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LOW ENERGY BUILDING DESIGN IN HIGH DENSITY URBAN CITIES

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ABSTRACT

This paper investigates the concept of low energy building, examines how urban density might affect building energy design in high density cities, and discuss the strategies for low energy building design in densely populated areas. Using Hong Kong as a case study, the characteristics of dense building development and the major factors affecting low energy building are evaluated. The approaches taken in Hong Kong to accommodate its growing population provide an interesting background for understanding the constraints and potential of low energy design. The energy situation in Hong Kong is explained and the major considerations for energy efficiency in high density conditions are discussed. It is hoped that the research findings would contribute useful information for designing methods to achieve low energy building in a complex and dense urban environment.

INTRODUCTION

With increasing urbanisation in the world, cities are growing in number, population and complexity. At present, 2% of the world's land surface is covered by cities and yet the people living in them consume 75% of the resources consumed by mankind. The 'ecological footprint' of cities is many times larger than the areas they physically occupy (Rees, 1999). Economic and social imperatives often dictate that cities must become more concentrated, making it necessary to increase the density to accommodate the people, to reduce the cost of public services, and to achieve required social cohensiveness. The reality of modern urbanisation leads to higher densities than were in traditional settlements and this trend is particularly important in developing countries. Today, the challenge before many cities is to support large numbers of people while limiting their impact on the natural environment.

Buildings are significant users of energy and materials in a society and energy conservation in buildings plays an important role in urban environmental sustainability. A challenging task of architects and other building professionals today is to design and promote low energy buildings in a cost effective and environmentally responsive way. Passive and low energy architecture has been proposed and investigated in different locations of the world (Yuichiro, Cook and Simos, 1991; Givoni, 1994); design guides and handbooks were produced for promoting energy efficient buildings (CIBSE, 1998; FSEC, 1984; State Projects, 1993; Watson, 1993). However, at present, little information is available for studying low energy building design in densely populated areas. In high density cities, because of the limitation of land and space, the energy efficiency task is more complicated. Designing low energy buildings in high density areas requires special care to the planning of urban structure, coordination of energy systems, integration of architectural elements, and utilisation of spaces. At the same time, the study of low energy buildings will lead to a better understanding of the environmental conditions and improved design practices. This may help people study and improve the quality of built environment and living conditions.

This paper investigates the concept of low energy building, examines how urban density might affect building energy design in high density cities, and discuss the strategies for low energy building design in densely populated areas. Using Hong Kong as a case study, the characteristics of dense building development and the major factors affecting low energy building are evaluated. The approaches taken in Hong Kong to accommodate its growing population provide an interesting background for understanding the constraints and potential of low energy design. The energy situation in Hong Kong is explained and the major considerations for energy efficiency in high density conditions are discussed. It is hoped that the research findings would contribute useful information for designing methods to achieve low energy building in a complex and dense urban environment.

WHAT IS LOW ENERGY BUILDING?

Before discussing the subject, it is important to clarify the meaning and objective of 'low energy building'. The term '*low energy*' is often not clearly defined in many demonstration projects and studies (Abel, 1994). It may mean achieving 'zero energy' requirements for a house or reduced energy consumption in an office building. A major goal of low energy building projects and studies usually is to minimise the amount of external purchased energy such as electricity and fuel gas. But sometimes the target may focus on the energy costs or a particular form of energy input to the building. As building design needs to consider other requirements and constraints as well (such as architectural functions, indoor environmental conditions, and economic effectiveness), a pragmatic goal of low energy building is to achieve the highest energy efficiency which requires the lowest possible need for energy within the economic limits of reason.

Because energy consumption in buildings is influenced by many complicated factors and phenomena, it is not easy to define 'low energy building' precisely and to measure and compare the level of building energy performance. The loose fit between form and performance in architectural design also make quantitative analysis of building energy use more difficult. Nevertheless, it is believed that 'super-efficient' buildings which have significantly lower energy consumption can be achieved through good design practices and effective use of energy efficient technologies (Todesco, 1996). In an ideal case, buildings can even act as producers rather than consumers of energy.

Besides the operational energy requirements of buildings, it is important to consider two related energy issues. The first one is the transport energy requirements as a result of the building and urban design patterns; the second one is the embodied energy or energy content of the building materials, equipment or systems being used. Transport energy is affected by the spatial planning of the built environment, transport policies and systems, and other social and economic factors. It is not always possible to study the effect of urban and building design on transport energy without considering the context of other influencing factors. The general efficiency rules are to promote spatial planning and development which reduces the need to travel, and to devise and enforce land-use patterns that are conducive to public transport (Owens, 1986).

Embodied energy is the energy input required to quarry, transport and manufacture building materials, plus the energy used in the construction process. It represents the total life-cycle energy use of the building materials or systems and can be used to help determine design decisions on system or material selection (Treloar, Fay and Tucker, 1998). At present, the field of embodied energy analysis is generally still only of academic interest and it is difficult to obtain reliable data for embodied energy. Research findings in some countries indicated that the operating energy often represents the largest component of life-cycle energy use. Therefore, most people, when studying low energy buildings, would prefer to focus on operating energy, and perhaps carry out a general assessment of embodied energy only.

EFFECTS OF URBAN DENSITY

To handle population growth on a limited land basis, the word '*density*' is unavoidable. Instead of expanding the boundary, cities often respond to development pressure by setting targets for increased urban densities. The result is reflected by the establishment of a high rise cityscape and compact urban settings. The effects of urban density on the total energy demand of a city are complex and conflicting (Givoni, 1998). Highly concentrated load centres and compactness of land use patterns will bring benefits to energy distribution and transport system design, but crowded conditions may create congestion and undesirable local microclimate. Table 1 gives a summary of the positive and negative effects of urban density.

Table 1. Effects of urban density on city's energy demand

Positive effects	Negative effects
Transport ♦ promote public transport and reduce the need for, and length of, trips by private cars ***Infrastructure*** ♦ reduce street length needed to accommodate a given number of inhabitants ♦ shorten the length of infrastructure facilities such as water supply and sewage lines, reducing the energy needed for pumping ***Thermal Performance*** ♦ multistory, multiunit buildings could reduce the overall area of the building's envelope and heat loss from the buildings ♦ shading among buildings could reduce solar exposure of buildings during the summer period ***Energy Systems*** ♦ district cooling and heating system, which is usually more energy efficiency, is more feasible as density is higher ***Ventilation*** ♦ a desirable air flow pattern around buildings may be obtained by proper arrangement of high-rise building blocks	***Transport*** ♦ congestion in urban areas reduces fuel efficiency of vehicles ***Vertical Transportation*** ♦ high-rise buildings involve lifts, thus increasing the need for electricity for the vertical transportation ***Ventilation*** ♦ a concentration of high-rise and large buildings may impede the urban ventilation conditions ***Urban Heat Island*** ♦ heat released and trapped in urban areas may increase the need for air conditioning ***Natural Lighting*** ♦ the potential for natural lighting is generally reduced in high-density areas, increasing the need for electric lighting and the load on air conditioning to remove the heat resulting from the electric lighting ***Use of Solar Energy*** ♦ roof and exposed areas for collection of solar energy are limited

Burchell and Listokin (1982, pp. 11-15) have discussed the urban energy advantage and believed that cities are more energy efficient for the following reasons: (a) the urban building stock, because of its density and compactness, consumes less energy; (b) cities benefit from advantageous transportation and commutation characteristics; (c) cities can easily capitalise from emerging more efficient energy systems; and (d) high density and mixing of land uses may contribute to better efficiency. Compact development patterns can reduce infrastructure demands and the need to travel by car. As population density increases, transportation options multiply and dependence on private cars lessens. Though vehicles operate less fuel-efficiently in congested areas, per capita fuel consumption is much lower in densely populated areas because people drive so much less. Tong and Wong (1997) have studied the advantages of a high density, mixed land use, linear urban development in Hong Kong and concluded that high accessibility enjoyed by residents, few roads and commercially viable public transport are the major merits.

Urban density is a major factor that determines the urban ventilation conditions, as well as the urban temperature (Givoni, 1998). Under given circumstances, an urban area with a high density of buildings can experience poor ventilation and strong 'heat island' effect. In warm-humid regions these features would lead to a high level of thermal stress of the inhabitants and, in air conditioned buildings, to increased use of energy. However, it is also possible that a high density urban area, obtained by a mixture of high and low buildings, could have better ventilation conditions than an area with lower density but with buildings of the same height. The use of natural lighting, natural ventilation, and solar energy is also affected by closely spaced or high rise buildings. If not properly planned, energy for electric lighting and mechanical cooling/ventilation may be increased and application of solar energy systems will be greatly limited.

All in all, denser city models require more careful design in order to maximise energy efficiency and satisfies other social and developmental requirements. Low energy design should not be considered in isolation, and in fact, it is a measure which should work in harmony with other environmental objectives. Building energy study provides opportunities not only for identifying energy and cost savings, but also for examining indoor and outdoor environment. As the quality of living and built environment is becoming a critical issue in many urban areas, it is useful to investigate low energy design and evaluate it against the social and environmental objectives.

From psychological and sociological points of view, high population density and the effect of crowding are interesting topics which have attracted much attention. A crowded and stressful urban environment may have unhealthy effects on the occupants, such as air pollution and noise problems. But the level of mobility and traffic speeds will benefit the working and living of the people. It should be noted that 'density' and 'crowding' are not necessarily found together. People who live under crowded conditions may not suffer from being crowded if the built environment has been designed to provide enough personal space and functional open space.

HONG KONG'S URBAN ENVIRONMENT

Hong Kong is a highly developed city with a subtropical climate and an extremely high population density. In the end of 1999, it has a population of 6.97 millions and an area of only 1,097 square kilometres (a population density of 6,360 people/sq.km). The geography of Hong Kong is hilly, with several high peaks; consequently agricultural land or indeed any flat land is scarce. Discounting such areas as country parks, conservation areas, water catchment areas, outlying islands, uplands, steep slopes and military land, the developable areas are limited. Figure 1 shows the densely populated areas in Hong Kong. Hong Kong's urban environment has an extremely high development density pervasively filled by buildings and roads. Population concentrates in the central urban areas surrounding the inner (Victoria) harbour and in some new towns. The most densely populated district, Kwun Tong, has a density of over 54,670 people/sq.km; some residential areas may even have over 100,000 people/sq.km.

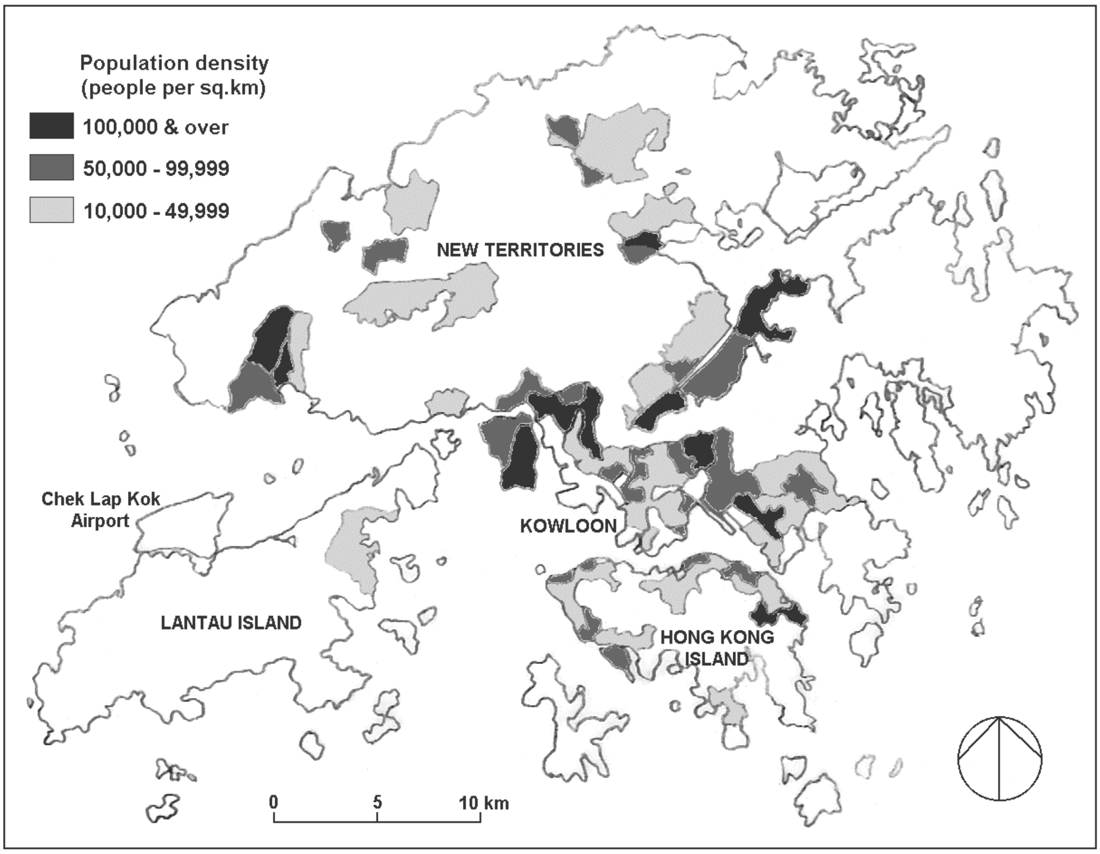

Figure 1. Densely populated areas in Hong Kong

Lam (2000) has described the urban morphology of Hong Kong. Older areas in Hong Kong show a fairly consistent street and block pattern, with building plots about 4-6 m wide and 10-12 m long. There is normally a narrow service lane about 2 m wide between the two rows of buildings that make up a block. Therefore, building blocks are between 20 and 30 m in width. Both the Hong Kong Island and Kowloon Peninsula are ordered by the harbour. On the Hong Kong Island, the principal streets run from east to west, parallel with the harbour; secondary streets run uphill from the harbour front, so the building blocks here are normally oriented east to west. The urban area stretches along the waterfront, some six to eight blocks deep, avoiding for the most part, the steep hillsides behind. Figure 2 shows the high rise cityscape of the Hong Kong Island.

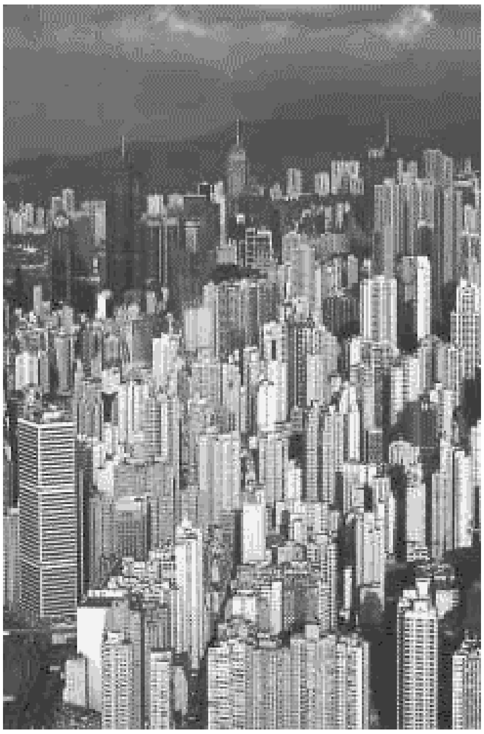

Figure 2. High rise cityscape of Hong Kong (north of Hong Kong Island)

The density of building development in Hong Kong is controlled through 'plot ratio' which is the ratio between the gross floor area (GFA) of a building and the area of the building site (Planning Department, 1999). Plot ratio controls govern the amount of GFA in buildings but affect population density only indirectly due to the interplay of other factors like, flat size and person per flat ratio. The maximum plot ratios permissible in Hong Kong, ranging from 0.5 to 10, are set out in the Building (Planning) Regulations. Actual densities are also affected by the outline zoning plans, airport height restrictions (indirectly), land lease conditions, and other town planning requirements. Figure 3 shows the Eastern District of the Hong Kong Island which has a maximum plot ratio of 8 to 10. High rise buildings, typically 20 to 40 storeys, are commonly found in this area.

Figure 3. Eastern District of the Hong Kong Island (maximum plot ratio 8 to 10)

Other urban settings can also be found in Hong Kong. Figures 4 and 5 shows the medium rise private housing in Hung Hom, close to the old Kai Tak Airport. The planning controls and building height restriction due to the flight path of the old Kai Tak Airport (it has been waived now) have prevented some parts of Kowloon from having very high rise buildings. The high density development under such a condition presents different constraints and requirements. In order to achieve better energy efficiency in buildings, the site characteristics, inter-relationships among the buildings, and the design of energy systems should be evaluated carefully. The layout of buildings should be designed so that good ventilation conditions can be maintained.

Figure 4. Medium-rise private housing (Hung Hom)

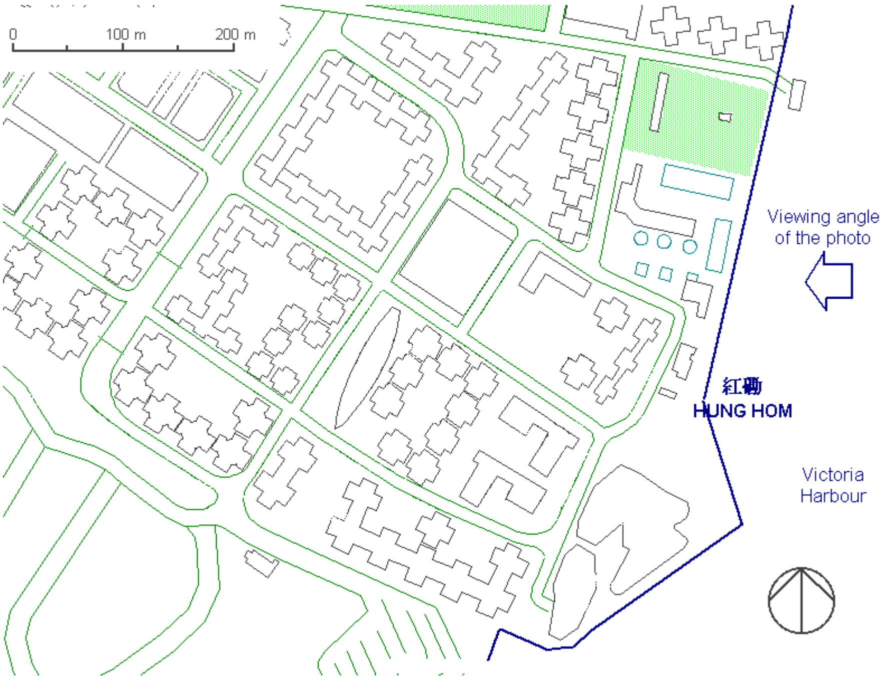

Figure 5. Building layout of the medium-rise private housing (Hung Hom)

The urban settings form an important background of the building development and will affect the potential and measures of low energy building design. It can be seen from Figures 2, 3 and 4 that there is a variety of urban forms in Hong Kong. The older areas have more planning restraints and contain a mixture of architectural expression. Lack of an overall coordination for urban and building design makes low energy consideration difficult since building development or redevelopment in these areas is usually carried out in a piecemeal manner. On the other hand, the new reclaimed land and new towns may allow design and coordination of urban functions. Criteria for better environment and efficient construction have been taken into account, but the objective to achieve low energy buildings has seldom been thoroughly considered and implemented in Hong Kong.

ENERGY SITUATION IN HONG KONG

The energy situation in Hong Kong is explained to develop a better understanding of the building energy use and policies. Hong Kong has no indigenous fuel resources and imports all its fuels for energy generation (including coal, oil, and natural gas). Electricity and town gas are the major forms of energy supply in buildings. The Hong Kong Government has a fundamental economic policy of minimum interference in the business sector – the laissez-faire policy. Market forces determine allocation of resources and the Government intervenes only when there are over-riding social considerations. The private energy companies supply energy of all forms to meet market requirements and regulation of the energy sector is relatively light-handed.

In the 1980s and early 1990s, Hong Kong has undergone an economic transformation from a manufacturing to a servicing center, energy use by the manufacturing sector was declining and building-related energy consumption was increasing steadily. Figure 6 shows the sectoral breakdown of end-use energy in Hong Kong for 1984-95 (EMSD, 1999). Nowadays, energy use in buildings represents a major portion of the community's energy demand, especially for electricity. In 1997, the building sector (commercial and residential) accounts for 84% of electricity consumption and over 40% of final energy requirements (CSD, 1990-99). The transport sector, which constitutes one third of the total end-use energy, is also affected indirectly by urban and building design.

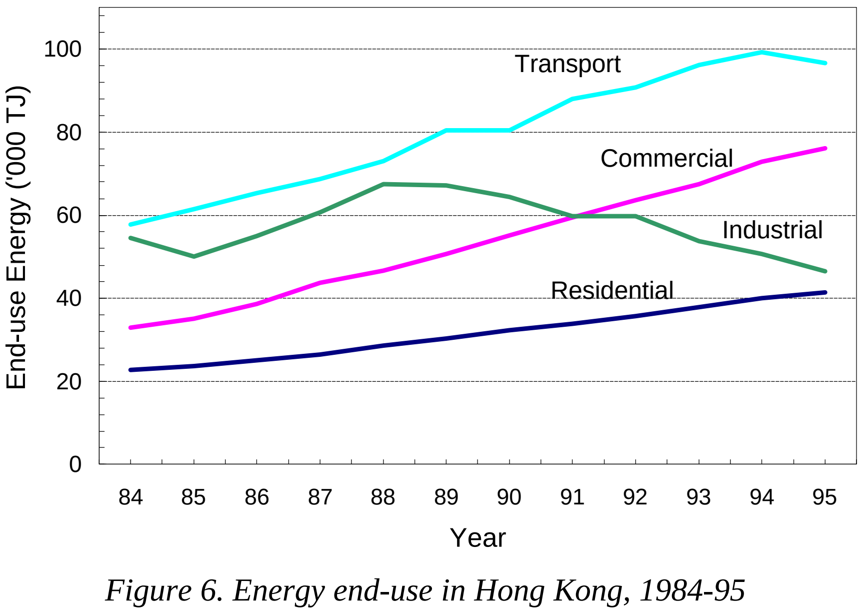

Figure 6. Energy end-use in Hong Kong, 1984-95

Analyses of the components of commercial and residential energy end-use in Hong Kong are shown in Figures 7 and 8, respectively. The commercial sector includes office buildings, retails, hotels, and restaurants; the residential include both public and private housing. It can be seen that 'space conditioning' (mainly air-conditioning) is the most important energy consuming component in both sectors. Other important components include lighting, cooking, and hot water services. Understanding of the energy demand and load components will help determine effective strategies for low energy design.

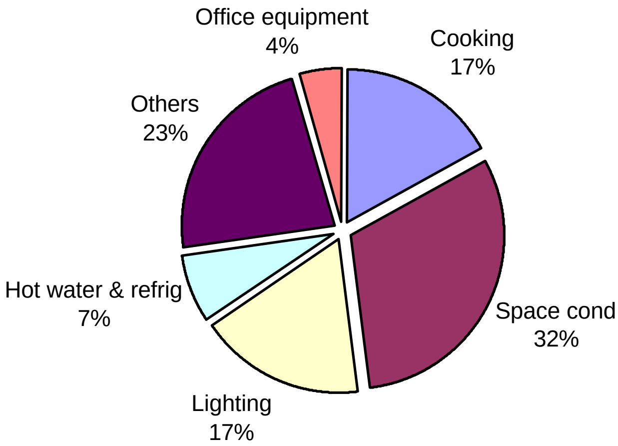

Figure 7. Components of commercial energy end-use in Hong Kong, 1995

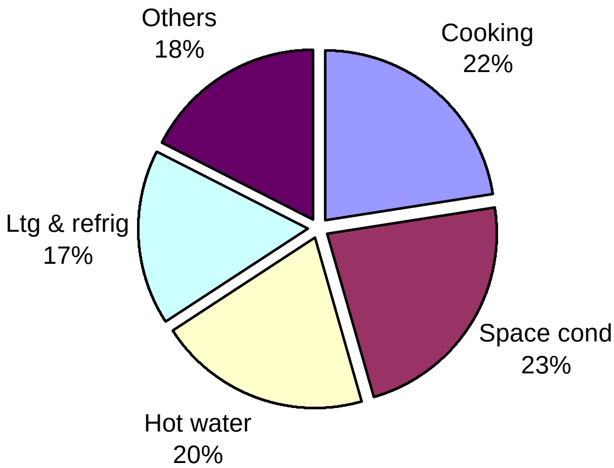

Figure 8. Components of residential energy end-use in Hong Kong, 1995

The energy consumption per capita in Hong Kong has been increasing in the past decades because of rise of living standard and change in economic activities. It is believed that the potential for energy saving in buildings is large in Hong Kong (Hui, 1999). However, various constraints and institutional barriers Kong have prevented the more efficient use of energy at present. Major factors include low environmental awareness of people, fast track building development, low energy price, division of interests between developers and tenants, shortterm investment outlook, institutional barriers, and competitiveness of the energy market. Both technical and non-technical factors are present and they will determine how far low energy design can go. With growing concern about energy and the environment, it is envisaged that low energy design will become more and more important in Hong Kong. Methods to improve energy efficiency in building for high density conditions are needed.

DISCUSSIONS

There is no single, simple formula for achieving low energy buildings. The basic principle is to minimise energy demand and to optimise energy supply through a greater reliance on local and renewable resources. Cities need to take a close look at how to make more efficient use of resources while fulfilling the needs of the people. An energy dimension should be included in the development process to measure the sustainability of urban and building design and growth planning models. Previous experience in public transport systems indicates that density is conducive to profitability and efficiency (Tong and Wong, 1997). A compact urban form with vertical zoning through multi-level and multi-functional urban clusters may be an efficient option for high density living.

Table 3 gives a summary of the major considerations for low energy building. There are opportunities for high density cities like Hong Kong to explore and develop effective energy technologies which can take full advantage of the concentrated loads and high rise context, such as by using district energy systems and vertical landscapes. Designing and constructing low energy buildings require the design team to follow an energy design process that considers how the building envelope and systems work together (Torcellini, Sheila and Judkoff, 1999). As low energy design is becoming more and more complicated, there is a need to develop analytical methods and skills, such as simulation and modelling techniques (Clarke, *et al.*, 1998), for the evaluation of energy performance of buildings and the analysis of design options and approaches.

Table 3. Major considerations for low energy building

1. *Efficient use of energy* - climate responsiveness of buildings - good urban planning and architectural design - good house keeping and design practices - passive design and natural ventilation - use landscape as a means of thermal control - energy efficient lighting - energy efficient air-conditioning - energy efficient household and office appliances - heat pumps and energy recovery equipment - combined heat and power systems - district cooling systems - fuel cells development
2. *Utilize renewable energy* - photovoltaics - wind energy - small hydros - waste-to-energy - landfil gas - biomass energy - biofuels
3. *Reduce transport energy* - reduce the need to travel - reduce the level of car reliance - promote walking and cycling - use efficient public mass transit - alternative sources of energy and fuels
4. *Increase awareness* - promote awareness and education - encourage good practices and environmentally sound technologies - overcome institutional and economic barriers - stimulate energy efficiency and renewable energy markets

Kausch (1998) pointed out that low energy building design is compatible with a wide range of architectural styles. Studio Nicoletti (1998) also illustrated the methods of architectural expression for low energy buildings in their projects. For high density conditions, some of their methods are still valid but adaptation or modification may be needed to satisfy the local requirements. Climate considerations is a key element and starting point for formulating building and urban design principles that aim at minimising the use of energy for environmental control. In densely populated areas, analysis of the climatic and solar conditions is critical for the design optimisation. It should be noted that in urban areas, the group of buildings will in fact modify the climatic conditions surrounding it.

Measures to maximize the use of high-efficiency generation plants and on-site renewable energy resources are important for raising the overall level of energy efficiency. For renewable energy systems, energy storage is still the major technical constraint to their applications (Lund, 1994). Loads concentration in high density cities might provide an opportunity for better utilisation of renewable energy systems. At present, Hong Kong does not make significant use of renewable resources to meet its energy needs (Hui, 2000). Lack of incentives and shortage of land and space are the key factors limiting the deployment of renewable energy systems. High rise buildings and high population density make it difficult to find suitable locations for solar collectors and equipment. As the demand for heating energy is relatively low in many buildings because of the warm climate throughout the year, the economic advantage of directly using solar heat is weakened. To promote renewables, it is necessary to create new development patterns and shift from a centralised view of energy sector to a regional perspective (Sarafidis, et al., 1999). Since Hong Kong is interconnected with the mainland China, if Hong Kong could develop renewables and collaborate with southern China (such as Guangdong) which has abundant renewable energy resources and land, then the cross-boundary cooperation could bring about greater benefits to both sides (Hui and Cheung, 1998).

One important aspect often being overlooked is the raising of awareness and the education about low energy design. More efforts are needed to educate the people and establish the culture so that more people would accept and consider low energy buildings an important element of their living and working environment. Bear in mind the social and economic conditions of Hong Kong, it is important to recognise that solutions to the energy problems are not simply a matter of applying technology and enforcement through legislation. It requires public awareness and participation as well. Therefore, measures to promote public awareness and education are crucial for the implementation of energy efficiency and renewable energy policies.

CONCLUSION

Many cities around the world are facing the problem of increasing urban density and energy demand. As cities represent a significant source of growth in global energy demand, their energy use, associated environmental impacts, and demand for transport services create great pressure to our planet. Low energy design of urban environment and buildings in densely populated areas requires consideration of a wide range of factors, including urban setting, transport planning, energy system design, and architectural and engineering details. It is found that densification of cities could have both positive and negative effects on total energy demand. With suitable urban and building design details, population should and could be accommodated with minimum worsening of the environmental quality.

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