitable than measures on constructions. Controls systems and optimization and/or adjustment and tuning of heating system are profitable. However, the economic measures do not individually give substantial energy savings; these give savings ranging between 2 and 9 % with exception of PVs combined with electric heating (resistive and HP) that give higher savings. For the electric heated buildings, air to air heat pump solution shows large savings which are economical. Aside from these ECMs, most figures are in the whereabouts of savings due to reduction of the indoor temperature with 1 °C, which yields 5–7 %.

Worth mentioning is the impact of HRX that may give savings up to about 30 % but also none at all (1 %). There are three reasons for this result. On the one hand, a leaky envelope depletes savings since uncontrolled air leakage passes through the building without heat recovery. On the other, the ventilation rate has to be increased in most buildings, since these have insufficient rates in comparison to regulations, which correspond to approximately 0.5 ACH. The third aspect is that the fans and controls of the HRX system require electricity, thus increasing electricity consumption.

Table 8.3 For each house (number in the top row as listed in Table 8.1, accompanied with heating type), the impact of individual ECMs is expressed as savings (%) in the left column and the profitability for individual measures (N = No in italics, Y = Yes in bold) in the right column

	1		2		3		4		5		6		7		8		9		10		11	
Measure	DH		DH		DH		DH		DH		Pellet		Pellet		Oil		GSHP		Res El		Res El	
Wall extra 100 mm	23	N	5	N	14	N	20	N	–	–	22	N	12	N	10	N	17	N	9	N	12	N
Wall extra 200 mm	27	N	6	N	17	N	23	N	–	–	26	N	15	N	12	Y	21	N	12	N	15	N
Attic extra 200 mm	5	Y	–	–	10	Y	–	–	1	N	–	–	–	–	2	Y	5	Y	–	–	–	–
Attic extra 400 mm	6	Y	–	–	–	–	2	Y	2	Y	–	–	–	–	–	–	7	N	–	–	–	–
Extra window pane	–	–	4	N	–	–	–	–	7	N	8	N	6	N	–	–	5	N	6	Y	10	Y
Window $U = 1.30$	–	–	7	N	5	N	–	–	9	N	10	N	9	N	4	N	8	N	9	N	15	N
Window $U = 0.85$	6	N	8	N	7	N	3	N	11	N	12	N	13	N	10	N	12	N	13	N	20	N
Door $U = 0.90$	–	–	–	–	–	–	–	–	–	–	2	N	–	–	–	–	3	N	3	N	2	N
HRX (leaky envelope)	–	–	–	–	–	–	–	–	15	N	–	–	12	N	7	N	1	N	–	–	3	N
HRX (tight envelope)	16	N	9	N	3	N	32	N	24	N	8	N	28	N	20	N	6	N	5	N	7	N
Solar thermal	9	N	7	N	8	N	11	N	9	N	8	N	9	Y	9	Y	8	N	7	Y	9	Y
Solar PV	6	Y	3	Y	3	Y	7	Y	2	Y	9	Y	8	Y	10	Y	17	Y	24	Y	12	Y
Adjust heating sys.	7	Y	5	Y	8	Y	8	Y	7	Y	8	Y	8	Y	7	Y	8	Y	–	–	–	–
Shower HR	4	N	3	N	3	N	4	N	–	–	3	N	3	N	3	Y	3	N	3	N	4	Y
Low-flow faucet	–	–	3	Y	3	Y	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Reduce temp 1 °C	7	Y	3	Y	5	Y	6	Y	7	Y	7	Y	7	Y	7	Y	7	Y	8	Y	7	Y
Air to air HP	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	34	Y	33	Y

A dash means that practical implementation is not possible. The upper part of the table has construction measures and the lower on building services and controls

Table 8.4 Today's energy use of each building and the savings that the packages have in terms of simulated energy use and saving in comparison to today's values

Building no.	1	2	3	4	5	6	7	8	9	10	11
Today's energy use (kWh/m^2 year)	181	138	176	119	123	162	183	213	87	171	195
Package 1											
New energy use (kWh/m^2 year)	96	96	88	52	64	84	99	125	35	111	109
Savings (%)	47	31	50	57	48	48	46	43	59	35	44
Package 2											
New energy use (kWh/m^2 year)	100	68	88	89	106	90	111	163	42	97	94
Savings (%)	45	51	50	25	14	45	39	24	53	43	52
Package 3											
New energy use (kWh/m^2 year)	155	138	148	70	106	148	183	199	24	138	142
Savings (%)	14	0	16	41	14	8	0	7	27	19	27

3.4 Influence of EMC Packages

In order to increase the magnitudes of energy savings, such as fulfillment of national targets of 20 and 50 % cuts, combinations of various ECMs must be performed. This does not mean that the sums of individual ECMs can be added up. Combinations of ECMs must be simulated for each case and the results are presented in Table 8.4.

The content of Table 8.4 indicates that there is a potential of technically reducing energy use by 50 %. The average savings of the packages are 45, 43, and 14 %. However, even if there is a potential, it is not always possible to use it. For example, building No. 5 is listed and there is no way of changing the external appearance. Package 1 shows that it is possible to reach approximately 50 % but the additional insulation of 40 mm would not be accepted due to alteration of the façade. Package 2 would be allowed, but does not come close to targets.

The next step is to investigate if the ECM packages are profitable, i.e., if the energy savings will be large enough to avoid increasing the rent of the apartment. The results are based on a discount rate at 6 %, meaning that the adjusted discount rate must be higher than approximately 1 % for electricity and oil-heated buildings and approximately 3 % for DH and pellets. Table 8.5 shows that Package 1 is not profitable for any buildings. Package 2 has four profitable examples. If the discount rate was set to 5 %, building No. 7 would also have a profitable package. Most of the ECMs of Package 3, suggested by the owners, are profitable. This is logical, since the measures do not involve large investments and do not give large savings. As seen in Table 8.5, the profitable cases of Packages 2 and 3 cost less than 170 €/m^2 giving savings about 20–25 % (especially for electrically heated buildings); but this does not mean that all low-cost investments are profitable. At the same time, large investments do not necessarily mean that large quantities of energy are saved. For example,

Table 8.5 Economic figures in terms of investment cost per floor area, annual energy saving in Euros, the amount of energy saved per invested Euro and the adjusted discount rate (Eq. (8.5))

Building no.	1	2	3	4	5	6	7	8	9	10	11
Main energy carrier	DH	DH	DH	DH	DH	Pellets	Pellets	Oil	GSHP	El	El
Package 1											
Invest. cost (€/m^2)	122	170	341	139	157	145	145	377	378	262	269
Annual savings (k€/year)	4.22	3.53	8.31	10.67	10.94	2.37	2.94	5.30	0.95	1.71	3.04
Saving ((kWh/year)/€)	0.697	0.249	0.259	0.483	0.377	0.537	0.581	0.234	0.137	0.230	0.320
Adj disc. rate (%)/viability	1.3/N	0/N	0/N	0/N	0/N	0/N	0.9/N	0/N	0/N	0/N	0/N
Package 2											
Invest. cost (€/m^2)	86	275	388	26	10	235	83	164	546	418	473
Annual savings (k€/year)	4.10	5.87	8.49	4.74	3.60	2.19	2.51	3.04	0.85	2.11	3.57
Saving ((kWh/year)/€)	0.942	0.254	0.226	1.149	1.72	0.308	0.865	0.308	0.085	0.178	0.214
Adj disc. rate (%)/viability	6/Y	0/N	0/N	5/Y	10/Y	0	2.5/N	3/Y	0/N	0/N	0/N
Package 3											
Invest. cost (€/m^2)	47	0	71	78	4	37	0	17	150	64	88
Annual savings (k€/year)	0.05	0	2.60	7.91	3.20	0.04	0	0.02	0.44	0.06	1.88
Saving ((kWh/year)/€)	0.543	0	0.388	0.631	4.342	0.372	0	0.849	0.158	0.519	0.603
Adj disc. rate (%)/viability	0/N	0	1.8/N	0/N	30/Y	0/N	0	13/Y	2.8/Y	4/Y	3.6/Y

With the assumption of a discount rate at 6 %, increased price rate of electricity and oil at 5 % and for DH and pellets at 3 %, the investment is profitable at approximately 1 % for electricity and oil and at approximately 3 % for DH and pellets the payback time for replacing a concrete balcony with an add-on balcony, to reduce the thermal bridge, is almost 500 years!

Table 8.6 shows primary energy use and CO_2-eq emission of each building, related to floor area. What can be noticed is that the buildings that use electricity have relatively high values based on average P.E. factors, aside from building No. 9 that has a GSHP. Due to that hydro- and nuclear power stand for a large part of the Swedish electricity production, emissions are not much larger than for the other types, other than oil. However, when emissions are based on marginal values, the emissions due to electric heating are in the same levels as fossil fuels (oil). In this case, ECMs are important in reducing P.E. use and emissions since measures done on one of these buildings will have the same total impact as performing the same measures in four similar buildings in a DH area. This is also a reason for not using electric or HP heating in DH neighborhoods. Pellets heating give larger P.E. than DH but lower CO_2-eq than the national average DH. However, pellets may in the future become a scarce resource and therefore be influenced by marginal effects, a scenario discussed by Liu et al. (2014).

4 Discussion and Conclusions

The discussion of the results is done in view of evaluating whether or not myths about building renovation are true. We use the observations and results of our investigation to provide the answer to “true or not?”

Myth: Regulations and laws are a good way of obtaining energy-efficient buildings with good indoor air quality.

This myth is not entirely true according to our investigation. The government can endorse laws with the purpose of improving energy efficiency and indoor air quality. Though the more recent building regulations state that buildings undergoing major renovation should strive to reach the same standard as set for new buildings, it is not compulsory. Therefore, the government does not in this case have the tools for improving energy efficiency in terms of building renovation. However, there are other laws that should be followed. Former building codes have always demanded that apartment be ventilated with at least a value corresponding to 0.5 ACH. The average value measured in this investigation is 0.41 ACH, where only three of 11 apartments would fulfill this requirement. The function check of the ventilation system is mandatory (OVK every three or six years, depending on ventilation system type) since 1992 and only five of 11 buildings has an approved certificate. EPC has been compulsory since 2008 and yet one of the 11 owners lacks the certificate for their property. EPC must suggest cost-efficient ECMs, but it is not mandatory to implement these. All in all, these numbers show that property owners either do not care for regulations and laws or are simply not informed or updated on these. The consequence is that targets are not achieved, even by legislation.

Myth: Heat recovery ventilation systems (HRX) always give substantial energy savings.

This is false according to our investigation. Retrofitting or improvements made in the building's service systems (HVAC) are more economical than actions taken to improve performance of building constructions. HRX can give up to 30 % saving but also almost 0 %, generally not economical. One of the problems is that apartments often have inadequate ventilation rates. With a mechanical ventilation system, rates will in many cases be increased, thus reducing the saving potential but on the other hand enhancing indoor air quality. Another aspect that decreases efficiency is leaky envelopes. An alternative to HRX is to use exhaust air heat pump, which will have better efficiency than HRX but on at the same time increase the use of electricity. A HRX system has two fans that will increase the use of electricity and thereby also primary energy and emission (especially when calculating with marginal production).

Myth: New windows are always cost efficient and are payed off after 15 years.

Not true according to our investigations. Large savings can be obtained by improving the building envelope, for example with additional insulation and by replacing new windows with old. However, these measures are not profitable, independently of how and with what the building is heated. This indicates that energy prices are too low or that the measures are too expensive, except for extra insulation in the attic unless this has not already been done. The low prices on pellets and DH (both are renewables) make many measures expensive and become more-so in a region where the buildings are quite small, i.e., reducing transmission losses through the envelope become vital to reduce energy use, but expensive. New windows are not profitable. A cheaper option is to fit an extra pane in the old window (if the condition allows this measure) but is only profitable in electric heated buildings (which have the highest heating cost). Worth noting—only building No. 8 (oil) shows profitability of extensive additional insulation on external walls (it is actually more profitable to change the heating source to a GSHP or a pellets boiler as shown in Akander et al. (2012).

Myth: Solar energy is not profitable in Nordic climates.

Not true according to our investigations. Solar energy is, despite the latitude of the region, economically viable—especially PV solar energy. This quite unforeseen result rendered interest among building owners. However, in a broader perspective, the question is if it is worthwhile to invest thermal solar energy in DH areas that to a large extent uses waste heat and relatively cheap renewable fuels (in this case to a large extent forestry production waste). In essence, solar thermal energy is replacing other cheap or renewable energy in the non-heating season. Photovoltaic panels (PVs) are viable—the combination of PVs and DH is beneficial since saving electricity is more important than thermal energy in DH areas, see Truong et al. (2014) and Thygesen and Karlsson (2013). However, the market situation is influenced by politics and for the time being, property owners can sell produced solar electricity to tenants. Excess production can be sold via the grid, but is not economical. The calculations are based on month-wise debit and no subsidies for installation of the PVs. Today, PV debit is on daily basis which require tax cuts for small-scale producers in order to make the technology and installation viable.

Table 8.6 Primary energy (P.E.) and emissions (CO_2-eq) of today are displayed for each building

Building no.	1	2	3	4	5	6	7	8	9	10	11
Main energy carrier	DH	DH	DH	DH	DH	Pellets	Pellets	Oil	GSHP	El	El
Primary energy use today											
Based on average P.E. (kWh/m^2 year)	174	125	161	108	116	198	223	261	131	257	293
Based on marginal P.E. (kWh/m^2 year)	192	126	167	111	125	210	235	278	218	428	488
CO_2-eq emission today											
Based on average CO_2-eq (kg/m^2 year)	13.6	10.2	13.1	8.8	9.2	2.5	1.8	60.4	7.4	14.7	16.5
Based on marginal CO_2-eq (kg/m^2 year)	19.3	10.5	14.7	9.5	12.0	6.3	4.5	65.7	35.3	68.5	78.0
Package 1 average											
New P.E. (kWh/m^2 year)	97	85	82	48	63	105	132	154	57	167	163
Savings (%)	46	31	50	57	48	47	46	44	58	35	44
New CO_2-eq emission (kg/m^2 year)	7.2	7.0	6.5	3.8	4.8	1.7	1.0	33.8	3.2	9.6	9.3
Package 1 marginal											
New P.E. (kWh/m^2 year)	116	86	88	51	72	117	135	171	93	277	271
Savings (%)	40	33	45	52	36	44	46	40	58	35	44
New CO_2-eq emission (kg/m^2 year)	12.9	7.0	8.6	4.6	7.9	5.4	3.7	39.3	14.7	44.5	43.7
Package 2 average											
New P.E. (kWh/m^2 year)	100	60	80	81	98	111	151	199	63	144	139
Savings (%)	44	52	50	25	14	44	39	25	52	44	52
New CO_2-eq emission (kg/m^2 year)	7.5	4.9	6.5	6.6	7.9	1.7	1.2	45.3	3.7	8.2	8.0
Package 2 marginal											
New P.E. (kWh/m^2 year)	118	60	81	84	103	123	149	216	102	243	235
Savings (%)	38	53	54	22	18	39	37	23	52	43	52
New CO_2-eq emission (kg/m^2 year)	13.2	4.9	6.7	7.3	9.4	5.6	5.6	50.5	16.8	38.7	37.6

The predicted impact of each package is shown for two scenarios of electricity production—based on the national average value and on Nordic marginal production value

Myth: Heat pumps (HP) use less energy than DH, which motivates use of HP in DH-heated areas.

Not entirely true. From owner perspective, the running cost of a HP seems less than for DH (if investment costs are disregarded) primarily due to the HP coefficient of performance COP. When looking at P.E. and emission, the situation becomes different since the national mix value of electricity production gives approximately the same as for DH while results for the marginal value show that a HP will use more natural resources than DH and increase emissions. Since marginal values are recommended to be used in predictions or planning phases, the results suggest that the use of HPs in DH areas is not a good choice in terms of resources and environment.

Myth: Deep renovation of multifamily buildings is not worthwhile—it is better to tear down old buildings and erect new ones.

This may be partially true and depends on the overall condition of the building. In terms of energy use, a 50 % reduction is technically and practically possible but not profitable. Deep renovation in real projects costs some 680–2300 €/m^2 (Byman and Jernelius 2012) of which about 20 % of the total cost is dedicated to energy measures (thus 120–680 €/m^2) where reductions of up to 70 % have been obtained. In the four projects presented in Byman and Jernelius (2012), the rent was increased with 7, 20, 35, and 40 %, respectively. In two projects, the renovations were considered to be profitable while the other two were more "goodwill". This should in turn be compared with the cost of a new multifamily building, which on a national basis (excluding Sweden's three largest cities) averages to about 3000 €/m^2 (SCB 2012) (this excludes the costs of disassembling the old building).

In this investigation, calculations indicate that energy reduction would cost approx. 120–540 €/m^2 to reach 50 % cuts, corresponding well with the real projects. Average costs of Packages 1, 2, and 3 are 228, 246, and 62 €/m^2 with the latter giving a 17 % saving in energy use.

A reduction of energy use by 50 % is possible in deep renovation. However, energy savings will not cover the renovation costs. Other factors such as socioeconomical and increased rents must be considered in order for the measures to be profitable.

Myth: Newly erected buildings are more energy efficient than old buildings.

This is only partially true. Statistics in Fig. 8.2 illustrates that buildings that were erected in the 1990s have poorer energy performance than those that were built after the oil crisis, primarily during the 80s, when building codes became stricter. The group that shows the worst performance is that of the 1970s, i.e., older buildings are apparently more energy efficient. This group stands next in line to be renovated, since major renovation is performed every 40th year. It is therefore important to use this occasion to perform substantial ECMs in this renovation process, since it will take another four decades until the next time which is beyond 2050 and by then used considerable amounts of primary energy and released vast quantities of CO_2. This investigation shows that there are potentials of creating sustainable energy-efficient renovated old buildings.

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Chapter 9
High-Rise Buildings in Context of Sustainability; Urban Metaphors of Greater Cairo, Egypt: A Case Study on Sustainability and Strategic Environmental Assessment

Mohsen M. Aboulnaga

1 Introduction

> *" Tall towers should have much greater resilience and last long enough to justify their huge cost. Materials should be fully recyclable and towers provide whole-life carbon analyses".*
>
> Simon Sturgis, Sturgis Associates

A high-rise building has been defined by the Council of Tall Buildings and Urban Habitat, CTBUH (2015) as "A building whose height creates different conditions in the design, construction, and use than those that exist in common buildings of a certain region and period". Nonetheless, CTBUH stated that there is no absolute definition of what constitutes a "tall building". It is a building that exhibits some element of "tallness" in one or more of three categories: (a) Height Relative to Context, (b) Proportion, and (c) Tall Building Technologies. Description of the three types is shown in Box 9.1.

The question raised is "are high-rise buildings meeting sustainability principles and measures?" This has been a long-lasting debate that has been ongoing during the past two decades. With interest in sustainability worldwide, it has been gaining even more momentum during the last decade. Sustainability worldwide is becoming a necessity since demands on natural resources, mainly energy in its two forms: primary energy; and secondary energy (electrical energy) is colossally increasing due to high consumption in cities and buildings. In Egypt, sustainability is increasingly becoming a necessity since energy is consumed colossally in all sectors, especially in the light of production capacity, particularly at peak times, i.e. summer months (June–September) where such high demands cannot be met. Nevertheless, planning for future demands has been recently manifested in the stake of electricity

M.M. Aboulnaga (✉)
Sustainable Built Environment, Department of Architectural Engineering—Environmental Design Division, Faculty of Engineering, Cairo University, Cairo, Egypt
e-mail: mohsen_aboulnaga@yahoo.com; maboulnaga@eng.cu.edu.eg

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Box 9.1 Tall building definitions according to Council of Tall Buildings & Urban Habitat, CTBUH (2015)

Height relative to context	Proportion	Tall building technologies
It is not just about height, but about the context in which it exists, meaning that a 14-storey building may not be considered a tall building in a high-rise city such as Chicago or Hong Kong, whereas in a provincial European city or a suburb it may be distinctly taller than the urban norm	A tall building is not just about height but also about proportion. There are numerous buildings that are not particularly high, but are slender enough to give the appearance of a tall building, especially against low urban backgrounds. There are numerous big/large footprint buildings that are quite tall but their size/floor area rules them out as being classed as a tall building	If a building contains technologies which may be attributed as being a product of "tall" (e.g. specific vertical transport technologies, structural wind bracing as a product of height, etc.), then this building can be classified as a tall building. Although number of floors is a poor indicator of defining a tall building due to the changing floor to floor height between differing buildings and functions (e.g. office versus residential usage), a building of perhaps 14 or more stories—or more than 50 m (165 ft) in height—could perhaps be used as a threshold for considering it a "tall building"

generation contracts signed during the international conference of economic development "Egypt the Future" with investments exceeding USD15 billion; where Siemens' share is worth ten billion (Egypt the Future 2015). This would give more hope that the new capital (North-east of Cairo) to be built with many high-rise buildings and skyscrapers to fulfil the requirements in terms of embodied energy[1] and operational energy for these tall buildings. Simply defined, embodied energy is "the energy requirement to construct and maintain the premises" (http://www.etool-global.com/wp-content/uploads/2012/10/Embodied-Energy-Paper-Richard-Haynes.pdf/).

Research indicates that it is indisputably true that high-rise buildings have advantages and disadvantages. Some residents who dwell in high-rise building's apartments revealed that they are lonely and unhappy while others state that it is advantageous to stay in high-rise apartments (Adalberth et al. 2001). In fact, it has been recognised that due to the increased demand of high-rise towers and decreased availability of space, tall buildings are now rapidly increasing especially in large cities around the world (Fig. 9.1). High-rise buildings unquestionably satisfy the drastic demand of house rentals in cities to the extent that they are excellent places for short stay in many cases. Economically speaking, prices of flats are less com-

[1] Embodied energy in residential buildings represents between 30 and 100 % of total life cycle energy consumption [new Ref—Saving the Environment Downsizing buildings in Japan http://youtu.be/HK1sHpBnhLA. Accessed 13 May 2015].

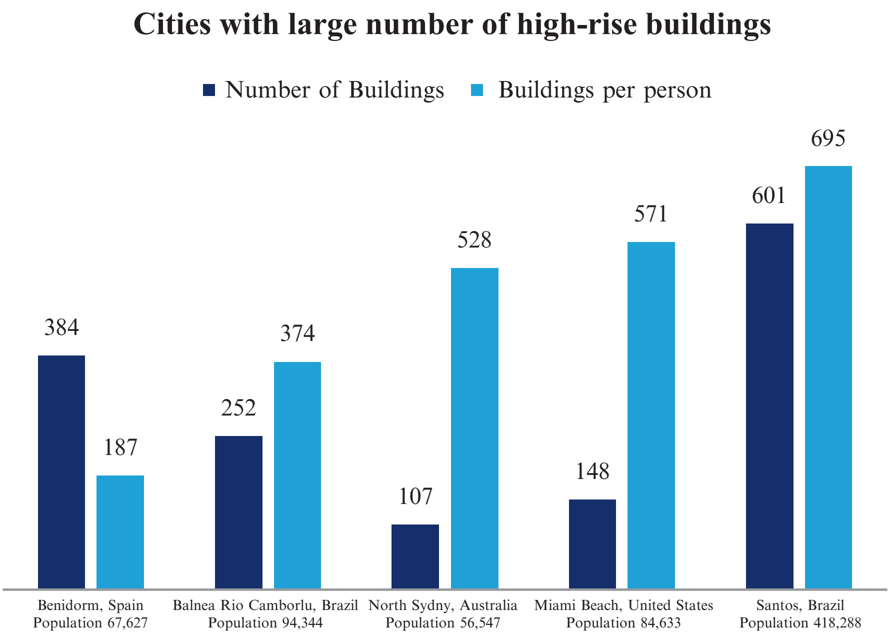


Fig. 9.1 Cities worldwide that have a large number of high-rise buildings. *Source*: http://www.emporis.com/statistics/worlds-tallest-buildings

pared to individual houses in cities (http://www.essayforum.com/writing-3/advantages-disadvantages-high-rise-apartments-48298/).

In today's world, there are many duties for architects, engineers, and urban planners to perform in energy efficiency, especially in tall buildings. Skyscrapers are vital in modern cities since these towers consume a great deal of energy, but nevertheless renewable energy can be an integral part of these skyscrapers and could significantly influence energy consumption patterns in these buildings and assist in reducing it. This has been manifested in many recent buildings in the Gulf, mainly in Dubai-UAE and Bahrain, e.g. Burj Khalifa and DIFC tower (designed by SOM & Atkins Overseas) and the World Trade Center in Manama, Kingdom of Bahrain (Lotfabadi 2015). Energy plays a key role in socio-economic development worldwide, particularly in Egypt. Many studies have emphasised the role of tall buildings to potentially diminish energy consumption. Lotfabadi, P. examined high-rise buildings and their environmental factors and illustrated the effects of some environmental factors, such as air pressure and density, wind speed, and other similar factors in high-rise buildings, from architects and ordinary people's point of view. She also compared these attitudes with each other in the case study (Lotfabadi 2015). Buildings, particularly high-rise buildings, worldwide use a huge amount of generated energy. Tall buildings which are considered an inevitable part of the community can meaningfully contribute to the reduction of energy consumption by using renewable energy and innovative ideas and solutions in designing these buildings.

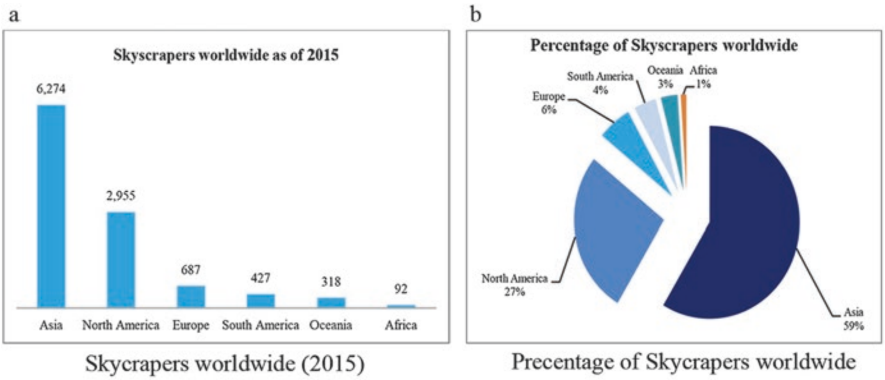


Fig. 9.2 Continents with high-rise buildings/skyscrapers. *Source*: http://www.emporis.com/statistics/most-skyscrapers

In contrast, research results have indicated that sustainable skyscrapers can be energy efficient and are closely related to their site and environment (Lotfabadi 2014).

According to Oral Buyukozturk, high-rise buildings have been demanded as a result of economic growth and increased demand for office space worldwide (Buyukozturk 2004). Figure 9.2 exhibits the number of high-rise buildings and percentage in six continents (Asia, North America, Europe, South America, Oceania, and Africa). By looking at skyscrapers by region, it is clear that Asia and North America have 64 % of the total number followed by Europe 18 %. In terms of the distribution of tall buildings worldwide, the top five cities with the largest number of high-rise buildings are located in Miami—North America, Brazil—South America, Spain—Europe, and Sydney Australia (Top 25 Nations with High Rise Building in the World 2015; EMPORIS 2015; The Top 5 Cities with the Most High-Rise Buildings/Population 2015). By comparing these cities, it is clear that high-rises in Sydney and Miami Beach city house the largest number of inhabitants However, the top 25 cities with skyscrapers are illustrated in Fig. 9.3, where Hong Kong, is the most crowded city in the world, has the highest number of skyscrapers as shown in Fig. 9.4 (http://www.emporis.com/statistics/most-skyscrapers; http://list25.com/25-cities-in-the-world-with-the-most-skyscrapers/5/; http://en.egypt.travel/attraction/index/cairo-tower/).

2 High-Rise Buildings' Metaphors in the Context of Planning within the Urban Structure

The top ten tall buildings in 2014 were built in Asia and North America, mainly the UAE, China, Saudi Arabia, New York, Taipei, Hong Kong, and Malaysia. Figure 9.5 presents the top ten buildings and their heights. In Egypt, particularly Cairo—the

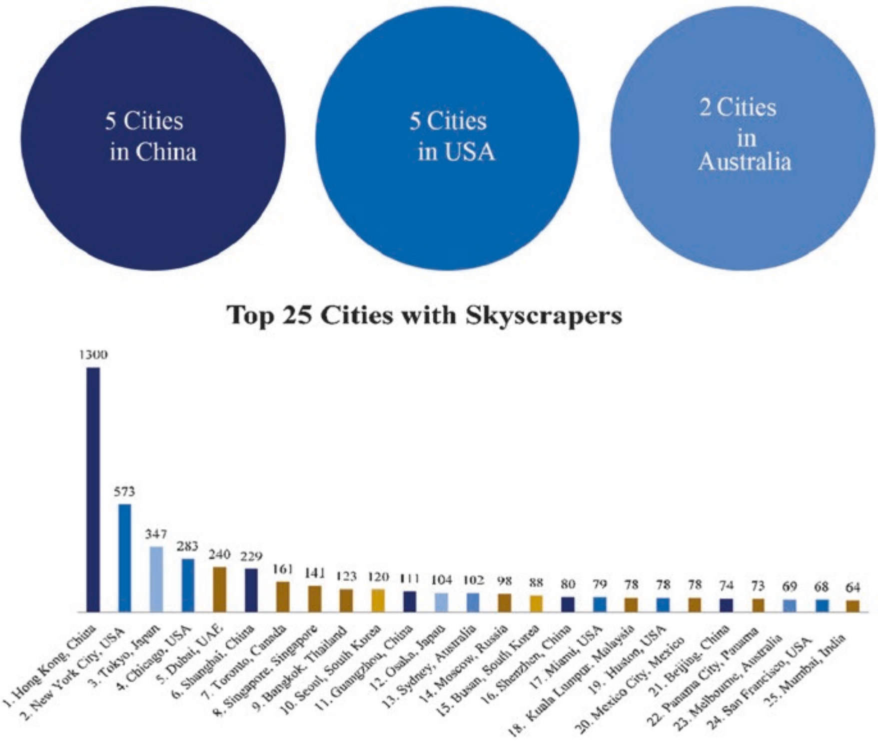


Fig. 9.3 Continents with tall buildings (skyscrapers). *Source*: http://list25.com/25-cities-in-the-world-with-the-most-skyscrapers/5/

capital, there are about 13 tall buildings to date as shown in Fig. 9.6. This figure classifies these buildings in terms of height.

The oldest is the Giza Pyramids of Khufu and the highest is Cairo tower (left) designed in 1954. The Cairo tower, 187 m high, was built in 1956 and opened in 1961. It is a free-standing concrete tower located in Cairo, Egypt, which has been the tallest structure in Egypt and North Africa for about 50 years as shown in Fig. 9.7 (http://en.egypt.travel/attraction/index/cairo-tower/). The second highest is a government public building (Ministry of Foreign Affairs, No. 2) followed by eight famous 5-star hotels, No. 3–7; and one is a public bank headquarter—National Bank of Egypt, No. 9, and the Great Mosque and Mohamed Ali Castle, No. 12; and last one (right) is Hilton Ramses hotel, No. 13 (Fig. 9.6). These tall buildings form the skyline of Cairo and Giza Governorates (Greater Cairo).

Till March 2015, these 13 tall buildings constitute the urban setting in terms of height and the city metaphor, but this will in fact started to change in August 2015. The kick-off of the new capital (North-east of Cairo), a mega project that was announced in March 2015 and will be awarded this year, encompasses enormous tall buildings and few skyscrapers as shown in Figs. 9.8 and 9.9. Figure 9.8a, b, c,

Fig. 9.4 Hong Kong skyscrapers, the world's top city. *Source*: http://list25.com/25-cities-in-the-world-with-the-most-skyscrapers/5; (http://list25.com/25-cities-in-the-world-with-the-most-skyscrapers/5/). *Image source*: (https://upload.wikimedia.org/wikipedia/commons/a/a2/Overlook_Hong_Kong_Island_north_coast,_Victoria_Harbour_and_Kowloon_from_middle_section_of_Lugard_Road_at_daytime_(enlarged_version_and_better_contrast,_revised).jpg)

illustrate the location of the New Capital from Cairo, an image of the new capital and the tall buildings zone, whereas Figure 9.9 shows the new iconic building, Zayed Crystal Spark. The plans for a Cairo skyscraper are based on Egypt's most famous historic monuments have been put forward by the Egyptian government. The 200 m high-rise tower, almost 50 storeys, is designed to resemble the ancient pyramids. The new tower is composed of two pyramids: one tall and slim; and the other broad (http://en.egypt.travel/attraction/index/cairo-tower/). It is in short Egypt's 2nd tallest building, 143 m higher than the Ministry of Foreign Affairs by over 50 m (Fig. 9.6).

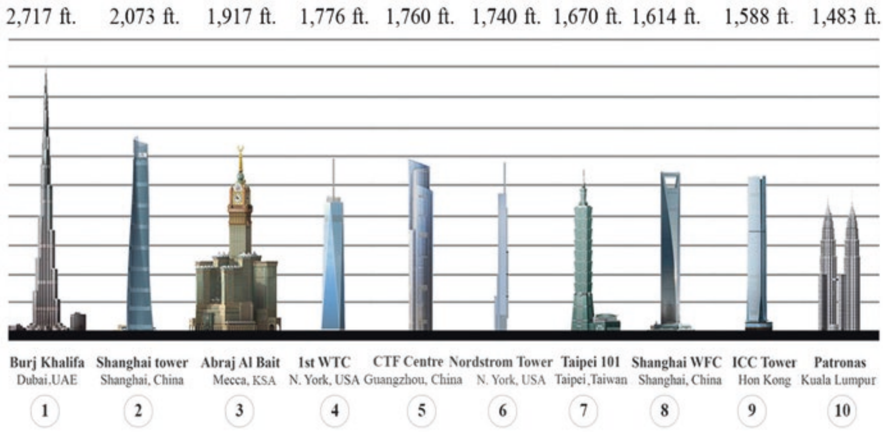


Fig. 9.5 Top ten tall buildings in the World 2014. Image sources: (1) https://upload.wikimedia.org/wikipedia/en/9/93/Burj_Khalifa.jpg. (2) http://www.e-architect.co.uk/shanghai/shanghai-tower-development. (3) http://murall.com.br/wp-content/uploads/Abraj-Al-Bait-Towers.jpg. (4) http://vignettel.wikia.nocookie.net/nations/images/7/74/Freedom_Tower_New.jpg/revision/latest?cb=20110829132335. (5) http://japan-product.com/wp-content/uploads/2014/04/Guangzhou-CTF-Finance-Centre-121x150.jpg. (6) http://www.6sqft.com/living-in-the-clouds-50-new-york-residential-towers-poised-to-scrape-the-sky-part-i. (7) http://skyscrapercenter.com/building/taipei-101/117. (8) http://deepest.net/8-tallest-buildings-in-the-world. (9) https://commons.wikimedia.org/wiki/File:Intemational_Commerce_Centre_201010.JPG. (10) https://www.pinterest.com/cerenarik/skyscrapers

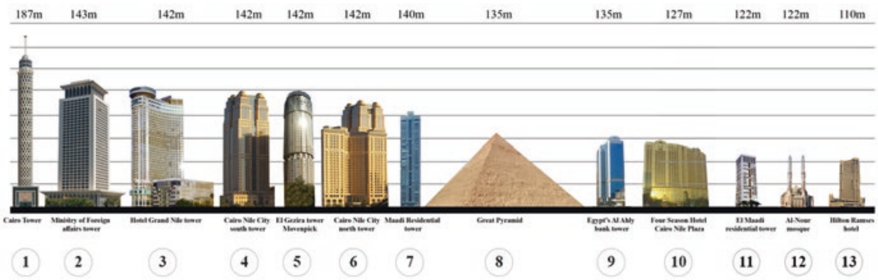


Fig. 9.6 Tallest buildings in Egypt 2015. *Images credit:* Author. *Image sources: (*1) https://upload.wikimedia.org/wikipedia/commons/a/a0/Cairotower.jpg. (2) https://upload.wikimedia.org/wikipedia/commons/7/76/Foreign_Ministry_Building_Cairo.jpg. (3) https://c1.Staticflickr.com/9/8508/8590204805_e201b24f1a_b.jpg. (4) http://almesryoon.com/images/a7b98ff3d0b-6da1226d3d0e71031b007.jpg. (5) http://www.emporis.com/images/show/852291-Large-fromfaaway-view-from-fish-garden.jpg. (6) http://almesryoon.com/images/a7b98ffld0b6da1226d3d0e71031b007.jpg. (7) http://farm6.Static.flickr.com/5228/5751675045_c9d439037f.jpg. (8) http://l.bp.blogspot.com/-5tmQwFIzK8Y/UGaUn7ym8wI/AAAAAAAAAok/s0L2M9uVeQk/sl600/Pyramids+of+Giza.jpg. (9) https://upload.wikimedia.org/wikipedia/commons/4/42/National_Bank_of_Egypt.JPG. (10) http://www.southtravels.com/africa/egypt/fourseasonsnileplaza/gifs/hotelview.jpg. (11) http://farm6.Static.flickr.com/5228/5751675045_c9d439037f.jpg. (12) http://www.arabcont.com/projects/Images/Nur-mosq-6-1.jpg. (13) http://www.egyptunlimitedtours.com/ramses-hilton-hotel.jpg

Fig. 9.7 Cairo Tower (day and night), the tallest building in Egypt in 2015. *Images source*: https://upload.wikimedia.org/wikipedia/commons/a/a0/Cairotower.jpg; http://preview.turbosquid.com/Preview/2014/05/19_22_00_00/c-00.pnge890f24c-57d6-469c-87ab-726f44b6ecf0Original.jpg

Fig. 9.8 The New Capital—East of Cairo, Egypt. (**a**) Location of Cairo New Capital (**b**) An image of Cairo New Capital (**c**) Tall buildings zone. *Images source*: http://thecapitalcairo.com/img/content/home.jpg; http://architecture.co.uk/wp-content/uploads/2015/04/som2.jpg; http://architecture.co.uk/wp-content/uploads/2015/04/som2.jpg; http://www.smh.com.au/content/dam/images/1/m/0/o/x/8/image.related.article.LeadNarrow.300x0.143ybu.png/1426532856395.jpg

Fig. 9.9 The New skyscraper, Zayed Crystal Spark in New Capital, East of Cairo, Egypt. *Image source:* http://thecairopost.youm7.com/wp-content/uploads/2015/03/slide4105565165400_free.jpg

3 Historical High-Rise Buildings in Egypt

3.1 The World's Oldest High-Rise Building: Great Pyramid of Giza

High-rise structures have been around for centuries, dating back to the great pyramid of Egypt. The largest of the pyramids is the Great Pyramid of Cheops at 481 ft high. It was built around the year 2500 BC, to serve as a tomb for the Egyptian pharaoh, Khufu (Fig. 9.10). This high-rise building has been ranked as the tallest structure for more than forty-three centuries and was only exceeded in height in the nineteenth century (DeSalvo 2003). In terms of its structure, over 2′ii million blocks of limestone, which weigh from 2 to 70 tonnes, were used for its construction.

Nevertheless, recent quarry indicates that there may be only about 750,000 blocks which weigh between half a tonne to 2 tonnes. The pyramid's base covers over 13 acres, where each side is 5 acres, and its volume is approximately 90 million cubic feet. It is estimated that the Pyramid of Khufu could build over 30 Empire State buildings with its masonry. It is about 454 ft high (originally rose to a height of 484 ft) which is equivalent to a modern 50-storey building (DeSalvo 2003).

Fig. 9.10 The tomb for the Egyptian pharaoh, Khufu in Giza, Egypt. (**a**) Great Pyramid of Giza. (**b**) Pyramids plateau. *Image source*: http://1.bp.blogspot.com/-5tmQwFIzK8Y/UGaUn7ym8wI/AAAAAAAAAok/s0L2M9uVeQk/s1600/Pyramids+of+Giza.jpg; https://upload.wikimedia.org/wikipedia/commons/thumb/e/e7/Giza_pyramid_complex_(map).svg/1204pxGiza_pyramid_complex_(map).svg.png>

3.2 *The First High-Rise, An Inspiring High-Rise*

Despite the fact that the great pyramid of Giza is the first high-rise building, yet it reflects innovative features which have been exploited in contemporary high-rise buildings. These innovative features address the building's form, aerodynamics, earthquake resistance, and construction innovation as well as energy aspects, yet emphasise sustainability. The following part describes that in detail.

3.3 *Aerodynamics and Building's Shape and Sustainability*

The economics of constructing tall buildings is greatly affected by wind as their height increases. To counteract wind loads and keep buildings' motions within comfortable limits mainly require robust structural systems, which drive up costs. In fact, both the loads and motions are often subject to dynamic amplification in both the along-wind and cross-wind directions (Irwin et al. 2008). These effects are heavily dependent on shape. Hence, the current trend towards considering the aerodynamics of the shape very early in the design of the very tall towers. Curtain wall loads also tend to increase with height primarily due to the fact that wind speeds in general increase with height, and the winds at ground level and on terraces or balconies are increased. All these effects are familiar to experienced developers and designers of tall towers and can be categorised as potential problems to be solved through the use of wind tunnel testing (Irwin et al. 2008). The pyramid's shape, which is a tapering one, is unique when dealing with the wind loads, which decreases due to the technique of tapering. Reducing floor areas gradually towards the top is a great approach to improve the lateral performance of a building, meaning that when hitting the building, the vortices will try to shed at different frequencies at different heights, thus resulting in a dramatic reduction of the associated fluctuating forces (Irwin et al. 2008).

Kim and You (2002) and You et al. (2008) investigated the effects of tapering on reducing the wind-induced response of tall buildings of square plan shape through wind tunnel test. This was on the four types of building models (400 mm height) with tapering ratio of 2.5, 5, 7.5, 10, and 15 % and on one square model using high frequency force-balance technique. The results showed that the mean along wind pressure coefficients was reduced by 10–30 % over an extended range of wind direction. Tapering effect for reducing fluctuating across the wind forces appeared evident when wind direction is 0°, meaning normal to windward face. The maximum reduction ratio of fluctuating across-wind forces is about 20 % and about 30 % for suburban terrain and urban terrain, respectively.

3.4 Earthquake Resistance

There are two well-known ways to decrease damaging effects of earthquake or wind-initiated shear waves, which may propagate in a building structure, namely to: (a) dissipate the wave energy with the properly engineered damping devices; and (b) absorb the resonant portions of the waves with the help of tuned mass dampers (Shustov 2000). Both energy dissipation and absorption assume installation of special structural control devices, often requiring a permanent maintenance, which makes such types of control rather expensive. There is, yet, a better choice to disperse the shear wave energy between a wide range of frequencies of oscillation by configuring the building elevation adequately thus preventing the structural system (Shustov 2000). In this respect, it has been proven that pyramid-shaped structures are better in terms of ability to handle seismic movement caused by earthquakes. The elevation of pyramid structures handles resonant amplifications very well. The structure of a pyramid disperses wave energy stopping resonant displacement amplification in the structure. The best examples of building elevation control are the pyramids of Giza, Egypt, which have been standing for thousands of years, particularly the strong tremor that hit Egypt in 1992.

3.5 Transamerica Pyramid

Like Japan's Millennium tower, tall buildings in Chicago—Illinois and San Francisco—California, USA namely John Hancock Centre and Transamerica Pyramid are built in an active earthquake region, thus it is vital that tall buildings are designed and built according to a stringent code to withstand strong tremors (Fig. 9.11). The Transamerica Pyramid, a 48 storey high office building (260 m high),

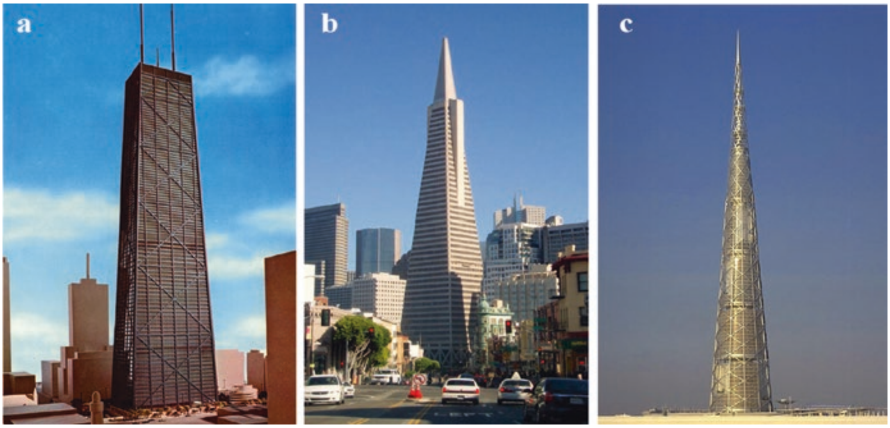


Fig. 9.11 Transamerica Pyramid skyscrapers in USA and Japan. (**a**) John Hancock Center, Chicago (**b**) Transamerica Pyramid, San Francisco (**c**) Millennium Tower, Tokyo. *Source links:* https://postcardemily.files.wordpress.com/2011/10/hancock-tower_front.jpg; http://i1.trekearth.com/photos/40227/sfa.jpg; http://www.fosterandpartners.com/media/Projects/0504/img1.jpg

was built in 1972. This unique pyramid shape gives the structure more stability than a typical skyscraper. Also, it is built on a steel and concrete foundation (16 m) deep in the ground and able to swing with tremors. During the 1989 Loma Prieta earthquake, the tall building shook for more than a minute and the top storey swayed nearly 0.3 m, but the Transamerica Pyramid was undamaged (Murdico 2006). Even under the 7.1 magnitude 1989 Loma Prieta earthquake in central California San Francisco's Transamerica Pyramid suffered no significant damage. This is attributed to the pyramid's shape and "earthquake-friendly" foundation, hence an added value to sustainability.

3.6 What Did High-Rise Buildings Look Like in Mid-Twentieth Century?

According to Terrapin Bright Green, New York in the middle of the twentieth century, particularly Manhattan high-rises exhibited many instances of energy inefficiency and difficulty to adapt due to their single-pane glazing, poor construction, and insubstantial insulation (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). A debate has been ongoing to replace these high-rise buildings with low or mid-rises, but better skyscrapers built in line with state-of-the-art outbreak technologies and environmental standards. Additionally, a report in 2013 argued that more efficiently designed contemporary replacements that were 44 % larger than their predecessors would consume 5 % less energy and offset their carbon cost of construction within 15–28 years (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.

co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). The point that was raised is “Can tall buildings be sustainable?” A debate over the 230 towers lined up to make the London skyline look more like Hong Kong’s has been conducted by Ike Ijeh (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). This statement has been swaying between a set of opposing answers. The conventional opinion looks at tall buildings as they are—a largely unsustainable form of development point of view. This point was based on the experience of many of the failed tower blocks of the fifties and sixties and the corrosive urban and environmental conditions that came with them (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). According to Ike Ijeh, critics relate this to social and environmental evidence as justification varying from energy inefficiency, poor life expectancy, and overheating risk to physical anonymity, economic severance, and social polarisation. Ken Shuttleworth, one of the designers of London ’s “Gherkin” tower, stated the era of the glass skyscraper is, or at least should be, dead (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article), but nevertheless, there is a substantial counterargument that reflects a different viewpoint. This view sees tall buildings offering unparalleled innovation and maintains that it was as much poor maintenance as poor design that was responsible for the high-rise urban ghettos of the latter half of the twentieth century. Likewise, technological advances that enable skyscrapers to be just as green if not greener than their low-rise counterparts. For example, the Gensler’s Shanghai Tower—the second tallest tower in the world is considered the greenest on the planet (Fig. 9.11), and the world’s first Passivhaus office tower was certified in Vienna less than 2 years ago (Fig. 9.12), and also the Shared tower, London (Fig. 9.13). Ken Yeang has promulgated tall buildings as lush, vertical “greenscapes” that offer an idealised, utopian ideal of a sustainable future (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). In accordance to David Fisk’s (Imperial College London) statement “You cannot have a sustainable city without social cohesion”. *But with 80% of the planned 230 towers allocated for residential use and, according to the NLA’s study, the vast majority of this luxury, what impact will this have on London’s social cohesion and thereby its wider sustainability aspirations?”* He also argued, if not dwell in tall buildings, then how else can such a volume of population density expect to be met in London and elsewhere? (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article); such a statement has highlighted the vital role of tall buildings in engulfing the skyrocketing population increase. It is also important nowadays to use efficient glazing with the lowest SHGC and shading coefficient, SC—meaning solar radiation is reflected, hence lower *U*-value—to ensure the least heat gain/ loss and minimise the use of power and energy that will result in lesser greenhouse gas emissions, mainly CO_2 thus contributing to make tall buildings sustainable.

Fig. 9.12 30 St. Mary Axe (Gherkin's), London, UK. *Image source:* http://londontopia.net/wp-content/uploads/2015/06/TheGherkin_safra-group.jpg

Fig. 9.13 Gensler's Shanghai Tower, Shanghai, China. *Image source*: http://images.adsttc.com/media/images/5204/05c6/e8e4/4e94/9b00/0183/medium_jpg/Gensler.ShanghaiTower.LujiazuiSkyline2_(Medium).jpg?1375995326

3.7 The "Yes" Versus "No" for Sustainable Tall Buildings

In the "No" side, it is quite simply a myth that high-rise means high density. Based on statistics, Manhattan with its iconic valley of skyscrapers has a density ratio of about 27,000 people per km^2 making it by far New York's densest borough.

Nonetheless, the centres of Paris and Barcelona, with their tight, compact grids of mid-rise apartment blocks and a complete absence of high-rises, generally offer density ratios of 26,000/km^2 and up to 36,000/km^2, respectively. It is difficult therefore to cite growing population as a justification for skyscrapers. In addition, the negative view poll by Lynne Sullivan, Environmental Design Studio Sustainable by Design sees that there are social concerns simply "Sustainable for whom?" She cites the increasing expansion of towers across London as symbols of a corrosive social rupture. "These towers are often privatised vertical cities that essentially operate as safety deposit boxes for foreign investment. Towers can't replicate the vibrancy of public realm or the livability of streets. They have more negatives than positives and there are better density models" (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article).

Moreover, the most negative arguments against the sustainability credentials of tall buildings are not social or demographic, but environmental. Various studies, including those by building physics consultancy Inkling, have identified a long list of detrimental environmental effects caused by tall buildings. In terms of energy, the increased use of glass in skyscrapers and the high concentration of inhabitants ensure that towers often consume extremely high heating/cooling loads, which will make them highly susceptible to overheating. Combating this normally requires a huge amount of mechanical ventilation which, coupled with other mechanical and motorised apparatus-like lifts and service shafts which require ever greater amounts of energy, hence more CO_2 emissions. Glass surfaces also ensure increased conduction heat loss.

From the microclimate viewpoint, tall buildings also cause wind speed to notoriously accelerate, in particular at their bases, which in turn, makes the surrounding areas suffer. Not only do these wind speeds make natural cross-ventilation within the building difficult, but they largely prohibit the use of open balconies at high levels, another aspect which many cite as evidence of tall buildings' innate incompatibility with the residential typology. The negative environmental impact of high-rise buildings can extend beyond the building's boundary line. Sets of towers can also create dark zones where concentrations of still air and pollution can be found when wind speed is low. As far as the urban heat island effect is concerned, tall buildings may increase the damage to the environment in warmer climates. But in terms of daylight and solar gain, towers can cast greater portions of the street level in shadow, resulting in a loss of daylight and solar gain for surrounding properties. This in turn could result in a greater reliance on artificial light which requires the use of additional energy. In old cities where urban sites are surrounded by high blocks, the use of renewable sources on tall buildings can be difficult due to the blocked sunlight for solar panels and once again forcing greater reliance on carbon energy (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article;http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article).

However, if the urban site is surrounded by low-rises then this is not a negative point. Simon Sturgis (Carbon Profilers Sturgis Associates) added that "the more you go higher the more inefficient the building becomes in terms of the net area measured against carbon emissions from operation, construction, and maintenance". He added that "the life expectancy of glazed cladding systems is only 40–50 years before replacement is required". In comparison, Sturgis recommended key suggestions that may make tall buildings more efficient and therefore more sustainable. "Tall buildings should have much greater resilience and last longer to justify their huge cost. Materials should also be fully recyclable and towers should have to provide a detailed whole-life carbon analysis and operate within an embodied carbon threshold" (http://www.bdonline.co.uk/can-tall-buildings-ever-be-sustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be-sustainable?/5074035.article). Recent tall buildings have considered such points however.

In contrast, the "Yes" poll, have many who are sharing enthusiastic support for sustainable tall buildings and purging Sturgis's argument. This is mainly seen in the Gherkin's double-skin facade and its swerving internal atrium (chimneys) assisted to render the building a pioneer of environmental high-rise design for its time (Fig. 9.12). Also, the 121-storey Gensler's Shanghai Tower (632 m) claims to be the world's first eco-skyscraper includes features such as its wind-minimising tapering form and one-third of its interior space being allocated to public gardens have earned the building a coveted LEED Gold certification and helped it reduce its carbon footprint by an impressive 34,000 metric tonnes a year in comparison with an equivalent building of the same size (Fig. 9.13). The 20-storey, 80 m-high RHW.2 tower in Vienna (Fig. 9.14) is considered the world's first Passivhaus office tower that is fully clad in glass, the signature skyscraper envelope material synonymous with environmental waste and efficiency. Three key measures made the RHW.2 to obtain the Passivhaus status. This innovative tall building uses 80 % less heating and cooling energy than an equivalent tower. This was obtained through the incorporation of a unique well-insulated double-skin facade which provides high air tightness and thermal efficiency levels. Also daylight was allowed to penetrate deeply into the interior through the floor plate's slender surface (18 m deep), thus reducing reliance on artificial lighting (http://www.bdonline.co.uk/can-tall-buildings-ever-besustainable?/5074042.article; http://www.building.co.uk/can-tall-buildings-ever-be--sustainable?/5074035.article). In addition, the Shard tower in London (Fig. 9.15) has a barrage of sustainability features which have enabled it to use 30 % less energy than a conventionally designed skyscraper of the same height. In this tall tower, a combined heat and power (CHP) unit which has a ventilated triple-skin façade was incorporated. This unit consists of low-ion glazing with low emissivity coating and an integrated energy system which maximises energy efficiency to balance energy demand in accordance with requirements at various times of the day. Lastly, the tower is fitted with highly advanced mechanical systems (automatic or manually operated shading system installed within the facade cavity and multiple occupancy

Fig. 9.14 Passivhaus RHW.2 Office Tower, Vienna, Austria. *Image source*: http://urbangreencouncil.org/content/events/passive-House-office-tower-vienna%E2%80%99s-rhw2/

Fig. 9.15 The Shard Tower, London, UK. *Image source*: https://upload.wikimedia.org/wikipedia/commons/c/ca/London_01_2013_the_Shard_London_Bridge_5205.JPG

and luminosity sensors to regulate energy use accordingly). Extra measures include photovoltaics, ecologically certified construction materials, openable inner-skin windows for natural ventilation, and a CHP that generates 60 % of the tower's power and 40 % of its heating.

4 Climate Change and the Building Sector

Today, it is widely accepted that human activities are contributing to climate change. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) estimated that between 1970 and 2004, global GHG emissions due to human activities rose by 70 % (Genge et al. 2014; Intergovernmental Panel on Climate Change (IPCC) 2007). While the full implications of climate change are not fully understood, scientific evidence suggests that it is a causal factor in rising sea levels, increased occurrence of severe weather events, food shortages, changing patterns of disease, severe water shortages, and the loss of tropical forests. Most experts agree that over the next few decades, the world will undergo potentially dangerous changes in climate, which will have a significant impact on almost every aspect of our environment, economy, and society.

The building sector contributes up to 30 % of global annual GHG emissions and consumes up to 40 % of all energy. High-rise buildings have a significant part to play in this situation. The GHG emissions from buildings primarily arise from their consumption of fossil-fuel-based energy, both through the direct use of fossil fuels and through the use of electrical energy. Significant GHG emissions are also generated through construction materials, in particular insulation materials, and refrigeration and cooling systems (Genge et al. 2014; IPCC 2007). By far, the greatest proportion of energy is used during a building's operational phase. Though figures vary from building to building, studies suggest that over 80 % of GHG emissions take place during this phase to meet various energy needs such as heating, ventilation, and air-conditioning (HVAC), water heating, lighting, entertainment, and telecommunications (Seppo 2004; Suzuki and Oka 1998; Adalberth et al. 2001). A smaller percentage, generally 10–20 % of energy is consumed in materials manufacturing and transport, construction, maintenance, and demolition. Governments can therefore achieve the greatest reductions in GHG emissions by targeting the operational phase of buildings.

High-rise buildings also have a major role in the operational phase. The building sector has the largest potential for significantly reducing GHG emissions compared to other major emitting sectors. This potential is relatively independent of the cost per tonne of CO_2 Eqt., (Genge et al. 2014; IPCC 2007). The IPCC's Fourth Assessment Report illustrates that the potential for GHG reductions from buildings is common to both developed and developing countries, as well as countries with transiting economies (Fig. 9.16). This means that with proven and commercially available technologies, the energy consumption in both new and existing buildings can be cut by an estimated 30–80 % with potential net profit during the building life span (Genge et al. 2014; IPCC 2007).

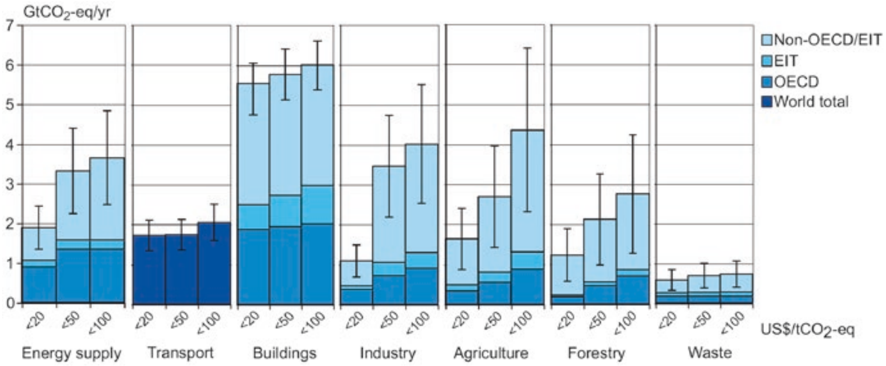


Fig. 9.16 Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. *Source*: IPCC (2007)

5 Why High-Rise Buildings for Climate Change Adaptation?

5.1 Population and Migration Trends

Among the most pressing issues that have encouraged tall buildings development and will likely continue is the colossal increase in urban population worldwide in conjunction with wealth accumulation. Currently, almost half of the world lives in urban areas while 20 years ago only one-third did. It is estimated that by 2030 approximately 60 % of the world's population will be living in urban areas. In 2050, over 80 % of the world population will live in urban areas at a time when the world's population is expected to reach nine billion. At that time, all major cities of the world, particularly those in Africa, Asia, and Latin America will have enormous populations, probably ranging from 30 to 50 million, or more (Tall & Green 2008). Accommodating such a large population in cities will be a huge challenge and will put severe pressure on shelter and energy; with land prices on the increase, high-rise buildings may be the solution to house this high increase of urban population.

Horizontal scale of cities is continually being strained with no alternative except to build upward to accommodate people. Rural-to-urban migration is one of the causes of urban population increase. Between 1945 and 1985, the urban population of South Korea grew from 14.5 to 65.4 %, and to 78.3 % of the total population by 2000. In China, it is projected that by 2025, 350 million people will migrate from a rural to an urban environment (Tall & Green 2008). According to Marcos Fava Neves estimation, it is predicted that five million buildings will be needed—an equivalent of ten cities the size of New York (Neves 2010). In contrast, Chinese cities need to be built to accommodate a population increase equivalent to the US population in just 15 years. Thus, high-rise development is the way forward to address this challenge. As urbanisation rates explode around the globe, governments and urban planners increasingly see more high-rise as the answer to reducing urban sprawl and creating more sustainable cities, for example. In China, Shanghai is a mega-city which houses 19.21 million people, mostly living in high-rise buildings (http://www.ee-highrise.eu/index.php/en/). Hong Kong and other mega-cities of China such as Macau, two of the most densely populated places on the planet (http://www.ee-highrise.eu/index.php/en/) are considered a means of vertical living. Australia is also no exception, both federal and state government policies have targeted high-density development, particularly along transport nodes. Nonetheless, questions are being raised about the sustainability of this approach—the amount of energy used by tall buildings and the energy embodied in their materials through to the social impacts of living and working in them. It is vital however that these high-rises must be sustainable.

6 High-Rise Buildings: Energy Consumption and GHG Emissions

Among the criticisms levelled at tall buildings is that the high quantities of structure and materials required to support, clad, and service them, coupled with energy intensive construction at height (Oldfield 2010). In different building phases, GHG emissions are responsible for the high use of energy. This takes into account two types of main energy consumption: (1) embodied energy, and (2) operational energy and comparing these two aspects to other building types.

6.1 Embodied Energy

Tony Arnel, Chair of Green Building Council of Australia (GBC-Australia) and the World Green Building Council World (GBC) challenged the high-density vision for our cities. He stated that high-rise buildings were not more sustainable than the suburban home. According to Arnel, a study suggested that buildings above three storeys begin to use more energy due to the need for lighting in common areas, lifts, security, and the lifestyle of residents (http://www.thefifthestate.com.au/innovation/energy/high-rise-living-%E2%80%93-is-it-the-Sustainable-answer/20345). The NSW Energy Australia study found that a high-rise apartment uses 30 % more power than a typical detached house, much of it in common areas such as foyers and car parks. On the question of water use, Sydney water statistics show that multi-unit dwellings account for 14.3 % of Sydney's water consumption compared to 45.7 for single dwellings. Nevertheless, a recent energy and water audit by Willoughby Council of the common areas in 25 Sydney multiunit buildings showed that high-rise buildings generated four times as much CO_2 as villas/townhouses and three times as much as low- and medium-rise buildings (http://www.thefifthestate.com.au/innovation/energy/high-rise-living-%E2%80%93-is-it-the-Sustainable--answer/20345). Regardless of the large number of people a tall building can shelter, the overall use and intensity of use of both power and water was much greater in high-rise buildings than in low-rise buildings. The Willoughby Council concluded that this was potentially due to "the additional centralised plants and equipment that often occur in high-rise buildings, such as swimming pools, spas, saunas, cooling towers, pumps, and lifts". Also it stated that "the high energy usage may also be attributed to the arrangement of central hallways and underground car parks in high-rise buildings which generally have no natural light and must be lit and ventilated at all times to ensure safety and amenity for the large number of occupants". Nonetheless, it has been seen when advance green technologies are incorporated in the four leading tall buildings, namely 30 St. Mary Axe (Gherkin's)—London, UK; Gensler's Shanghai Tower—Shanghai, China; the Passivhaus RHW.2 Office Tower—Vienna, Austria; and The Shard Tower—London, UK (Figs. 9.12, 9.13, 9.14 and 9.15), power, energy, and water uses, and CO_2 emissions were significantly reduced but that depends on innovative solutions.

In this regard, embedded energy is another issue. According to a study conducted a decade ago, researchers at the School of Architecture, Deakin University, and the School of Architecture, University of Tasmania, found that high-rise buildings had 60 % more energy embodied per unit GFA in their materials than the low- to medium-rise buildings. While this figure has improved due to improved manufacturing processes, embedded energy is still greater in tall buildings because of the higher load requirements (http://www.thefifthestate.com.au/innovation/energy/high-rise-living-%E2%80%93-is-it-the-Sustainable-answer/20345). But nevertheless, the Corporation of London, as the local municipal authority indicated that tall office buildings are becoming increasingly necessary as a result of the efficient use that they make of the limited land available (Will Pank et al. 2002). In this context, the primary design concern for many tall buildings is their operational efficiency rather than their environmental impacts; hence a balance is needed between these two factors. In London where buildings are accountable for 75 % of energy use, lifts use about 10 % of a tall building's energy, whereas lighting is liable for about 20 % (Will Pank et al. 2002).

Life cycle assessment (LCA) of buildings and construction materials is gaining weight. About 10–20 % of the energy consumed in buildings over their lifetime is in the form of embodied energy incorporated in materials and the process of the building itself. Lifecycle analysis shows that much can be done to reduce the embodied energy of buildings, particularly in tall buildings with repetitive floor plans and large areas of the façades. Whilst there are advantages and disadvantages of building tall, the potential for improving the sustainable development of new high-rise buildings in cities is immense (Will Pank et al. 2002).

The impact of global warming and uncertainty over long-term energy supplies makes it vital to find means of reducing energy. It is important to notice that most office buildings' energy consumption over its lifetime lies in lighting, lifts, heating and cooling, and computer usage. Buildings in the City of London can be made more sustainable by architecture that responds to the conditions of a site with integrated structure and building services. The fossil energy use in buildings can be reduced by effective use of passive solar heat and the thermal mass of the building,

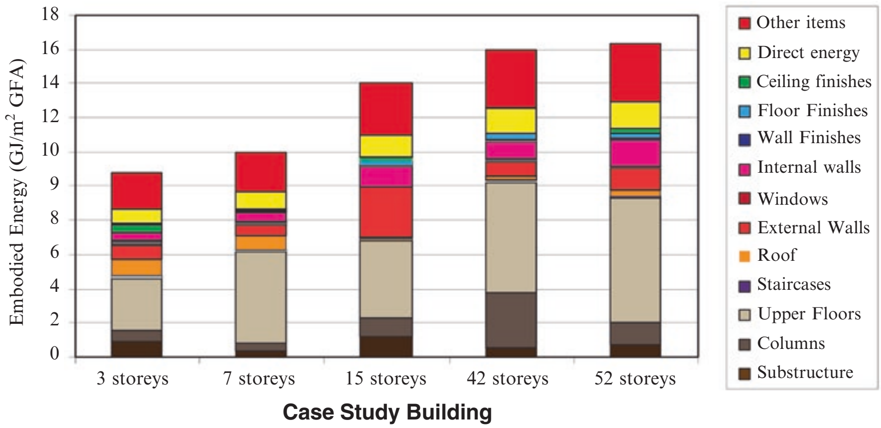


Fig. 9.17 Embodied energy of five office buildings in Melbourne, Australia. *Source*: (http://www.emerladinsight.com/doi/pdfplus/10.1108/02632770110387797)

high insulation levels, natural daylighting, and wind power can all help to minimise. In tall buildings, maximising daylight can be achieved by making floor plans narrow rather than deep. However, office buildings in the City of London can consume 1000 kWh/m^2 or more per year for heating, hot water, lighting, and computers (Will Pank et al. 2002). In contrast, one of the Europe's tallest buildings is the Commerzbank building in Frankfurt, Germany where all offices have natural ventilation and opening windows to assist in reducing energy use and succeeding in creating a pleasant and energy-efficient working environment (Will Pank et al. 2002).

A well-referred study by Treloar et al. (2001) examined the initial embodied energy in five office buildings in Melbourne, Australia—3, 7, 15, 42, and 52 storeys in height (Fig. 9.17). It showed that two of these high-rise buildings have approximately 60 % more embodied energy per unit gross floor area than the two low-rise buildings. Furthermore, the same study identified the embodied energy in the structural building elements (columns, walls, etc.) and energy from the construction process as increasing with height, whilst other building elements (such as substructure, windows, and finishes) did not appear to be influenced by the building height (Foraboschi et al. 2014). Also, embodied energy per unit floor area increases with the storey height (Foraboschi et al. 2014).

In 2014, Paolo Foraboschi et al. conducted a study on sustainable structural design of tall buildings. This study was based on the embodied energy where the consumption is measured by the energy required for tall building structures (20–70 storeys). It is expressed in terms of cradle-to-gate embodied energy which shows that if some design decisions are dictated by the embodied energy, the premium for height of the embodied energy is not substantial, proving that tall building structures can be sustainable. However, a structure with the lowest weight does not imply the lowest embodied energy. It becomes clear from the study that embodied energy depends mainly on the flooring system where steel consumes more embodied

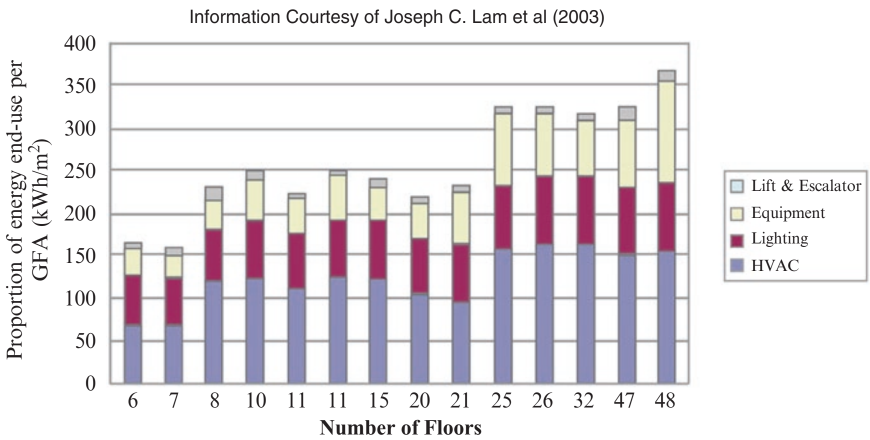


Fig. 9.18 Breakdown of electricity end-user in selected office buildings in Hong Kong. *Source*: Lam et al. (2004)

energy than reinforced concrete. Embodied energy is ultimately confirmed to be a viable tool to design sustainable tall buildings, and the results presented herein may address design issues towards minimising the embodied energy, which means to save environmental resources (Treloar et al. 2001).

6.2 Operational Energy

Tall buildings use twice the amount of energy used as their equivalent of low buildings. The energy is needed to provide building users with their goods, visitor accessibility, and water supply. This requires electrical energy which leads to more GHG emissions compared to mid-rise and low-rise buildings (Roaf et al. 2005). Figure 9.18 portrays the breakdown of electrical energy end use in selected buildings in Hong Kong. The study includes buildings as high as six floors up to 48 floors (Lam et al. 2004). It is clear that there is a jump in energy use for lifts and escalators, as well as other equipment, but for that of lighting and HVAC there is a slight increase which fluctuates in comparison with those in buildings that are ten and 15 storeys high as shown in Fig. 9.18.

7 Operation Versus Embodied Energy in Tall Buildings

According to Ken Yeang, the energy consumption in high-rise buildings that is allocated for HVAC is over 75 % of the total use (Lam et al. 2004). This energy use could be classified as operation and embodied energy. Examining the LSA of the Mary Axe Tower, London, UK—a 180-m high-rise building, designed by Sir

Fig. 9.19 The 30 St, Mary Axe Tower 26 in London, UK. *Images source:* http://edmonleongl.sites.livebooks.com/data/photos/1410_1r9s7a3195.jpg; http://www.propertymall.com/press/images/33335pk.jpg; http://www.ctbuh.org/Portals/0/Feature%20Archive/Tall%20Building/2013/30StMary/30StMaryl.jpg

Norman Foster (Fig. 9.19), it includes the cradle-to-end of life vision of the building, encompassing all CO_2 emissions until the end of the building's effective life, but the demolition or disposal of materials was excluded (Yeang 1999). All major architectural elements such as structural frame, substructure, upper floors, and building envelope, internal walls, partitions, stairs, finishes, and building services formed the analysis boundary. Elements that were excluded in this boundary are the fit-out and furniture and embodied carbon of local infrastructure and landscaping. A full list of case study building characteristics and data sources is outlined in the table (Yeang 1999). Figure 9.20 showed that the total life cycle carbon emissions of the building over a 50-year life span stood at 320,069 tonnes of CO_2, or approximately 5 tonnes of CO_2 per metre gross floor area. If agreeable with sustainability thinking, it is the operational emissions that are primarily responsible for this, contributing 77 % of total emissions (Fig. 9.20). This reinforces the general consensus that reducing tall building operational emissions has the best potential for improving their environmental performance. The total embodied carbon of the building stands at 73,797 tonnes of $CO_{2,}$ or 1147 kg CO_2/m^2 GFA equivalent to 15 years of operating emissions. Whilst this is only 23 % of the total carbon emissions, it is clear this is not an insignificant proportion, and strategies to reduce embodied carbon, particularly to structural elements, services and finishes, will have a positive impact on tall building sustainability (Figs. 9.21 and 9.22) (Yeang 1999).

In addition, the life cycle carbon analysis (LCCA) assumes that the case study has operational emissions typical of a modern office building (Oldfield 2012). Nevertheless, due to the increased environmental awareness, stricter building regulations and technological advances of operational emissions in buildings are likely to fall significantly in the coming years. It has been noticed in tall buildings that are already completed and in towers under construction that large reductions in operating energy requirements were achieved if compared to the norm. The Bank of America Tower in New York (Fig. 9.23), for example uses 50 % less energy than the norm (Fox 2008). Also, DIFC Lighthouse Tower, Dubai (Fig. 9.24) has 50 % less energy than the norm (ATKINS 2009); Pearl River Tower, Guangzhou and International Tower, Xiamen in China (Fig. 9.25a, b) has 58 % less than conven-

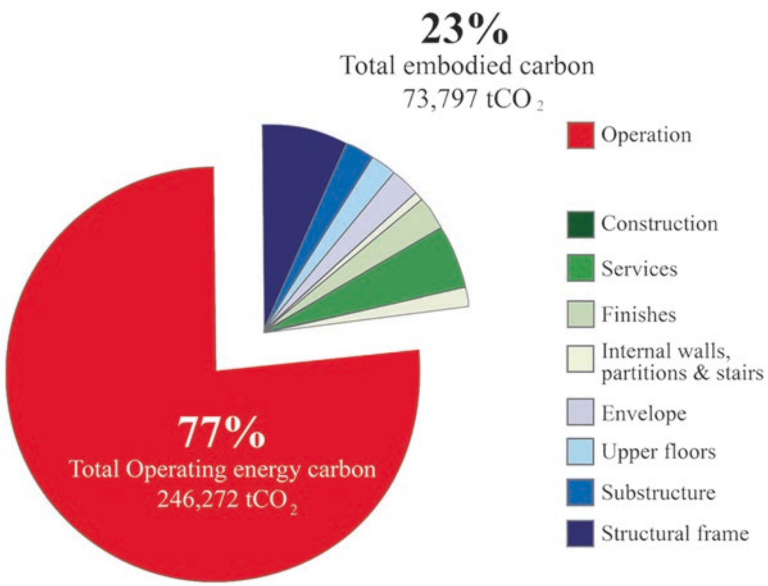


Fig. 9.20 Case study building total life cycle carbon operation embodied emission over a 50-year period element. *Source*: Yeang (1999)

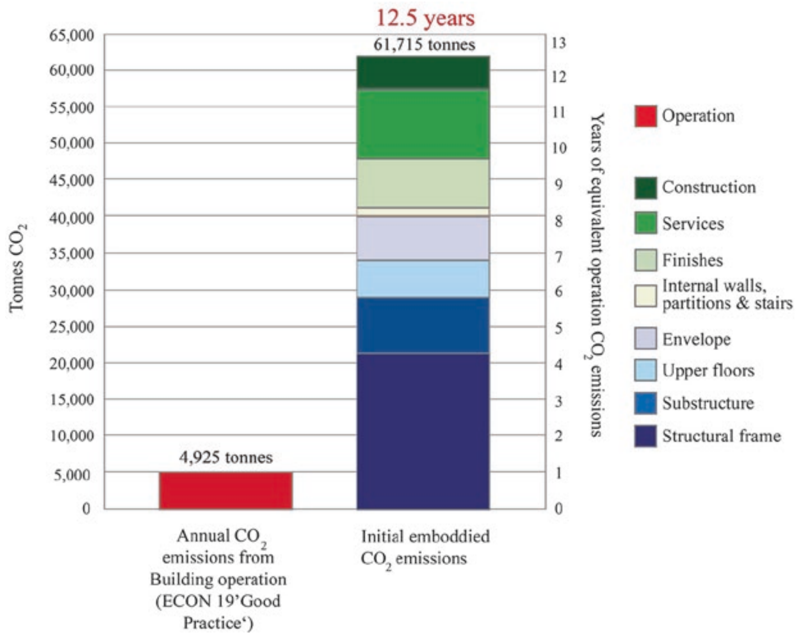


Fig. 9.21 Comparison between building annual carbon emissions and initial carbon by building. *Source*: Yeang (1999)

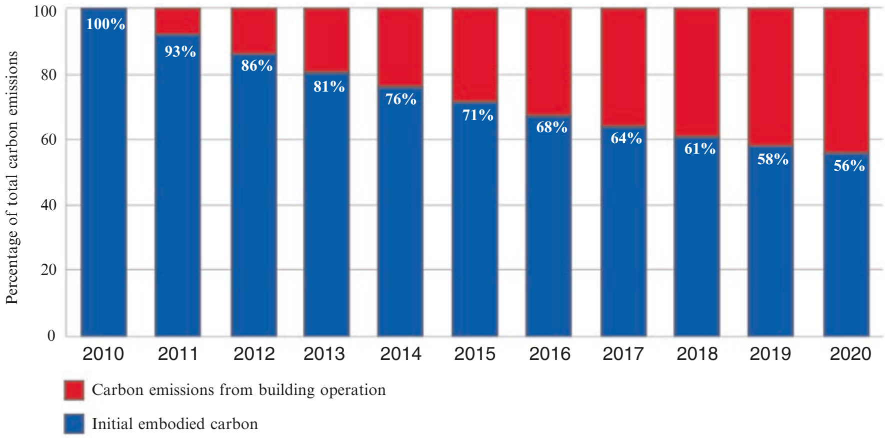


Fig. 9.22 Case study building initial embodied carbon and operating carbon emissions 2010. *Source*: Yeang (1999)

Fig. 9.23 The Bank of America Tower N.Y., USA. *Image source*: http://skyscrapercenter.com/building/bank-of-america-tower/291

Fig. 9.24 The DIFA Lighthouse Tower, Dubai. *Image source*: http://www.e-architect.co.uk

Fig. 9.25 Skyscrapers in China. (**a**) Pearl River Tower, Guangzhou (**b**) C & D International Tower, Xiamen, China. *Image source*: Gravity Partnership: (http://www.bustler.net/index.php/article/ctbuh_selects_the_4_best_tall_buildings_for_2013). http://www.wind.psu.edu/buildings/guangzhou.asp

tional buildings (Frachette and Gilchrist 2008). It is obvious that these examples will become the standard and trend in the future, and embodied emissions will play a much greater role in the tall buildings' life cycle environmental impacts.

In London, the initial cost of the mechanical and electrical equipment in a tall building, including lifts, is often more than 25 % of the total construction cost (Fig. 9.26). Superstructure and foundations generally account for 10–20 % of the total, with the building envelope costing approximately the same, and internal finishes about half (http://www.echarris.com/market_issues/client_successes.aspx). If this is made efficient, then the cost can be reduced.

In Shard Tower, London, the CHP is proven to be a highly efficient energy source when suited to densely built-up areas. CHP is the simultaneous production of power, heat, and sometimes, chilled water for air-conditioning, and is also known as co- or tri-generation. The CHP avoids transmission losses because electricity is generated close to the point of use.

In European cities such as Stockholm, Helsinki, and Copenhagen, they provide most of their electricity and heating from CHP systems because after the initial investment, they are the most energy- and cost-efficient systems available. These systems are particularly effective in urban areas with compact layouts. The overall efficiency for conventional power stations is about 40 %, where surplus heat is

Fig. 9.26 The Shard in London, UK by Renzo Piano Building Workshop. *Image source*: Sellar Property Group (http://www.bustler.net/index.php/article/ctbuh_selects_the_4_best_tall_buildings_for_2013)

usually dissipated to the environment via cooling towers. CHP plants therefore have lower fuel requirements and lower costs in comparison to conventional energy supplies. The simultaneous production of electricity and heat in a useable form enables overall thermal efficiencies of up to 80 % to be achieved, meaning that less fuel is used for a given amount of work. It saves cost and lead to a substantial reduction in produced CO_2. Emissions from CHP installations are generally a minimum of 30 % lower than the levels arising from conventional power generation techniques (The International CHP/DHC Collaborative: Advancing Near-term Low Carbon Technologies, IEA 2007).

Despite the fact that embodied energy and operation energy are crucial in tall buildings assessment, they have many added values in cities. The clustering of buildings in densely built-up spaces is widely seen to be very efficient in transport terms. Studies by Newman and Kenworthy illustrated that cities such as Hong Kong and Singapore, where the clustering of tall buildings is the pattern, are among the world's most transport efficient (Newman and Kenworthy 1989). Figure 9.27 shows the consumption of petrel per person in 32 densely populated cities worldwide.

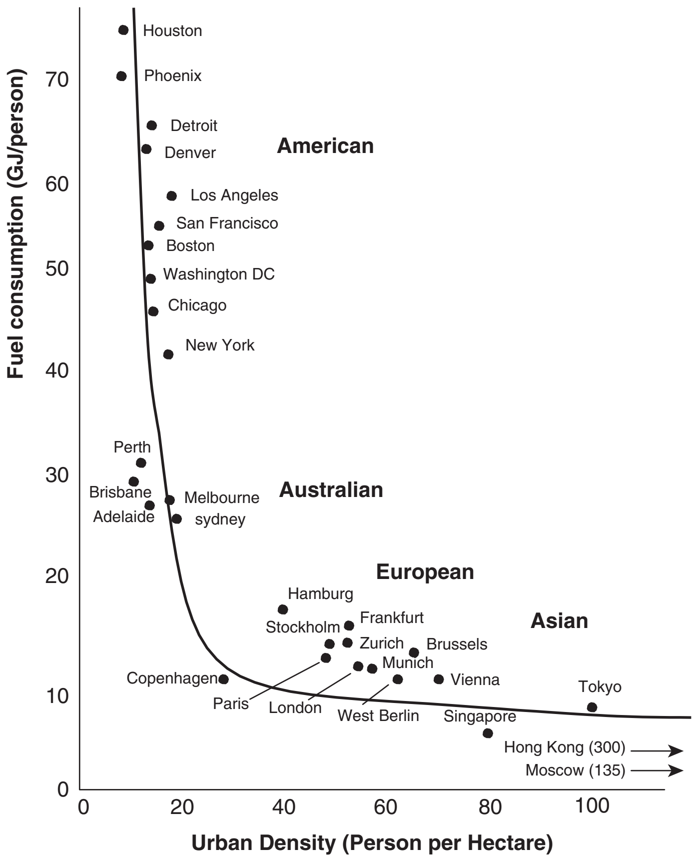


Fig. 9.27 Population density against petrol consumption/person in 32 cities. S*ource*: (http://www.essayforum.com/writing-3/advantages-disadvantages-high-rise-apartments-48298/)

8 High-Rise Buildings that are Most Affected by Climate Change

Tower blocks can be considered the most vulnerable building type to climate change due to their exposure to the elements and their unfavourable volume-to-surface ratio (Bahaj et al. 2008). In tall buildings, where countless people are dependent on machinery for their very survival, hence consuming more and more energy, to compensate for the climate change. In February 1998 in Auckland, New Zealand, all four main cables into the central city failed, cutting electricity to offices and more than 5000 apartments. Backup cables also failed, due in part to the extreme summer temperatures 38 °C and for up to 8 weeks there was chaos in the city buildings, where temperatures soared to over 50 °C and allegedly in the top floors of tall buildings to over 80 °C, making their habitation impossible. Buildings with extremely high energy costs and exposure to extreme winds and solar gain may be one of the evolutionary types of buildings that die out first as the climate changes and the cost of energy rises over the next decades (Yeang 1999).

Traditionally, building design has relied to a considerable extent on historic climate data accumulated over time to provide design criteria for everything in buildings including structural systems, cladding and windows, site drainage, and HVAC systems. With the manifestation of climate change, this approach is also changing experts believe that historic data may no longer best represent future environmental conditions over the service life of buildings.

According to Shankha P. Bhattacharya and Sonam Singh, energy generation in high-rise buildings has been summarised (Bhattacharya and Singh 2013). Historically, the development of high-rise buildings can be clustered into five energy generations. These five generations are separated by each other with a connecting event. Four such connecting events are recognised as (1) introduction of 1916 New York zoning law; (2) innovation and use of curtain walls as building façade, 1951; and (3) the energy crises in 1970s; and (4) Rise of an environmental consciousness in 1997 (Oldfield et al. 2009). This study concludes that climatic change and global warming have presently become a burning issue worldwide. The requirement of environmental sustainability and further reduction in primary energy demand in buildings was noticed in late twentieth-century buildings. The sustainability index is measured for some selected energy conservation technology and design principles, and the analysis finally reveals that the traditional solar passive design principles with a building surface solar and wind energy generation technology could be the appropriate solution at present. Using recycled and industrial by-product materials with rain water capturing systems will enhance the overall sustainability of the Indian tall building, but nevertheless this is limited to the Indian context (Oldfield et al. 2009).

A recent book by Stefan Nijhuis and edited by Han Meyer and Daan Zandbelt (2013) has addressed many questions on high-rise buildings and the sustainable city; among these questions are: Can high-rises make a fruitful contribution to making cities more sustainable? Many argue that high-rises deliver positive environmental effects, such as densification, and reduction of traffic and carbon dioxide emissions. Questions such as the impact of tall buildings on the environment; their ideal densities; successful design features in a tall building; reputations of high-rise buildings and their expectations; their sustainability, reuse, and reduction of negative environmental impact were discussed. The study also tackled the meaning of high-rise buildings for a sustainable city and asks when urban form can be considered as "sustainable". The second part focuses on transformation and area development and the processes necessary to densify the city and to develop high-rise buildings. The main question here is if it is possible to develop high-rise projects that energise city life. It was concluded that discussing the design features of the buildings themselves as sustainable structures will contribute to a healthy indoor and outdoor environment and to a reduction of materials, energy, and costs (Nijhuis 2013). All these points are very crucial in considering the development of tall buildings and climate change impacts.

Fig. 9.28 High-rise buildings with glass façades in Abu Dhabi and Dubai, UAE. *Photos credit*: Author

Over the next 40 years, if buildings do experience increases in environmental loads (temperature, relative humidity, rainfall, snowfall, wind pressures, and UV radiation), in addition to changing the design criteria, these changes could have a significant impact on buildings stock (Lotfabadi 2015). Obviously, these issues are of interest to design professionals and policy makers. As skyscrapers are consuming a great deal of energy and are indispensable in modern cities, considering new ways of benefiting from renewable energies can have a vital role in reducing buildings' energy consumption (Lotfabadi 2015). This would assist in the adaptation measures to encounter climate change risks.

One of the most crucial elements in energy consumption in tall buildings development is the envelope, mainly the glass used in enormous skyscrapers around the world, for example the UAE as shown in Fig. 9.28. Glazing, a major feature in reducing energy use that also offsets the impact of climate change is carefully examined and properly selected in tall buildings. Glazing may lessen GHG emissions, mainly CO_2 and offset climate change risks. A study was conducted in the UAE on a typical 30-storey residential building with a WWR of 50 % and a north–south orientation focussing on the decision of selecting a glass type for a high-rise building to assess the significant impact on the initial and running cost of the building. The glass types (b, c, d, e, g, f, g, h, i) were classified in terms of SHGC and *U*-value from 0.25 to 0.14 and 2.00 to 1.10 W/m^2 K, respectively (Tibia and Mokhtar 2014). It focused on several competing factors which influenced the architect's decision to focus on the relationship between the glass thermal characteristics and its cost using an energy simulation modelling tool to provide data on the impact of different types of glass on the cooling load, and hence the energy consumption. The simulation relies on both the simple payback period and the life cycle cost (LCC) reduction techniques, optimal glass thermal properties. Results indicated that glass type g (SHGC of 0.20 and *U*-value of 1.30 W/m^2 K) shown in Box 9.2 has one of the shortest payback periods and the lowest LCC in Abu Dhabi, Dubai, and Sharjah (the three largest emirates in the UAE). The study also recommended the use of this glass type for high-rise residential buildings with about a WWR of 50 % and with an almost north–south orientation in a hot–humid climate (Tibia and Mokhtar

Box 9.2 Minimum glass thermal characteristics when the WWR = 50 % (Tibia and Mokhtar 2014)

Abu Dhabi	Dubai	Sharjah
• *U*-value = 1.9 W/m² K	• *U*-value = 1.9 W/m² K	• *U*-value = 2.1 W/m² K
• SHGC = 0.23 (Using prescriptive path*w*ay *v*alues of Estidama)	• SHGC = 0.28	• SHGC = 0.30
• This is roughly glass type E	• This is roughly glass type C	• This is roughly glass type B

2014). It is worth noting that the currently used codes in these emirates require the following minimum glass thermal characteristics when the WWR = 50 % (Tibia and Mokhtar 2014).

9 Advantages and Disadvantages of High-Rise Buildings

Another dimension associated with high-rise buildings is Environmental psychology. Richard Wener and Hannah Carmalt studied the Environmental psychology and sustainability in high-rise structures from the social viewpoint. This study addresses the human elements of sustainable design in urban high-rise buildings. It also discusses social, psychological, and behavioural issues that need to be addressed in high-rise facility management, as well as the potential for sustainable buildings to ameliorate some of the problems in those areas traditionally associated with high-rise buildings (Bautech 2005). A number of questions according to Richard et al. remain concerning sustainable design and occupant behaviour: What kinds of behaviours are expected and/or required of residents in a sustainable skyscraper? How “sustainably robust” are technologies? How much behaviour change is tolerated before a building falls below its stated sustainability goals? How does living in this kind of setting differ from life in low-rise and/or traditional high-rise buildings? (Wener and Carmalt 2006). According to Richard Wener et al. mega-structures may have certain advantages of centralisation and economies of scale, but they come with built-in challenges with respect to the social and psychological needs of building users. People within mega-structures lose an element of personal control over their life conditions and safety. Inside these buildings, occupants become significantly dependent on technology for air, light, and even the shortest of trips. As discussed, the larger the structure, the more people are disengaged from natural elements. There is increasing evidence that such separation has negative consequences for psychological conditions and behaviour resulting in poor health and productivity loss (Wener and Carmalt 2006). What if people live in the world’s tallest residential skyscraper (422 m high) that will be ready for dwelling by the first

Fig. 9.29 The World's tallest residential skyscraper, Dubai, UAE. *Image source:* (http://www.designmena.com/thoughts/worlds-tallest-residential-tower-is-70-complete/)

quarter of 2016 (Fig. 9.29). In a 117-storey residential tower, this may cause psychological and behaviour issues (http://www.designmena.com/thoughts/worlds-tallest-residential-tower-is-70-complete/).

If the skyscrapers are green, they will have potential improvement on energy performance. It can approach zero impact in part by giving control back to the individual and by being designed to support basic behavioural needs. It can also assist in restoring the lost connection with nature that most high-rise occupants suffer by providing greater access to and contact with natural elements in the form of vegetation, daylighting, appropriate ventilation, non-toxic materials, and views of the world outside (Wener and Carmalt 2006).

Based on the research and the discussion earlier, then, how can designers use behavioural and psychological information to create a more holistic approach to sustainable high-rise building designs (Wener and Carmalt 2006). A full summary of the steps that may be appropriate to create sustainable tall buildings can be found in (Wener and Carmalt 2006).

To reduce GHG emissions and combat climate change improving the energy performance of existing building refurbishment is identified as one of the key measures. In recent research, 46 potential methods commonly used for major sustainable building refurbishment in high-rise residential buildings located in cities with a sub-tropic climate like Hong Kong were identified through the literature review (Cleveland and Morris 2009). Using various energy-efficiency measures which may be adopted during the sustainable refurbishment exercise have been examined by S. Thomas Ng et al. (2014). These sustainable building refurbishment methods are classified under five criteria, namely (a) energy, (b) user patterns, (c) domestic, (d) high-rise buildings, (e) climate features and other building characteristics. In this study, a questionnaire survey was used to assess the feasibility of the identified refurbishment methods based on the perception of owners and occupants. It was revealed that those methods classified under building services category such as lighting, appliances, ventilation, and lifts receive greater support from owners and occupants. It is stated that owners and occupants did not favour those sustainable refurbishment options which are related to the building envelope when it comes to major refurbishment. In terms of renewable energy refurbishment methods, their acceptability is improving indicating that there is huge potential for being incorporated into the major building refurbishment (Ng et al. 2014). It is seen that these results would significantly assist in improving the understanding on what factors contribute to the satisfaction of owners and occupants of existing tall residential building in a major sustainable refurbishment scheme. Nonetheless, in the selection of sustainable refurbishment strategy it depends more on the acceptability of owners and occupants. This is the case of Hong Kong, however.

10 Sustainability and Environmental Impact Assessment (SEIA), High-Rise Buildings

The Environmental Impact Assessment (EIA) is a process of evaluating the likely environmental impacts of a proposed project or development, not taking into account interrelated socio-economic, cultural, and human health impacts, both beneficial and adverse (Cleveland and Morris 2009). According to the UNEP, the SEA is defined as a tool used to identify the environmental, social, and economic impacts of a project prior to decision-making. It aims to predict environmental impacts at an early stage in project planning and design, find ways and means to reduce adverse impacts, shape projects to suit the local environment, and present the predictions and options to decision-makers (Conventional on Biological Diversity (CBD) 2005).

Hotels and the wider accommodation sectors represent one of the most important sub-sectors of the travel and tourism industry. There is no recent detailed data on the size of the hotel sector but it can be reasonably estimated at the level of over 360,000 facilities and 30 million beds worldwide (Conventional on Biological Diversity (CBD) 2005; H & RA 2000). Premises located in Europe account for almost 50 % of the overall global market (H & RA 2000). Hotels provide accommodation to half of all national and international visitors, which, in Europe alone, account for 160–200 million international visitors per year (Institution of Civil Years 2015). Due to the high level of resource utilisation (energy, water, consumables) in hotel facilities, the environmental footprint of hotels is typically larger than those of other types of buildings of similar size (World Tourism Organization (WTO) 2003). In this section, an SEA is conducted for Hilton Ramses hotel in Cairo. It will also be pursued with its broader definitions considering the economic and social issues in high-rise buildings' energy consumption and GHG emissions. The objectives of the SEA of Hilton Ramses hotel are summarised in the following three points:

1. Environment assessment: energy consumption (embodied energy, operational energy), water consumption, transportation impact.
2. Economic impact assessment: revenues per night, construction materials.
3. Social impact assessment: society welfare (job opportunities), and social

11 Introduction on the Selected Case Study

The Hilton Ramses building was chosen to be the case study. It is designed by Warner Ton Bond office in partnership with Architect Ali Nassar. Hilton Ramses hotel is located in Cairo's city center; the site is surrounded by Abd El-Meniem Riyad square, Corniche El-Nile Street, 6th of October Bridge and overlooking the Nile-River (Fig. 9.30).

11.1 The Hilton Ramses High-Rise

The building was built in 1980, a modern style building. It is ranked the 13th highest building in Egypt at a height of II 0 m (Fig. 9.6). It consists of 35 floors of which five floors contain the entrance and services facilities such as restaurants, multipurpose rooms, and kitchens. These floors occupy 17,884 m^2 (about 24.3 %) whereas the other 30 floors form typical hotel floors at different settings (single and double rooms, and suites). Each floor is composed of 24 rooms and six suites occupying approximately 55,799 m^2 forming almost 76 % of the total building area as shown in Fig. 9.31.

11.2 The Hotel Building's Envelop

The building envelope includes an outer shell that maintains a cool indoor environment and facilitates the stabilisation of the indoor comfort in both the summer and winter seasons (Rada 1996). It also has components such as the exterior walls, fenestrations, a root, and ground floor as shown in Fig. 9.32. The properties of the building envelop (*U*-value, SHGC, and Visible Transmission as well as layers of each component) are shown in Fig. 9.33.

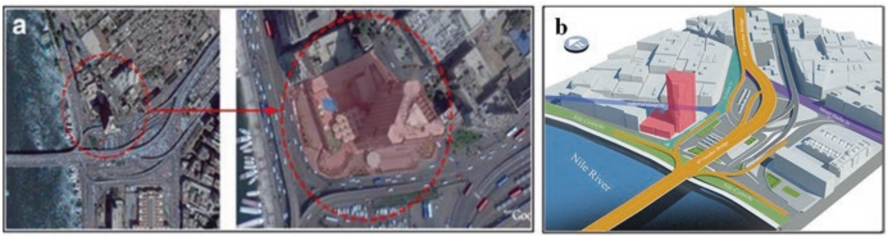


Fig. 9.30 Site of Hilton Ramses Hotel in Cairo, Egypt (**a**) Site Ariel view of Hilton Ramses Hotel (**b**) The hotel site in 3-D showing the network. *Image source:* www.google.earth.com. *Images credit:* Author

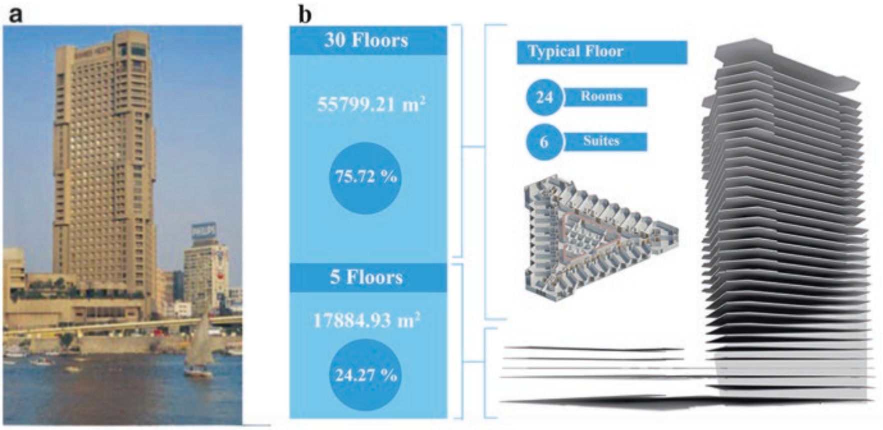


Fig. 9.31 Hilton Ramses Hotel in Cairo, Egypt. (**a**) General view of Hilton Ramses Hotel (**b**) Hilton Ramses floor areas. *Image source:* www.arabtravelgate.com. *Images credit:* Author

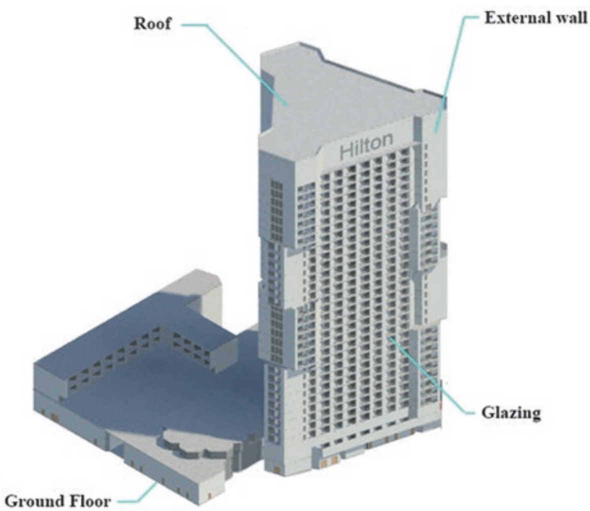


Fig. 9.32 External envelope of Hilton Ramses hotel. *Images credit:* Author

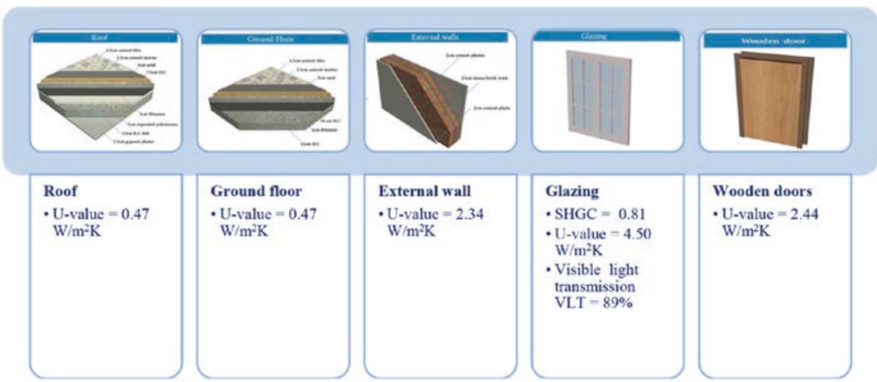


Fig. 9.33 Building's envelop components and properties

11.3 Strategic Environmental Assessment

In the case study of Hilton Ramses hotel, we focused on the three pillars of Strategic Environmental Assessment (SEA): the environmental, economic, and social impacts.

11.3.1 Environmental Impact

The scope in environmental impact for Hilton Ramses will be mainly on energy use, water consumption, and transportation.

Energy

Energy consumption will be classified into embodied energy and operational energy. Embodied energy is defined as "the sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service" (Conventional on Biological Diversity (CBD) 2005). It can also be defined as "the energy requirements to construct and maintain the premises" (http://www.circularecology.com/embodied-energy-andcarbon-footprint-database.htrnl#.VdUS28votdg/). In practice, nevertheless there are different ways of defining embodied energy depending on the chosen boundaries of the study. In this study, we focused on the cradle-to-gate approach (Box 9.3), i.e. energy required to produce the finished product without any further considerations to determine the embodied energy of Hilton Ramses hotel. The amount of materials used in the project was calculated by creating a BIM model of the building in REVIT software and using quantity takeoff command to calculate each material amount. Only the main construction materials such as reinforced concrete, bricks, glass, wood, aluminium were taken into consideration as they represent the effective amount during construction. The embodied energy for each material was assigned from "inventory of carbon & energy (ICE)" version 1.6a, which is produced under supervision of the University of Bath which contains a database for construction materials in terms of embodied energy and equivalent CO_2 emissions (International Tourism Partnership 2008).

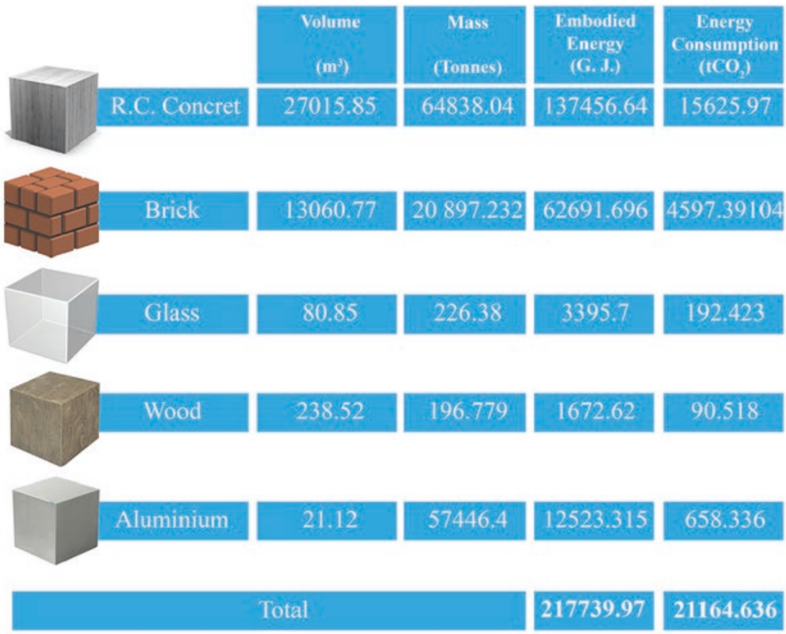
The amount of each main building material in the building and their embodied energy and carbon emission equivalent to produce these materials is shown in Fig. 9.34. It was found that the total embodied energy for all construction materials 217739.37 gigajoule of energy and carbon equivalent of 21164.636 tonnes of carbon dioxide CO_2.

The percentage of materials used in construction is highlighted in Fig. 9.35. It shows that reinforced concrete (R.C.) has the highest percentage at 67 %, followed by the bricks at 32 %, whereas glass, wood, and aluminium about 1 % each. The carbon dioxide equivalent (CO_2 Eqt.) for each building material is presented in Fig. 9.36. It shows that reinforced concrete has the highest CO_2 equivalent due to the high amount used in the construction.

Box 9.3 Cradle to gate, site, and grave Approach of Energy Use in Buildings

Cradle to gate	Cradle to site	Cradle to grave
• A cradle-to-gate model simply describes the energy required to produce the finished product without any further considerations	• Embodied energy of an individual building component as the energy required to extract the raw materials, process them, assemble them into usable products, and transport them to site	• This definition is useful when looking at the comparative scale of building components and relates more to the 'good' in Cleveland & Morris's definition as it neglects any maintenance or end-of-life costs

Source: http://www.ice.org.uk/topics/energy/I3riefing-Sheets/Embodied-Energy-and-Carbon/



	Volume (m^3)	Mass (Tonnes)	Embodied Energy (G. J.)	Energy Consumption (tCO_2)
R.C. Concret	27015.85	64838.04	137456.64	15625.97
Brick	13060.77	20 897.232	62691.696	4597.39104
Glass	80.85	226.38	3395.7	192.423
Wood	238.52	196.779	1672.62	90.518
Aluminium	21.12	57446.4	12523.315	658.336
Total			217739.97	21164.636

Fig. 9.34 Amount of building materials, embodied energy, and CO_2 equivalent of these materials

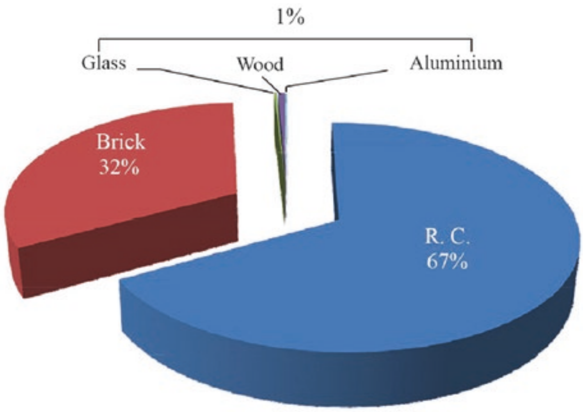


Fig. 9.35 Percentage of materials used in construction

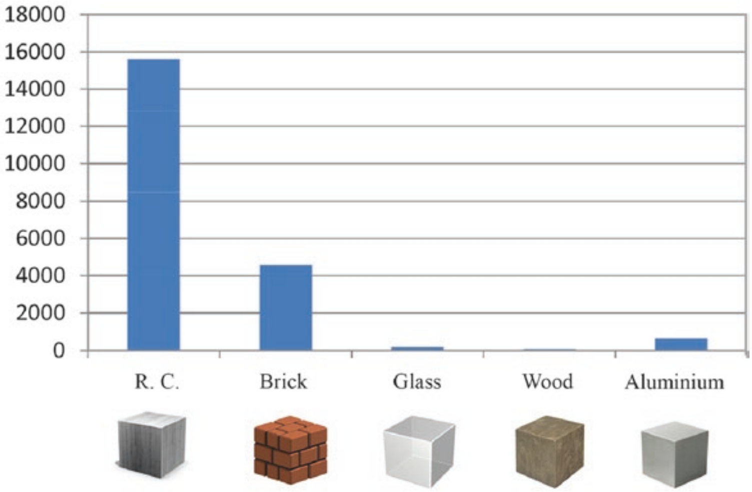


Fig. 9.36 CO_2 equivalent of embodied energy for the materials used in construction

Operational Energy

Operational energy is defined as the energy used to heat or cool a building/facility, run appliances, heat water and its pumps and light rooms, spaces or corridors as well as elevators or escalators (Institution of Civil Years 2015). For the calculations of the operational energy, a computer simulation was used by creating a BIM model for the whole building (hotel) with the properties specified earlier (Fig. 9.32). The interior properties of all rooms of the hotel are specified in Fig. 9.36 while the building occupancy pattern has a critical role in determining operational energy as specified in Fig. 9.37. Also the number of occupants and their sensible heat, lighting load

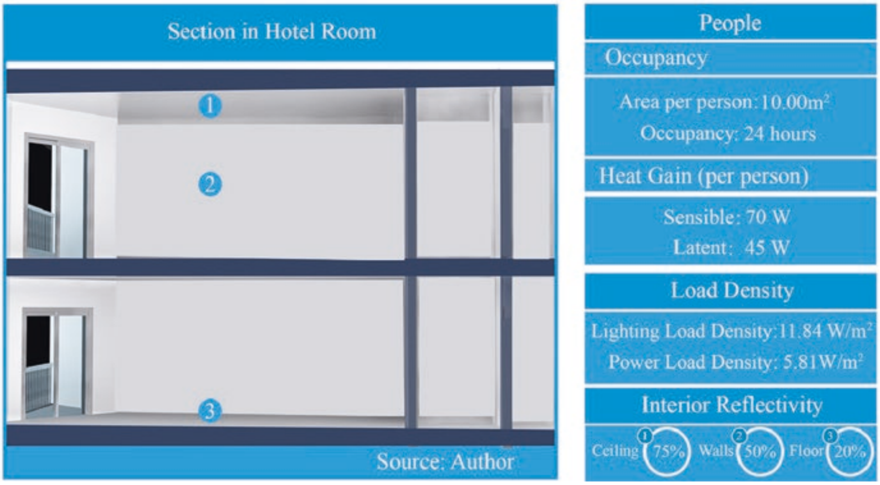


Fig. 9.37 Occupancy, heat gain, load density, interior reflectivity of hotel rooms

density, and power load density of the building rooms are also shown in Fig. 9.36. The energy consumption in Ramses Hilton hotel was compared with reference to the benchmark of energy consumption of luxury hotels, which is classified according to climate zones and consumption to excellent satisfactory, high (United Utilities Web Site 2015). Nonetheless, the results of the simulation indicated that the energy consumption in the 5-star hotel was found to be in the high consumption region, is from 345 to 290 kWh/m^2, with an energy consumption of 324 kWh/m^2 (Figs. 9.38, 9.39, and 9.40).

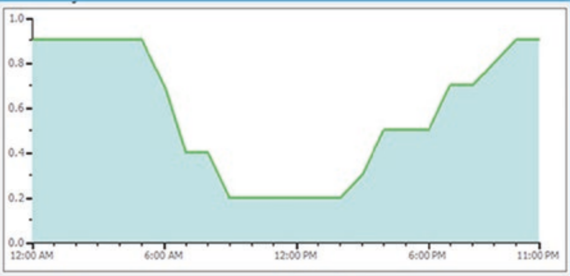
Water Consumption

Water is essential to the hotel and tourism industry—for food preparation, cleaning and hygiene, guest comfort, and recreation. Hotels also depend upon the survival of their supply industries such as agriculture and the food and beverage industries—none of which could function without sufficient water. In this respect, water accounts for around 10 % of utility bills in many hotels. Even in areas where water is scarce, it makes commercial sense to use it wisely (United Utilities Web Site 2015).

Hotel Water Consumption Estimation

To determine the water consumption, the number of guests in the hotel should be determined to be able to use benchmark of water consumption of each guest to determine the total water consumption. The typical floor of the Hilton Ramses hotel is illustrated in Fig. 9.41. It contains 24 rooms and six suites in total of 30 rooms in

Lighting and Power Schedule



Time	Factor	Time	Factor
12:00 AM	90.00%	12:00 PM	20.00%
1:00 AM	90.00%	1:00 PM	20.00%
2:00 AM	90.00%	2:00 PM	20.00%
3:00 AM	90.00%	3:00 PM	30.00%
4:00 AM	90.00%	4:00 PM	50.00%
5:00 AM	90.00%	5:00 PM	50.00%
6:00 AM	70.00%	6:00 PM	50.00%
7:00 AM	40.00%	7:00 PM	70.00%
8:00 AM	40.00%	8:00 PM	70.00%
9:00 AM	20.00%	9:00 PM	80.00%
10:00 AM	20.00%	10:00 PM	90.00%
11:00 AM	20.00%	11:00 PM	90.00%

Revit software: Based on ASHRAE

Fig. 9.38 Lighting and power schedule (obtained from REVIT simulation results)

Energy Simulation Results

Calculated Results	
Peak Cooling Load (W)	**1,653,651**
Peak Cooling Month and Hour	July 4:00 PM
Peak Cooling Sensible Load (W)	1,477,268
Peak Cooling Latent Load (W)	176,383
Maximum Cooling Capacity (W)	1,653,651
Peak Cooling Airflow (L/s)	81,311.7
Peak Heating Load (W)	**730,980**
Peak Heating Airflow (L/s)	44,050.2

Total annual consumption	594,220 kW
Annual consumption	324.12 kWh/m^2

Fig. 9.39 Energy simulation results (obtained from REVIT simulation results)

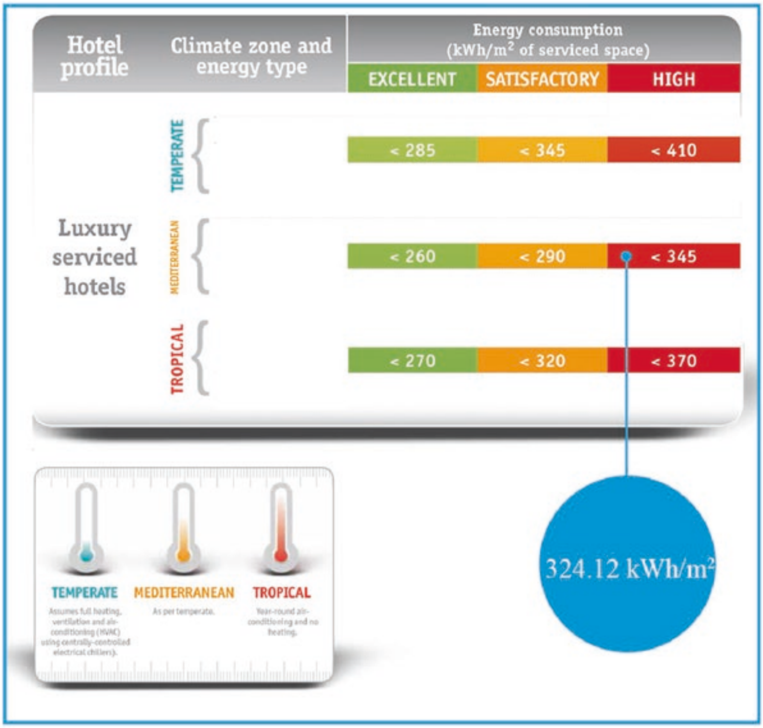
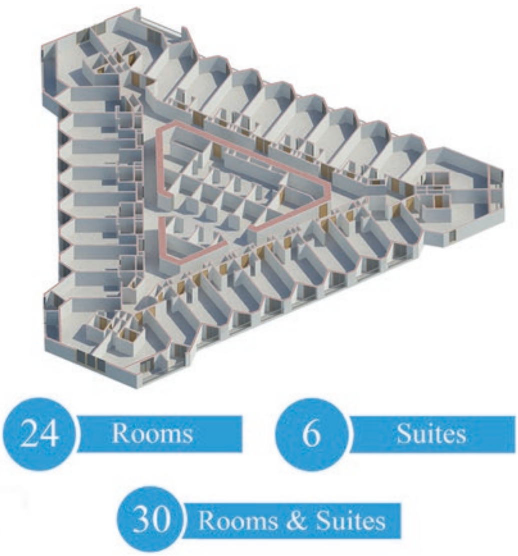


Fig. 9.40 Energy consumption benchmark. *Source*: Environmental Management for Hotels

Fig. 9.41 Typical floor plan of Hilton Ramses hotel



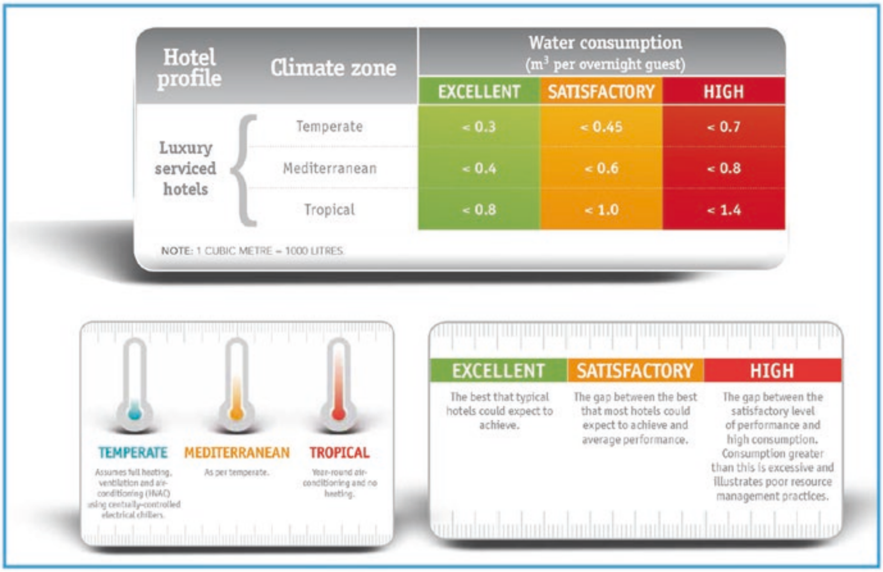


Fig. 9.42 Water consumption per person overnight. *Source*: Environmental Management for Hotels

Box 9.4 Annual hotel occupancy

Annual occupancy	Number of floors	×	Rooms each floor	×	Days of the year	×	Occupancy percent	×	Occupancy rate	
	30	×	30	×	365	×	0.70	×	1.2	=275,940 people

suites. Thus, the total annual water consumption was calculated by multiplying water consumption level per person multiplied by the number of annual occupants in the hotel, and the benchmark for water consumption per person is presented in Fig. 9.42. Hilton Ramses hotel has satisfactory water consumption level. The total annual occupants is the result of multiplying the number of rooms per floor by the number of floors, days of occupancy (365 days), occupancy percent, and occupancy rate per room as shown in Box 9.4. Also, the total annual water consumption is exhibited in Box 9.5. It shows that the total water consumption of the hotel is 165,564 m^3.

Box 9.5 Annual water consumption for hotel

Annual water consumption	Annual occupancy	×	Water consumption/ prison	
	275,940	×	0.6	$=165{,}564\ m^3$

Box 9.6 One cubic metre of water usage

1 Cubic metre of water provides enough for:
13 baths
or 14 washing machine loads
or 28 showers
or 33 dishwasher loads
or 111 toilet flushes

Source: United Utilities Web Site (2015)

Magnitude of Water Consumption

In order to obtain a sense of the magnitude of this number, we will show what only 1 m^3 of water is capable of as shown in Box 9.6. It indicates that 1 m^3 of water is enough for 13 baths, or 14 washing machine loads, or 28 showers, or 33 dishwasher loads, or 111 toilet flushes (United Utilities Web Site 2015). Another way to show the magnitude of the number is by illustrating the quantity of drinking water supplied to hotel guests. This yields the hotel annual consumption of 165,564 m^3, hence the water consumption per day will be 453.6 m^3/day equivalent to 453,600 L, and the average litre of drinking water needed for adults is about 1.89 L (The Cleveland Clinic 2007). Therefore, the amount of water used per day by the hotel is capable of providing drinking water for 240,000 persons.

Transportation

The environmental impact of transport is significant due to the fact that it is a major consumer of primary energy and burns most of the world's gasoline, estimated at 33 %. This creates air pollution, including nitrous oxides NO_2 and particulates, thus it is a significant contributor to global warming through emissions of CO_2 (Fuglestvedt et al. 2007), for which transport is the fastest growing emission sector. By sub-sector, road transport is the largest contributor to global warming (Fuglestvedt et al. 2007).

Hilton Ramses hotel has a great transportation impact since the hotel overlooks the main square of Abdel Meniem Riyad and Downtown Cairo which is considered the central transportation area since it is close to the 6th October Bridge. This would place the hotel in a highly congested area, and thus it affects traffic. This point has been examined and analysed in the following part. The focus is centred on the current situation and the impact of the hotel on traffic and transportation in terms of CO_2 emission excluding the construction transportation phase.

Traffic Properties

The first stage in assessing transportation is to determine the street sections and their traffic properties service volume, speed, density, and different flow conditions according to Box 9.7. The near capacity values (highlighted in red) are used to estimate the maximum condition so to assess the maximum CO_2 emissions. Also, street sections and their properties are shown in Fig. 9.43.

Upon determining street sections and their traffic properties, the types of vehicles and their CO_2 emissions per kilometre should be determined. Figure 9.44 shows that all the vehicles and their CO_2 emissions, the types of vehicles in the surrounding streets in our case study are vehicles, buses, and motorbikes.

Traffic Flow Simulation

The basic data required to give us an overview of the streets and their traffic properties and types of vehicle and their CO_2 emissions acquired. This data will be used as input for traffic flow simulation using the software "AIMSUM" which has the ability to determine the flow of traffic, CO_2 emissions, speed, delay time, and density of flow in addition to the surrounding streets' layout and the presence of the case study in that location. The street layout with colour coding shows the density of the traffic flow in each road as shown in Fig. 9.45. It indicates red colour to represent the highest density while the green presents the lowest density and good traffic flow. The

Box 9.7 Traffic properties

Flow conditions	Service volume (veh/h/lane)	Speed (miles/h)	Density (veh/mile)
Free	700	>60	<12
Stable	1100	>57	<20
High density	1850	46	40
Near capacity	2000	>30	67
Breakdown	Unstable	≲30	>67

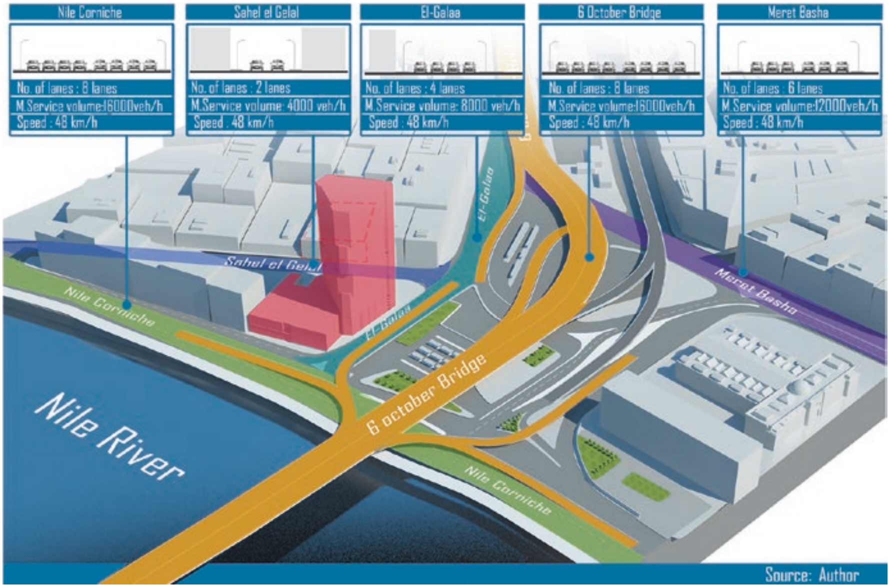


Fig. 9.43 Streets' sections and traffic properties

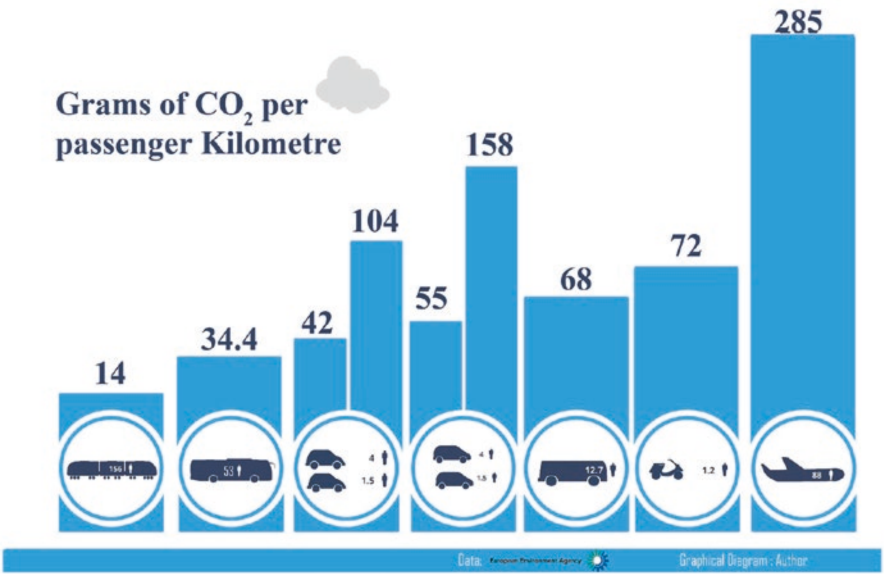


Fig. 9.44 Vehicles' CO_2 emissions per kilometre

Fig. 9.45 Traffic flow density in the surrounding streets *Image credit:* Author

Box 9.8 Traffic simulation results at maximum roads capacity

Traffic simulation results at maximum road	
Factor	Result
Delay time	76.69 s/km
Density	35.19 Veh/km
Flow	23,435 Veh/h
Speed	40.65 km/h
Total travelled distance	23,299 km/h
Percent of vehicles	95 %
Percent of busses	5 %

Box 9.9 CO_2 emissions associated with transport

Emission of vehicles	22,263 km	5.287 tCO_2	6.538 tCO_2
Emission of busses	1171.75 km	1.251 tCO_2	

results of the simulation are in Box 9.8. It shows that delay time in the trips in surrounding streets is 76.69 s/km at maximum street capacity and density of 35.19 Vehicle/km and flow of 23,435 Vehicle/h.

The main focus here will be on the total distance travelled by all vehicles throughout the streets surrounding our case study which is equal to 23,299 km. The total distance travelled then used as input of “GHG emission calculation tool version 2.6”, which is a tool designed to estimated CO_2 emission according to vehicle types and distance travelled (Fuglestvedt et al. 2007). It was found that the emissions resulting from cars was 5.287 tCO_2 while for buses 1.25 tCO_2, the total of all emissions was 6.538 tCO_2 as shown in Box 9.9.

11.3.2 Economic Impact

Economic impact in the case study focuses on the hotel revenue from rooms and suites reservation, and the impact of construction in term of materials used that will provide opportunities for factories.

Hotel Revenue

The estimated hotel revenue is composed of two main sources: the hotel rooms/suites and the hotel services, mainly restaurants, business centres, and multipurpose halls as indicated in Fig. 9.46. In the case study, the revenue was mainly calculated based on room and suites reservation per night as it is obvious and can be calculated accurately. The Hilton Ramses hotel contains 24 rooms and six suites per floor, making the total of 720 hotel rooms (single/double) and 180 suites in the whole hotel. The average price of rooms, single and double, on average price was USD139

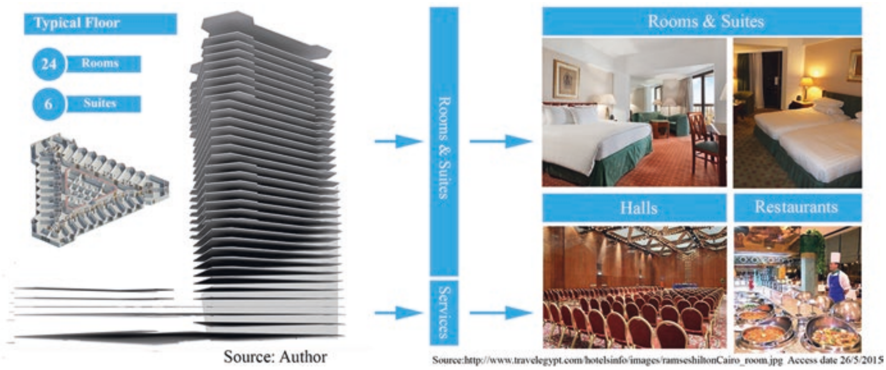


Fig. 9.46 Hotel revenue components

Box 9.10 Hotel rooms and suites' revenues

Number of rooms each floor	Total rooms/suites	Price of each room per night	Total
24 rooms	720 total rooms	139 average USD/night	USD100,080
6 suites	180 total suites	271 Average USD/night	USD48,780
At 100 % occupancy			USD148,860
At 75 % occupancy			USD104,202

Table 9.1 Elementary construction materials in Hilton Ramses hotel

Materials	Volume (m^3)	Mass (tonnes)
R. C. concrete	27,015.85	64,838.04
Brick	13,060.77	20,897.23
Glass	80.85	226.38
Wood	238.52	196.78
Aluminium	21.12	57,446.4

per night while the average price per suite per night was USD271 (Booking Website 2015). The total revenue from hotel room suites shown in Box 9.10 indicates the revenue at occupancy of 70 % and occupancy of 100 %. The total rooms and suites revenue were found at occupancy of 70 % to be USD104,202 per night and at occupancy of 100 % to be USD148,860 per night, higher by 42.86 %.

Construction Materials

The construction of a hotel of this size would require large amounts of materials, which have to be met by local factories (steel, cement, glazing, brick, aluminium factories, etc.). This leads to an economic flourish of these crucial industries as well as the transportation of tremendous amounts of materials from the factories to the site. The amount of the elementary construction materials estimated for the construction of the hotel is shown in Table 9.1. For example, the steel production for "Egyptian Iron and steel Co." was 278,683 tonnes/year at 2012/2013, which is about 23,223.5 tonnes steel per month (Egyptian Iron and Steel Co. 2015), the steel in our structure is about 8104.775 tonnes—about 34 % of the factory monthly production, so the highest amount of materials provides factories with ways to sell their products which in turn causes an economic flourish, the same principle can be used for other materials for construction.

11.3.3 Social Impact

Hilton Ramses hotel has social impacts which will be discussed in this section with focus on society welfare (job vacancies), social interaction.

Society Welfare (Job Vacancies)

The number of jobs provided by the hotel is estimated by the number of employees per room guest for this type of 5-stars hotel which has full-time hotel staff in all departments, including bell service, restaurants, turndown bed service, and telecommunications personnel, among others. Hotels with theatre shows, casinos, and 24 h services require extra personnel and are employed at a still higher ratio, perhaps 1.5 employees per guest room (Vallen and Vallen 2009). The number of employees in Hilton Ramses hotel, which has 900 rooms and suites, is 1350 employees. This number of employees is even extended by almost 5 % in the event of social events and conferences to reach 1417 employees. Hence, it provides high employment opportunities as a building.

Social Interaction

Hilton Ramses hotel hospitality offers a set of multipurpose halls that can be used by the society for various events, and also the restaurants' services can be used by the public. This allows for social interaction between communities as well as the tourists.

12 Discussion and Conclusions

High-rise buildings worldwide have been reviewed. The top ten tall buildings (Asia and North America) in 2014 were also reviewed. Continents with high-rise buildings/skyscrapers have been presented with emphasis on the top 25 cities around the globe with tall buildings/skyscrapers; with Hong Kong as the world's leading city housing the highest number of tall buildings and skyscrapers. Additionally, the 14 tall buildings in Egypt to-date have been discussed. The world's oldest high-rise building: the Great Pyramid of Giza was also analysed and discussed in terms of its unique stance, aerodynamic and building's shape, and sustainability as well as earthquake resistance. Three Transamerica pyramids have been illustrated to link between the oldest high-rise building, Chicago and Tokyo's tall buildings (Transamerica Pyramids).

Operational and embodied energy in tall buildings were examined. According to Ken Yeang, the energy is allocated for HVAC constitutes over 75 % of the total energy consumption. This energy use could be classified as operational and embodied energy. The study also showed high-rise buildings should importantly meet climate change adaptation measures. It has been seen that high-rise buildings could be most affected by climate change due to many reasons. Tall buildings can be considered as the most vulnerable to climate change due to their exposure to the elements and their unfavourable volume in relation to their surface. Nevertheless, if high-rise building designs are developed as sustainable structures that may lead to energising city life and contribute to providing a healthy indoor and outdoor environment, as well as reduce materials, energy, and costs. All these points are crucial in considering the development of tall buildings in relation to climate change impact especially since skyscrapers are key in modern cities, and if their envelopes are not highly energy efficient, particularly if glazing is used, a great deal of energy is consumed.

Also considering new ways of benefiting from renewable energies can play a vital role in reducing building energy consumption, which would assist in adaptation measures to encounter climate change risks.

According to the International Renewable Energy Agency (IRENA) recent report published in 2015 (IRENA 2015), the cost of generating power from renewable energy sources has reached parity or dropped below the cost of fossil fuels for many technologies in many parts of the world which in turn has led to 75 % decline of costs of solar photovoltaic (PV) cells cost decline since the end of 2009 and the cost of electricity from utility-scale solar PV dropping 50 % since 2010.

This study addresses the human elements of sustainable design in urban high-rise buildings. The advantages and disadvantages have been listed for tall buildings. This included the impact of high-rise buildings on environmental psychology and their sustainability from a social viewpoint. The social, psychological, and behavioural issues that need to be addressed in high-rise facility management, as well as the potential for sustainable buildings to ameliorate some of the problems in those areas traditionally associated with high-rise buildings have been presented. Concern on sustainable design and occupant behaviour was stated by Richard et al., but they stated that mega-structures may have certain advantages of centralisation and economies of scale, but they come with built-in challenges with respect to the social and psychological needs of building users. Inhabitants of these mega-structures lose an element of personal control over their life conditions and safety. Studies revealed that the larger the structure the more residents will be disengaged from natural elements. There is increasing evidence that such separation has negative consequences for psychological conditions and behaviour resulting in poor health and productivity loss. Reference to the world's tallest residential skyscraper (422 m high) that will be ready for dwelling by the first quarter of 2016 has been illustrated to emphasise Richard's viewpoint.

One of the 13 tall buildings in Egypt, Hilton Ramses hotel that is ranked among the 13 tall buildings in Egypt was selected for sustainability assessment due to the availability of data. Additionally, the analysis of Hilton Ramses hotel focused on SEA. The SEA study was carried out to comprehensively analyse the environmental (energy, water—magnitude of water consumption, and transportation in terms of traffic properties and traffic flow simulation), social (jobs and social interaction) and economic (revenues and materials consumption) pillars and effect of such a tall building to assess its impact on the context. The assessment revealed the following main findings:

- The construction of the building will have great embodied energy due to the large amount of materials and not using fly ashes concrete and recycled materials to mitigate the effect of embodied energy.
- The total embodied energy for all construction materials was 217,739.37 gigajoule of energy and carbon equivalent of 21,164.636 tonnes of carbon dioxide CO_2.
- When comparing the energy consumption in Ramses Hilton hotel with the benchmark of energy use of luxury hotels (classified according to climate zones

and consumption to excellent satisfactory), results of the simulation indicated that the energy consumption in the 5-star hotel was in the high consumption region from 345 to 290 kWh/m^2, with an energy use of 324 kWh/m^2.

- Operational energy compared to benchmarks in the research was considered high, so energy-efficient techniques are required to reduce the operational energy such as LED lighting, lighting sensors, and displacement ventilation and perhaps incorporating building management systems (BMS). This would assist in reducing energy consumption based on hotel activities and its frequency, the influx and the number of occupants, the pattern and time of these activities per day.
- Water consumption in the hotel was assessed. This demonstrates that the hotel's annual water consumption is 165,564 m^3 that is water consumption per day is 453.6 m^3/day which is equivalent to 453,600 L. The amount of water used per day by the hotel can provide drinking water for 240,000 persons where the average amount of drinking water needed for an adult is 1.89 L.
- Transportation and the impact of the hotel location which is already a busy hub has led to more CO_2 emissions associated with transport at 6.538 tCO_2 emissions.
- It has been seen that during construction, the hotel helped in flourishing some construction industries which has had a positive economic impact at the time. A hotel of such size used a large amount of materials, which have to be supplied by local factories (steel, cement, glazing, brick, aluminium factories, etc.), hence, it led to an economic flourish of these crucial industries as well as the transportation for tremendous amounts of materials from the factories to the site for instance, in one industry, steel production increased to 34 % of the factory's monthly production. Also, the total revenue from rooms and suites was found at an occupancy rate of 70 % to be USD104,202 per night and at 100 % occupancy to be USD148,860 per night, an increase of 42.86 %.
- In terms of social issues, it provides a good rate of jobs and social interaction.

It has been seen that the sustainability of high-rise/tall buildings need further assessment to reach a solid conclusion of the level of sustainability. I strongly believe that more debates and research are needed to come to a solid conclusion on this topic.

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Chapter 10
High-Rise Buildings in Mediterranean Climate: *“Illa de la Llum”* Case Study in Barcelona

Helena Coch and Cristina Pardal

1 Introduction

The construction of high-rise buildings has always been where the newest technological advances were displayed for the first time.

This building typology is intimately related with the growth of big metropolis. This growth was initiated in the United States at the end of the nineteenth century and last during the twentieth century, being the leading cities first Chicago and after New York. If the huge demographical growth, the lack of space and the consequent rise of the land value generated the need, the latest technological advances made it possible (Lepik 2004; Marino 1992).

The image of the first high-rise buildings is characterised by certain eclecticism and the use of neoclassical ornaments. The Masonic Temple of 1892 in Chicago or the Singer Tower of 1908 in New York, which takes references from the Louvre in Paris, are examples of this style (Eisele and Kloft 2002). It is not until the twentieth century that European architects are compelled to travel in the United States due to the Second World War. These exiled architects introduce the International Style, pure shapes free of ornament that soon become the high-rise buildings image (Landau and Condit 1996). The curtain wall glassed facade is the system still associated with this building typology.

During the era of the first skyscrapers, the resolution of the structure and its stabilisation against horizontal loads was the main technological challenge. The braced framed tube of the John Hancock Center, built in Chicago between 1965 and 1970, reached 100 floors—344 m—with a total steel weight similar to that needed by some other buildings just to achieve 80 m less (Fig. 10.1). Fazlur Khan, its engineer, also

H. Coch (✉) • C. Pardal
Department of Architectural Technology I, Universitat Politècnica de Catalunya UPC, Barcelona, Spain
e-mail: helena.coch@upc.edu

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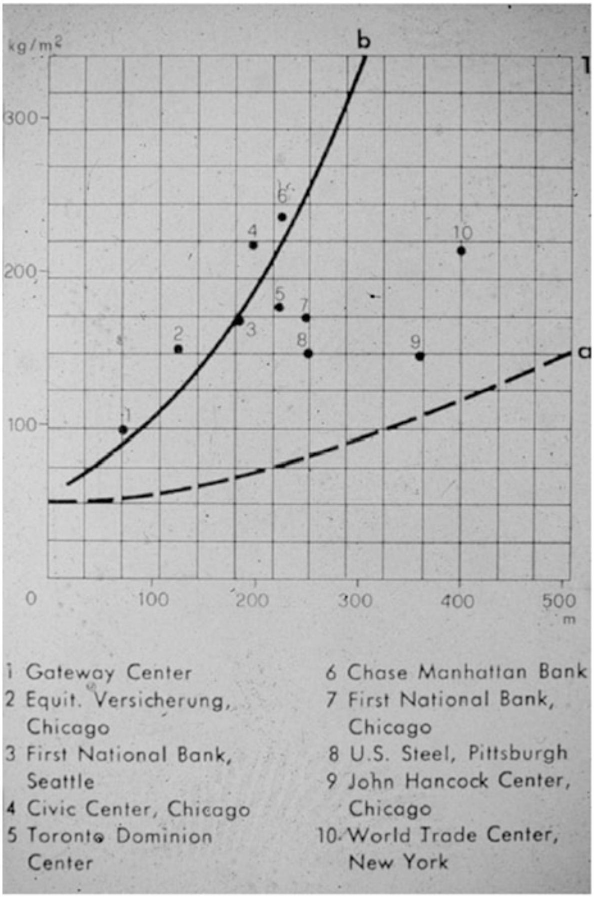


Fig. 10.1 Amount of steel per square meter of various buildings

designed the juxtaposed tubular profiles structure of the Sears Tower in Chicago, 120 floors high, during the same time period (Bennett 1995). However, after solving the structure, there are still a lot of things to take care of, one of those being the façade.

2 The Façade in High-Rise Buildings

In general towers are exposed to its four sides generating a big façade surface that needs to be solved in a situation where technical and functional requirements are extreme and, probably, curtain wall is no longer the best solution.

2.1 Constructive Requirements

High-rise building façades, even being exempted from assuming main structure loads, are still subject to considerable mechanical efforts due to the wind loads achieved at certain heights depending on the geographical localisation and climate. Wind load high values make difficult not only the façade proper functioning: junction tightness, exterior elements fixing, windows opening and so on, but also the assembly process.

The main issue is building a façade at a height where wind loads are much higher than usual. In the case of the Turning Torso building by Santiago Calatrava, we can see a clear example of an extreme wind exposition. The Turning Torso, in the Swedish city of Malmo, is an exempt tower of 180 m height built in a residential area next to the sea, where most of the buildings have around four floors. The mechanic action was quantified in a range between ±2.5 and ±4.5 kPa, 255 and 460 kg/m^2 at the wind tunnel (Banco de montaje de módulos 2005). This load is conditioned, among other things, by the geometry of the receiver's body, that is to say, this range of loads would be the ones acting over the finished tower. Even though, it is logical to think that during the construction process some wind gusts can originate wind loads of similar values. In this case, there would be some situations where it would be impossible to work *on-site*.

Big format components, either as panels with different claddings or as lightweight frames, have been widely used in high-rise buildings.

In 1951, Mies Van der Rohe used a big format frame grid-shaped to partially solve the façade of Lake Shore Drive buildings, in Chicago. The frame was made with three steel I-shaped profiles connected by horizontal plates that redrew the slabs edges in the façade. Each frame solved the façade between two pillars and two floors high. The joint between pieces was positioned in front of the pillar and in the fraction between two floorings at approximately 1/3 of one of them. The frames allowed to reach the site with a fragment of façade pre-assembled that, with very few assembly operations *on-site* solved a big façade surface. The frames were raised before pouring concrete in the slabs made by prefabricated elements: steel beams and plates. Frames acted as lost formwork (Fig. 10.2) (Campi 2000).

Nowadays, frames systems live together with the unitised one: facade panels usually made with aluminium profiles and clad depending on the project needs. They are directly anchored to the main building structure. In this case, the façade arrives to the site nearly finished, with only some final endings left in some cases. Other façade types may have sense in less height towers.

The objectives are clear:

- To complete the façade as soon as possible with the installation workers accessing from the floor slabs at all times, limiting the use of auxiliary resources and spending as little time as possible in an exposed situation.

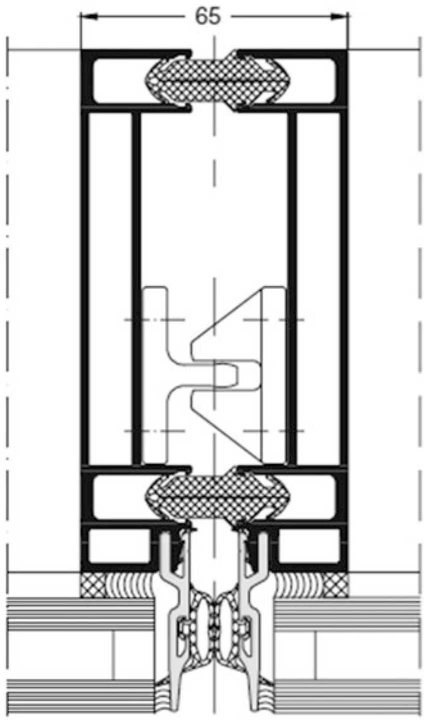
Fig. 10.2 Exposed Façade

- To make use of the possibilities offered by the industry to customise mass-produced elements and systems, designing with constant contributions from the various professionals involved (Convergent Design) and the quality guarantees.
- To limit and monitor the generation of loss or waste, that because it is not produced on the different floors of the tower but rather at the site where the frame or unitised module is assembled, in other words the workshop, are more easily managed.

While the unitised system clearly responds to the aforementioned objectives, the frames façade still requires in situ work. Which is the advantage then? The usual unitised systems resolve the watertightness of the joints thanks to a triple plane sealing with a drainage chamber that is created when pressing the two panels at their butt joints (Fig. 10.3). In other words, the proper functioning of the joint depends on a pressure that must be exerted in parallel to the façade plane. In contrast, the frames system is implemented by placing the cladding from the interior and the exterior over the frame, that is, the cladding can be secured by applying pressure over the frame perpendicular to the façade plane. This pressure is easily increased when the climatic conditions worsen, improving the behaviour of the joint.

Going back to the example of Turning Torso, the company Folcrá designed some unitised panels for this façade that are fitted from the exterior, applying pressure over mullions that had been positioned previously. In other words, the system makes use of the advantages of the panel that is completely finished in the workshop and those provided by a frame that is fitted by applying pressure from the exterior (Fig. 10.4).

Fig. 10.3 On site panels fabrication to reduce excessive labor



2.2 Comfort Requirements

The interior conditioning requirements on a high-rise building are similar to those of a relatively low building, but conditioned by a very exposed exterior situation. The façade, the filter that manages the energy and adapts it to the different situations, is one of the essential elements to enable the proper functioning of the ensemble. Smooth glass façades popular with the Modern Movement are no longer efficient. They were already barely efficient then, but were acceptable in a less demanding society; nowadays, the need to limit the consumption of fossil fuels and the emission of polluting gases into the atmosphere forces us to be much more stringent in the design of façade envelopes.

The façade must prevent the interior space overheating due to excess solar radiation, and at the same time guarantee the access of natural light and visual contact with the exterior; make use of thermal gain in winter in cold climates; control the thermal flow due to conduction through the envelop; all of this requires an appropriate envelop design that, far from responding to a global image, must be adapted to the climatic conditions of each location. It is important to remember that in this type of building the cooling needs due to occupation usually exceeds that of heating. If we

Fig. 10.4 Finishing panels to be pressed from the outside

add the thermal loads due to the powerful solar radiation, solar protection becomes essential. This solar protection must be placed in the inner side of the façade, protected from wind loads, despite this position may decrease its efficiency.

3 Lifestyle in Mediterranean Climate

The Mediterranean climate is characterised by its changing conditions all over the year as well as along the day. As a result of that, facades are implemented with a huge number of architectural filters, barriers and connecting elements that allow its adaptation to these varying conditions. Short and cool winters are separated from short and hot summers by intermediate periods with mild conditions in which the most part of the day the exterior conditions are comfortable. The extroverted character and lifestyle of those societies is the result of this climate conditions that invite to a close relation with external space.

The architectonic result of these variable conditions is evident in the great amount and variety of **buffer spaces** that characterise Mediterranean architecture and where this lifestyle can be developed. Those elements confer our architecture special interest. Patios, balconies, porches, conservatories, etc. create a repertoire of shapes that are repeated and are adapted to the needs without detracting from the formal quality of the architecture, but rather quite the opposite. High-rise buildings, generally with glass envelopes that cannot be opened and a simple inside roller blind for the shade, generate rejection in users in these benign climates accustomed to an intense relationship with the outside. The greater transparency achieved by those glass facades does not prevent users from feeling a sensation of claustrophobia and overexposure due to the lack of practicable windows, shading devices and intermediate spaces.

The search for light is not a priority in a place where there is an excess of radiation and where environmental quality is determined by the delicate balance between light and shade. The most invisible of the media in which we are immersed, the air, becomes our best ally in this climate and the sealed skins of high-rise buildings reject it radically. Fresh air and, more importantly, cool and warm air from the exterior are an element that the inhabitants of the Mediterranean want to be able to manipulate to their taste to achieve an environmental quality that could be defined as a significant element for their quality of life.

The tendency (which can be observed when comparing the first high-rise buildings with some current structures) to substitute single skin facades by double ones corroborates, purely from an energetic point of view, the value of making use of the exterior ambient conditions when they can provide greater quality to the inside space or also save energy.

Another of the characteristic elements of Mediterranean architecture, in addition to intermediate spaces, is **solar protection**. The immense variety of solar protection systems present in the architecture (fixed, mobile, flexible, etc.), from the most humble abodes to elegant palaces, has awakened the interest and fascination of observers from all over the world.

Apart from vernacular Mediterranean architecture, magnificent examples of shading devices can be found among the pioneers on Modern Movement in other places where the sun exposure is too high: the Golconde building (1945) by Antonin Raymond in India, the Panama Hotel (1946) by E. D. Stone, or the Panamá University (1950) by Bermúdez, De Roux and Méndez Guardia, as well as the great number of works designed by the Brazilian architects as L. Costa, O. Niemeyer, A. E. Reidy, A. F. Costa, etc. A large bibliography dealing with shading devices, starting in the book of Olgyay brothers in 1957, can be found today (Olgyay and Olgyay 1957). This fact shows the interest of these apparently so simple elements that are really complex and effective solutions even though their adaptation to high-rise buildings is complex due to the singularity of the typology and the extreme conditions to which they are exposed (Fig. 10.5).

4 Case Study: A High-Rise Building in the Mediterranean: La Illa de la Llum

The building presented combines the presence of **shading devices** with the creation of **intermediate spaces** all in a high-rise building right on the coast in the city of Barcelona.

Fig. 10.5 Intermediate spaces with shading devices

The *Illa de la Llum* is a residential complex located in the city district of Diagonal Mar. This city district began as a consequence of the administration's desire to provide continuity to the city right up to the sea, accompanying one of its main arteries, Avinguda Diagonal. Practically contemporary and neighbour to the Fórum area that in 2004 was home to the Cultural Forum, it is made up of residential complexes such as the *Illa del Bosc* by Tusquets, Díaz y Asociados; the *Illa del Cel* by Alonso y Balaguer Arquitectos with Carlos Ferrater; the *Illa del Mar* by the Oficina de Projectes Integrals with Muñoz and Albin; the *Illa del Llac* by BST and KM+P with Tusquets, Díaz y Asociados; and the building that concerns us: the *Illa de la Llum* by Lluis Clotet and Ignacio Paricio architects. They are all organised around a large park by the architects EMBT Miralles Tagliabue.

4.1 The Building

The *Illa de la Llum* comprises two towers with a square floor plan, one with 26 floors and the other with 18, that in conjunction with an extended volume that is five floors high, they close off a private site with various facilities for exclusive use by the 230 dwellings. The three constructions respond to similar criteria of function, shape and construction, appropriate in each case to the specificity of each volume, its orientation and relationship with the surroundings. In this text we are going to focus on the analysis of the tallest tower as it is the most representative of the innovations introduced in the project (Fig. 10.6).

It is a tower with 26 floors, 88 m tall, on the seafront in an area that is very exposed to the effects of a marine environment. The square plant has its perimeter

Fig. 10.6 High-rise buildings in a marine environment

altered as the tower gets higher, mainly at its north side. This square plant, with sides measuring 28.5 m, forms concentric rings around a central concrete structure that houses the lifts and staircases. The first ring surrounds this core organising the distribution of the different dwellings that occupy each floor. The next ring has all of the supply and evacuation installations that provide service to the dwellings and that, given their location, are accessible from the corridors. This ring of installations also has the first set of columns that are repeated near the square perimeter, in this case hidden between the elements that close the façade. A cantilever of 3 m compensates the excessive span between columns.

This clear and well-organised layout of the elements that pass through the slab floors vertically enables the liberation of a sufficiently spacious area for the different types of apartments without any fixed elements that limit the layout possibilities. The cantilevers are used as terraces (Fig. 10.7).

The dimensions and distribution of the dwellings was very heavily influenced by the promoter and by the market requirements at that time. The free plant allows easily responding to this market just by changing the distribution. The designed partitions could be considered circumstantial. Despite this almost ephemeral nature of the interior distribution there are aspects of the dwellings that are repeated and respond to characteristic traits of the work of the architects Clotet and Paricio. The position of the living room in the corner, delimited on two sides by large glazed

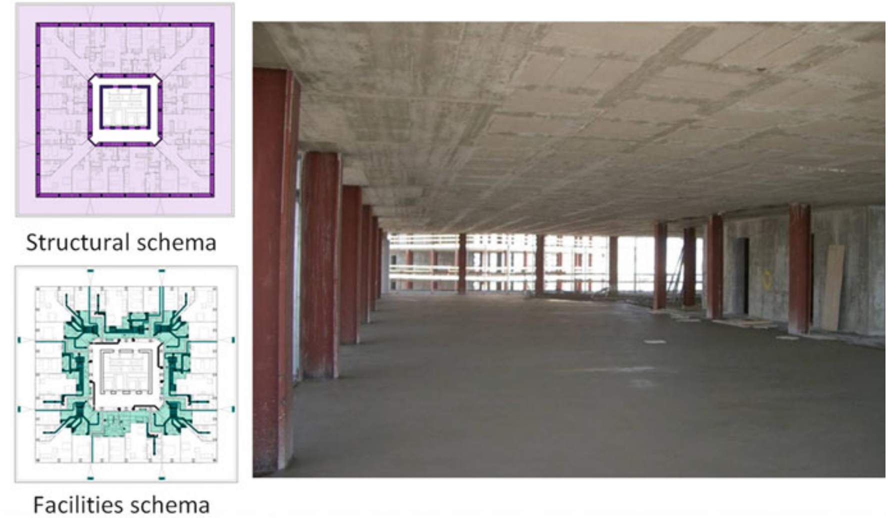


Fig. 10.7 Adequate use of glazing to create a terrace space

openings that communicate directly with the terrace, prolongs the living space almost to the sea.

At a height of 80 m on the seafront the views are spectacular, but this can also lead to a sensation of vulnerability. Evidently the degree of exposure is not the same as in the Swedish tower by Calatrava in the city of Malmo mentioned at the start of this text, but it is still considerable.

The enormous sliding panels of moving aluminium slats that run along the edge of the cantilever guarantee the sensation of security on the terraces meaning that spaces that could become inhospitable recover the quality and sensuality of the porches and lath houses that are so common in the Mediterranean climate (Fig. 10.8).

4.2 Constructive and Functional Adaptation

The *Illa de la Llum* shies away from the usual image of a sealed glass prism that accompanies high-rise construction, distancing itself from technological displays and conventionality, and for this reason we have selected it for this text. It is the high-rise building of the Mediterranean, in accordance with the benign nature of the climate and respectful of the local customs that greatly value life in contact with the outside and give precedence to empirical and sensorial aspects that are difficult to quantify above standard values of comfort.

Despite its apparent technological simplicity, the Illa de la Llum takes the structure to the limit and is a clear example of efficient strategy regarding the resolution

Fig. 10.8 The building "Illa de la Llum" shows a unique strategy by incorporating functionality and equipments

of the layout of the equipment up to the roof, where they practically disappear. It shows clear care in the design and execution of the smallest details, and is innovative in the incorporation of a new "in situ" prefabrication system.

4.2.1 Commitment to the Challenges of Prefabrication

The variation in the distribution of the different floors, the recessed geometry of the façades and the diversity of volumes, two towers and a lower body, entails the complexity of a considerable dimensional variability. Resorting to a frame facade supporting either glasses panes or blind ones was the simplest solution.

The façade is a dry construction based on prefabricated frames obtained by assembling galvanised steel tubes. Those frames assembled on-site provide a solution for the skeleton of the façade while ensuring it is correctly staked out.

The system is straightforward, conceptually the same that used Mies van der Rohe in the Lake Shore Drive buildings. The difficulty lies in being able to mass-produce a set of different frames.

A metalwork workshop was organised on-site where one person cut the tubular profiles at a cutting table, all with the same section, according to the measurements indicated in templates (one per frame) with self-adhesive labels that the operator would stick to each profile once cut. The set of profiles that made up each frame were organised on stands for later assembly. The assembly of two tubular sections joined at 90° is always the same regardless of the length of the profile. In other words, with simple operations of cutting and assembly organised using an unequivocal system of reference codes, it was possible to transport small parts to the construction site, and assemble them on-site in their own workshop, directly positioning the frame in the corresponding location and floor (sequence in Fig. 10.9).

Fig. 10.9 Small parts of the buildings exported from the main workshop

Once the frames were in place, the rest of the elements of the façade were installed from each slab. The continuous terraces on almost all floors enable easy access from both the inside of the enclosure and the exterior.

4.2.2 Adaptation to the Climate

The highest tower has its four facades perfectly orientated to each of the cardinal points while the other is rotated 45°. The objective is having the most of the dwellings well orientated. As shown in Fig. 10.10, while the south façade of the highest tower is completely flat the north one has a more complex geometry achieving to provide openings to east or west and view to the sea to all the flats.

Fig. 10.10 The orientation is well demonstrated in designing these buildings

Fig. 10.11 The importance use of sliding panels

The large concrete overhangs and the sliding panels of moving aluminium slats, which characterise the ensemble, are the elements that adapt the tower to the Mediterranean climate. The former, responsible for blocking the excess solar radiation from the south in summer and giving the dwellings large terraces, disappears in sections of the façade where, due to either orientation or dwelling type, they are not necessary. In the latter, the slats are repeated in all orientations, either on the edge of the overhangs or adjacent to the enclosure where there is no overhang. Their presence is always necessary. The sliding panels of moving slats not only protect from the sun but also safeguard the terraces from excessive exposure to the wind, at the same time as drawing an enclosure plane that on the highest floors prevents the sensation of vertigo. This double skin creates intermediate space that can be used almost all year long (Fig. 10.11).

The mobility of the panels of slats and the variations in terms of the depth of the envelope with regard to the edge of the slab floors generate a vibrant effect in the façades emphasised by the recessing that cuts away the virtual prism that the tower apparently is.

5 Conclusions

The high-rise building has become established in emerging big cities coinciding with the consolidation of a globalised world. Globalisation, possibly desirable in certain aspects, is often accompanied by a loss of identity. Skyscrapers proliferate in the different cities of the planet regardless of the architectonic tradition of each of them. If the skyscraper was the test site for glass skins, and in some ways this solution for the façade was linked to the type, it has been repeated over the world.

At this point in time, the action of human activity on the environment and the repercussions of excessive energy consumption to maintain pleasant environmental conditions in buildings are a point of debate that architects cannot avoid.

Current times require a rereading of the type of high-rise building in accordance with each climate and culture, understanding culture to be the inheritance of centuries of knowledge of the place.

In the case at hand, the Mediterranean climate and society, the presence of buffer spaces, formed by high-rise balconies enclosed by slats that ensure solar protection and yet offer the necessary safety, enable us to restore the traditional lifestyle in architectonic types that tend to renounce it.

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Concluding Remarks

The world is moving rapidly towards urbanism due to exponential population growth, transport complexity and the need for fast communications and increased commercial activities. Mega cities exist now in more than 100 countries. Architects and builders have the responsibility of making high-rise buildings cities within city "within a city" having adequate levels of comfort, green space, recreation activities with minimum pollution and excessive use of energy.

In this book, there are many examples and demonstrations of high-rise buildings, their important features and functionality, from different architects and designers from ten countries in various regions and climates: Malaysia, The Netherlands, Yemen, China, Portugal, UK, USA, Sweden, Egypt and Spain, Canada and South America.

The book represents comprehensive knowledge of social and economic aspects, materials, space requirements, and services in high-rise buildings. There are more than 300 references cited and over 500 illustrations.

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About the Authors

Mohsen Aboulnaga
Dr. Aboulnaga is a Professor of Sustainable Built Environment at Cairo University and Government Strategy and Policy Advisor. He is member of The Ministry of Planning's task force responsible for developing Egypt's Strategy on Sustainable Development and Green Economy 2030. He is an Associate Partner at Oil and Gas Skills—OGS (MoPMRs), and an Associate Expert at the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE). He is an expert on Sustainability, Sustainable Development and Sustainable Built Environment. Dr. Aboulnaga obtained his Ph.D. from University of Leeds, UK, and Master's Degree (M.Sc.) and Bachelor's Degree (B.Sc.) from Cairo University. He has over 25 years of diverse experience (18 years were in the UAE) in government, senior management, consultancy and academic positions. His areas of competency include strategy planning, policy development, low-carbon society, green cities and sustainable building policies, as well as renewable energy and climate change. Dr. Aboulnaga is former Strategy & Policy Advisor—Environment & Infrastructure at His Highness, the Prime Minister's Office of the UAE (Feb 2009—April 2010) responsible for implementing and monitoring the federal Government Strategy (cycle 2008–2010). Prior to that, he held a position in the Capacity of Strategy & Policy Advisor at The Executive Council, Government of Dubai (May 2007–Jan 2009) where he developed many strategic projects, namely Dubai Government policies, and detailed policy for Dubai Sustainable Urban Development Framework 2020 and Green Building Guidelines for UAE Ministry of Public Works, which was presented to the

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States of Arab League (LAS) in Jan 2009. He founded and established the Emirates Green Building Council in 2006 (no 8 worldwide in that year) and was elected the first chairman of the Council and Board of Directors. Prof. Aboulnaga holds an Honorary Fellow of the Institute of Green Professionals, USA. He is an Associate Partner of the European Sustainable Development Network, Austria, and a registered expert with UNEP and ESCWA since 1997. In Dec 2013, Dr. Aboulnaga participated in the European Commission—JRC expert meeting in Italy to review the guidebook on Sustainable Energy Action Plan (SEAP) for the ENPI South Countries (Mediterranean cities). He has been an invited speaker to more than 120 int'l and regional conferences, seminars and workshops and training programs, and has more than 100 int'l publications and presentations. He taught at University of Leeds, UAE University, American University in Dubai and University of Dubai from 1986 till June 2013. He is currently teaching at Cairo University. Prof Aboulnaga has more than 70 Intermetal publications (journals, conferences and books). He was also invited keynote speaker to more than 100 international conferences, seminars, workshops and training as well as an external Ph.D. examiner at the University of Sheffield, UK.

Mastura Adam
received a Master in Urban Design in Oxford Brookes, United Kingdom, and a Ph.D. from the University of Salford at School of Built Environment United Kingdom in 2013. She has been teaching at the Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, since 1996. Her 19 year career as an academician in UM contributed to several successes in the department including architectural school recognitions from Royal Institutes of British Architects (RIBA part I and RIBA II), numerous batches of Bachelor Sc. and Bachelor in Architecture graduates and Mubin Sheppard awards for Measured Drawings. Her area of expertise is architectural design with emphasis on sustainable design and sustainable urban mobility. Her research focuses on the outdoor thermal comfort in public urban spaces and pedestrian environment. She published several papers for conferences and journals on sustainable design for urban mobility, urban design and universal design. She recently collaborated with local and international experts in an endeavour to advocating walking in the city with a goal of establishing a Pedestrian Charter for Kuala Lumpur.

Khaled A. Al-Sallal

Dr. Khaled A. Al-Sallal is currently a professor of architectural engineering and the director of the Daylighting Simulation Laboratory at UAE University and his area of expertise is sustainable design with emphasis on building energy. He has a Ph.D. from Texas A&M University and a Master's degree from Arizona State University. He has been involved in many research projects and consulting services that introduced new building sustainable technologies to the UAE and the Middle East. His teaching and research has focused on building performance and simulation, carbon-neutral design, daylighting, and vernacular and climatic responsive architecture. He developed a novel methodology to measure and simulate trees interception of natural lighting in architectural spaces useful for sustainable design applications. He produced numerous publications in international refereed journals (18) and scientific conferences proceedings (46), and wrote 8 chapters in 7 edited books by reputable scientific publishers (Elsevier, Francis & Taylor, Hogrefe & Huber). He is also the editor of a new book on low carbon low energy architecture that includes chapters contributed by well-known international scholars (CRC Taylor & Francis). He gave numerous lectures and presentations in various conferences, meetings and scientific forums. He serves in the editorial board of four scientific journals and he has been active in professional and scientific societies. He is a member of the IBPSA Board of Directors and founder and president of IBPSA-UAE Affiliate (IBPSA-UAE) since 2005. He is the WSSET Vice President, Middle East, since 2009. He is an active full member of ASHRAE, Vice President of ASHRAE Falcon Chapter since 2011, and a Member of Board of Governors since 2009. He is also a member of CTBUH and served as the country representative of the CTBUH-UAE. He received several awards including Best research project award of Engineering for 2007; Award of Excellence in Teaching 2000, UAE University.

Arch Mona Azarbayjani Mona Azarbayjani is an Assistant Professor in the School of Architecture at the University of North Carolina at Charlotte (UNCC) where she is currently teaching Design Studio, core building technology courses, Energy Simulation and the use of renewable energies in architecture. Dr. Azarbayjani holds a Ph.D. from the University of Illinois Urbana Champaign. She was the Lead Principal investigator and faculty team leader for the UNC-Charlotte Solar Decathlon team 2013. Her research in energy performance, natural ventilation, high-performance skins and carbon neutral building will serve current building technology expertise in the Integrated Design Labs, Energy Performance Lab (EPL).

Helena Coch
Prof Coch is the director of Arquitectura, energia i medi ambient
Escola Tècnica Superior d'Arquitectura de Barcelona
Av. Diagonal 649, 7a p. 08028 Barcelona
Spain (UPC)
She is involved in 194 publications and research work. She worked closely with the late Prof Rafael Serra. Helena is a member of several national and international organizations.

Manuel Correia Guedes
Dept of Civil Engineering & Architecture Instituto Superior Tecnico, Lisbon, Portugal

Professor, Director of the Architectural Research Centre (ICIST-N8), Portugal

He is Director of the Architectural Research Centre of the Instituto Superior Tecnico (ICIST—Group 8). He is Responsible for several Disciplines of the courses of Architecture, Civil Engineering and Territorial Engineering. He is supervising several Ph.D. and M.Sc. students.

Participation in various research projects: Chief Coordinator of a COOPENER E.U. project (SUREAFRICA), National Coordinator of an ASIA-LINK project, Dr. Guedes, participated in various international and national conferences, seminars and workshops.

His Ph.D. was on Environmental design in Southern European Office Buildings covering sustainability, passive design, energy efficiency and thermal comfort. Both his Ph.D. and M.Phil. were done at Cambridge University, Martin Centre. The M.Phil. thesis was sponsored by the E.U. "Praxis" scholarship on Environmental Design, "Aspects of Environmental design of Office Buildings in Portugal".

Since 1985 he participated in various projects, namely the Portuguese Pavilion in Seville's EXPO 92, two residential buildings in Vila Real, the competition for the National Assembly building, and the building of the Agronomy Faculty (UTL). He worked as an architect in several Portuguese architectural companies.

He published many articles and papers in the fields of bioclimatic architecture and the built environment.

Neveen Hamza
Dr. Hamza is a Senior Lecturer in the School of Architecture, Planning and Landscape, Newcastle University, United Kingdom. Her research interests include looking at the thermal and daylight performance modelling of buildings to improve human comfort and productivity. She also directs the M.Sc. in Sustainable Buildings and Environments in the School aimed at developing a new generation of architects that are proficient in environmental modelling of buildings and micro urban environments. She has several publications and seven Ph.D. students completed their research in this technical and social area of research.

She is a Vice Chair for the International Building Performance Simulation Association-England (IBPSA-England) and the Arab Society for Computer Aided Architectural Design (ASCAAD). She is a reviewer for more than ten scientific journals in the field as well as being on the editorial board for some of them.

Puan Sri Datin Seri Nila Inangda Manyam Keumala
is an Expert/Research Consultant in Department of Architecture, Faculty of Built Environment in University of Malaya. She was one of four pioneer of Architecture Program in University Malaya, the pioneer University in Malaysia. She leads the Research Center for Urban Study, Conservation and Tropical Architecture, under Sustainability Science Cluster, University Malaya. She obtained her degrees in Bachelor of Architecture and Master of Philosophy in Architecture from University Technology of Malaysia (UTM). She was an Associate Professor and Head, the Department of Architecture, before she led the Equatorial and Sustainable Design in Faculty of Built Environment, University Malaya. She is a member of the Malaysian Board of Architects (LAM), Malaysian Institute of Architects (PAM), an individual member of CIB (International Council for research and Innovation in Building and Construction), and BRE (Building Research Establishment). She is the Advisor to the Women Graduate Association of Malaysia (PSWM), a life member of Malaysian Heritage Trust. Currently, she chairs the Endowment Fund Committee, for the Faculty of Built Environment, University Malaya. Her research projects, supervision and programs cover, Sustainable Architectural Design, POE, Building Conservation, and Architecture of the Muslim Word.

Baizhan Li
is a Professor in Sustainable Built Environments and Building Energy Efficiency at the Faculty of Building Construction and Environmental and Engineering, Chongqing University, China. He is the Director of National Centre for International Research of Low-carbon and Green Buildings, MOST, China; Manager of the National Base of "111" Program, MOE & SEFEA, China; Director of Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, MOE, China; Project Commissioner of MOST; Vice Chairman of China Green Building Committee. He is an Honorary Professor of University of Hong Kong, and a Guest Professor of University of Reading and the University of Melbourne. He is an Academic Leader of Science and Engineering of Urban Human Settlements Environment Assurance, Key

Discipline of “211” Project, China. He is a Fellow of Chartered Institution of Building Services Engineers, Fellow of Royal Institution of Chartered Surveyor, Member of ASHRAE 55 Standard Committee, Vice Chairman of E1 Branch of International Institute of Refrigeration. He has published over 200 academic papers and authored or co-authored nine books.

Bahram Moshfegh
He studied at the Linköping University, Sweden, where he received a Ph.D. degree in Energy Systems in 1992. He was appointed Professor of energy systems there in 2000. Professor Moshfegh is the Chairman of Division of Energy Systems at the Linköping University since 2000. He has been involved as expert for Swedish parliament and funding research council both nationally and internationally, member of the scientific committee for the Swedish Research School Energy Systems, member of the scientific committee and organization committee as well as invited speaker for many *International Conferences*. Referee for many international journals and international conferences in the field of energy and building. He is Swedish expert and Subtask leader in the *Annex 51—Energy Efficient Communities: Case Studies and Strategic Guidance for Urban Decision makers* acting under IEA International Energy Agency, Energy Conservation in Buildings and Community Systems Programme (2009–2012). Professor Moshfegh was the Chairman for the *World Renewable Energy Congress (WREC-2011) on May 8–13, 2011* in Linköping, Sweden. Professor Moshfegh has authored or co-authored more than 150 papers and research reports mainly presented in international journals or at international conferences with referee.

Cristina Pardal
Department of Architectural Technology I, Universitat Politècnica de Catalunya UPC, Barcelona, Spain. Dr. Pardal involved in 1. Formal Issues—Representative architecture

1. The use of glass as the only mean to give the building an image associated with power and economic success is being gradually replaced by some other mechanisms.

If in the time of the Modern Movement constructing a large and completely smooth glass skin was a challenge, in our days complex and non-repetitive geometries are the main topic.

- The disproportion of the building typology is extended to every direction
- Glass limits
- Form freedom thanks to CAD CAM tools

Case Studies

Glass: Shard (London)/One World (NY), Geometry: Eight Spruce Street (NY)/Turning Torso (Malmo)

2. Extreme conditions affect the tower execution and difficult the fulfilment of the basic requirements of the building in service

Workers safety and accessibility	Turning Torso (Malmo)
Climate comfort	Shard (London)/The New York Times Building
Water and air tightness	Turning Torso (Malmo)

Case Studies

Shard (London)/Turning Torso (Malmo)/The New York Times Building

3. Façade design mechanisms responding to climatic conditions. Looking for comfort

- The glass façade and its filters
- Half blind façades and its resources
- The integrated façade: Unitized modules getting closest to climate artefacts Capricorn

Case Studies

Shard (London)/Eight Spruce Street (NY)/The New York Times Building/Capricorn Haus (Düsseldorf)

Ali Sayigh
UK Citizen, Graduated from London University, & Imperial College, B.Sc., AWP, DIC, Ph.D., C.Eng. in 1966. He is Fellow of the Institute of Energy, and Fellow of the Institution of Engineering & Technology, Chartered Engineer, Chairman of Iraq Energy Institute.

Prof. Sayigh taught in Iraq, Saudi Arabia, Kuwait, Reading University and University of Hertfordshire from 1966 to 2004. He was Head of Energy Department at Kuwait Institute for Scientific Research (KISR) and Expert in renewable energy at AOPEC, Kuwait, from 1981 to 1986.

He started working in solar energy in September 1969. In 1972, he established "The

Journal of Engineering Sciences" in Riyadh, Saudi Arabia, and in 1984 he established International Journal for Solar and Wind Technology, as an Editor-in-Chief. This has changed its name in 1990 to Journal of Renewable Energy. He is editor of several international journal published in Morocco, Iran, Bangladesh, Nigeria and India. He established WREN and the World Renewable Energy Congress in 1990. Member of various societies related to climate change and renewable energy.

He was consultants to many national and international organizations, among them, the British Council, ISESCO, UNESCO, UNDP, ESCWA and UNIDO. He run conferences in 40 different countries, published more than 600 papers and associated in 36 books. He supervised more than 80 M.Sc. and 35 Ph.D. students. He is editor-in-chief of famous Renewable Energy Magazine, RE and the year, since 2000.

He is the Editor-in-Chief of Comprehensive Renewable Energy coordinating 154 top scientists, engineers and researchers' contribution in eight volumes published in 2012 by Elsevier which won 2013 PROSE award in USA.

Runming Yao
is a Professor in Energy and the Built Environment; academic lead for the Innovative and Sustainable Technologies (IST) Research Group and Course Director of the postgraduate programme 'Design and Management of Sustainable Built Environments' within the School of Construction Management and Engineering at the University of Reading, UK. She is a Visiting Professor of Chongqing University and a Co-Director of the International Centre for Low Carbon and Green Buildings by the Ministry of Science and Technology of China. Prior to joining the University of Reading in 2007, she was a Senior Research Associate in the Department of Architecture at the University of Cambridge where she worked for 6 years in the field of environmental architectural design. Prof. Yao is a Chartered Engineer; a Fellow of the Chartered Institution of Building Services Engineers (CIBSE); a Fellow of the Chartered Institute of Building (CIOB); a Member of the American Society of Heating Ventilation, Refrigerating and Air-Conditioning Engineers (ASHRAE) and a Fellow of the Higher Education Academy (HEA). Prof. Yao's research focuses are on energy efficiency; indoor environment and well-being; urban microclimates, and occupants' thermal comfort and adaptive behaviour. She has completed numerous research projects by a wide variety of resource.

Wim Zeiler
He studied Mechanical Engineering at the University of Twente, specializing in design and construction and methodical design. In 1983, he joined the building services company Kropman, in which he currently holds the position of specialist in building services technology. In 2001, he became full professor of Building Services at the Department of the Built Environment at Eindhoven University of Technology, Unit Building Physics and Services. His research is on design methods, building services technology, sustainable buildings, smart grids, intelligent agent process control and human comfort. Zeiler was member of the board of TVVL (Dutch Society for Building Services in the Built Environment), chairman of the Electrical Engineering department of TVVL and is member of the board of advice of ISSO (the Dutch society for stimulation of research on building services in the Netherlands). He received the B.J. Max price of TVVL in 1993, and in 2009 he was honoured with their lifetime achievement award, the Gold medal. In 2014, he received the REHVA professional science award.

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