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Opportunities for low carbon sustainability in large commercial buildings in China

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ABSTRACT

China's building sector consumes one quarter of total energy consumption in the country and plays an important role in long-term ability of the country to achieve sustainable development. This paper discusses a comprehensive approach to achieving low carbon sustainability in large commercial buildings in China incorporating both energy and carbon-reduction strategies. The approach concentrates primarily on three complementary aspects: (a) the introduction of an effective energy management system; (b) the incorporation of relevant advanced energy saving technologies and measures and (c) the promotion of awareness among occupants to make changes in their behaviour towards a more environmental-friendly behaviour. However, reference is also made to the role that renewable energy and offsetting may have in the effective management and environmental performance of buildings.

Nine examples of large commercial buildings in Beijing and Shanghai were studied and the average electricity consumption of around 153 kWh/m^2 per annum is about 5 times higher than average electricity use in residential buildings. At the same time the associated green house gas (GHG) emissions are around 158 kg/m^2 per annum.

1. Introduction

With an annual GDP growth in excess of 10% in recent years, China has become one of the largest energy consumers and green house gas (GHG) emitters in the world. As well as the need to reduce GHG emissions it is also facing both internal and external pressures with regard to energy security and environmental protection issues. In 2007, China's primary energy consumption was 2354.45 million tonnes of standard coal equivalent (or 19,168 TWh) (National Bureau of Statistics, 2008) and since 2000 the energy consumption has been rising at 8.98% per annum (Fig. 1, Table 1). This increase is at a lower rate than the rise in GDP so that the energy ratio (i.e. the energy requirements per unit of GDP) is improving at 4.47%. Table 1 also shows equivalent data from the UK (as derived from DUKES, 2008) as a comparison. It is noteworthy that despite the fact that the energy ratio improvement in China is much higher than in the UK, the absolute value of the ratio at 7.7 kWh/£ is still 3.5 times higher than in the UK.

China's building sector consumes one quarter of the total energy in the country (Fig. 2) and with an estimated total area of over 50 billion m^2 the annual energy use is around 6700 TWh (Jiang et al., 2007). This energy consumption includes the direct energy use in maintaining thermal comfort and normal operation and indirect embedded energy use associated with the construction of the building and including the material manufacture and transport of those materials to site. With a high growth in energy consumption in recent years (Fig. 2a), this sector plays an important role in China's long-term sustainable development strategy.

The two largest cities of Beijing and Shanghai, with populations of 17 million and 18 million, respectively, not only have the largest number of commercial buildings but also the highest growth rate in this sector. In both cities, the energy use in non-residential buildings is significantly higher than in residential buildings, particularly in those buildings classed as large buildings (i.e. over 20,000 m^2 is area) which include hotels, office buildings and shopping malls. To achieve overall energy conservation and carbon reduction within the building sector, priority must thus be given to this type of building. In addition, energy security and environmental protection are two other serious issues now facing China and there is no doubt that the building sector will play an important role in China's long-term ability to achieve sustainable development.

For example, in 2007, while energy use in urban buildings was double the level of consumption during the 1990s, this is predicted to rise significantly by 2020 (Jiang et al., 2007). Qiu (2007) developed a methodology to estimate the total energy

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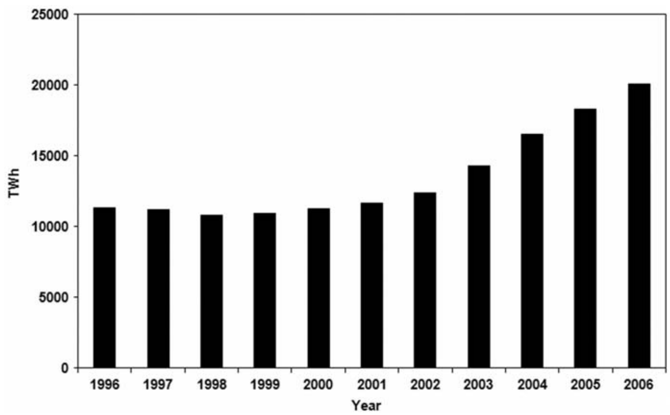

Fig. 1. Primary energy consumption in China (National Bureau of Statistics, 2007).

Table 1
Energy consumption and GDP data for China and UK.

	China			UK		
	Primary energy (TWh)	GDP (£billion)	Energy ratio (kWh/£)	Primary energy (TWh)	GDP (£billion)	Energy ratio (kWh/£)
1978	5110	36	140.2	2485	628	4.0
2000	10,500	992	10.6	2789	1042	2.7
2007	19,168	2495	7.7	2687	1247	2.2
Change 1978–2007 (%)	4.66	15.69	−9.53	0.27	2.40	−2.08
Change 2000–2007 (%)	8.98	14.08	−4.47	−0.53	2.60	−3.06

Chinese data were derived from the National Bureau of Statistics (2008), while those from UK were derived from Dukes (2008). For comparison an exchange rate of £1 = 10 RMB was assumed.

consumption in buildings using data up to 2003. In this method, he extracted data from the relevant National Statistical Yearbook to determine the total energy consumption in the building sector (E) using the following relationship:

$$E = e_f + e_c + e_r + e_p + e_d \quad (1)$$

where e_f is the energy associated with the supply of fuel to buildings, e_c the energy used in the construction industry, most of which is associated with buildings, e_r the energy used in retail and commercial premises, e_p the energy use in other buildings (mostly public buildings and administration) and e_d the energy used in the domestic sector.

This methodology of Qiu (2007) gives the energy consumption in buildings as 27.09% of the total energy consumption in China for 2003 compared to 27.45% in 2000. Sun and Li (2005) used the figure for 2000 and noted that this figure had risen from 15% in 1992. On this basis, they projected that by 2020 the percentage would rise further to over 40%. However questions must be raised on the validity of this estimate. The present authors have used the methodology of Qiu (2007) and the latest data from the National Bureau of Statistics (2008) to extend the data range of Qiu (2007) and estimate a percentage of 25.01% in 2007 (Fig. 2). The current trend is thus moving away from the projections of Sun and Li.

Urban buildings cover 40% of total area of all buildings but account for almost 90% of the total energy use in buildings in China (Jiang et al., 2007). With much of this energy supplied from electricity and with the high carbon factor for electricity generation in China, this energy consumption is associated with an annual carbon emission of over one billion tonnes of CO_2 equivalent (CO_2e) (Jiang, 2009). Noteworthy is the fact that energy use per square metre in the non-residential sector as a whole (i.e. including both small and large commercial buildings) is over 3 times that in the residential sector in both cities (Table 2).

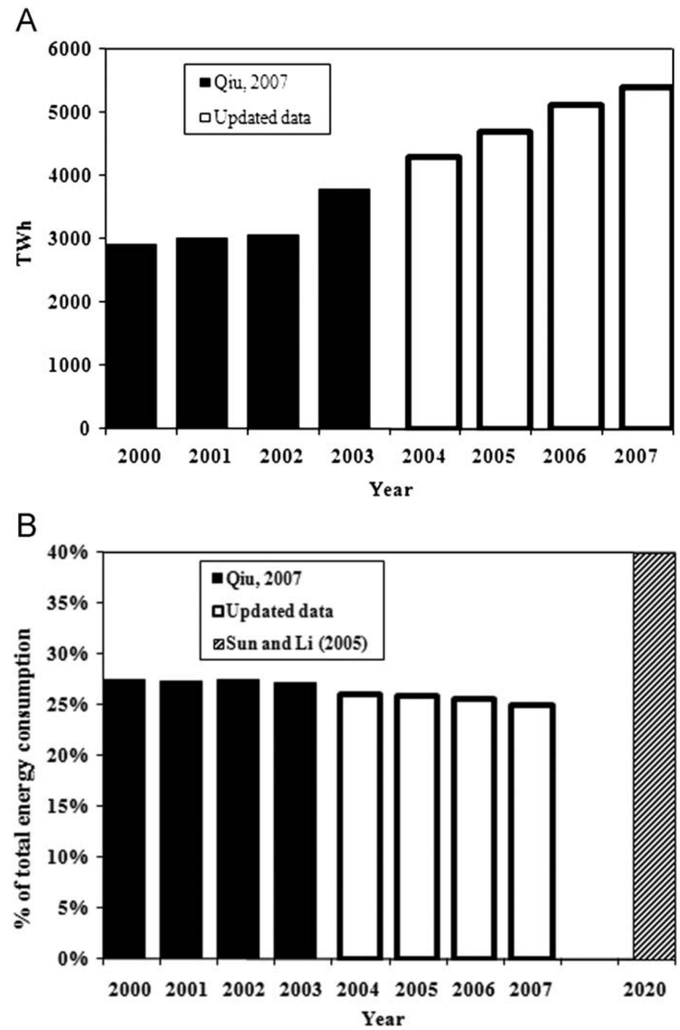

Fig. 2. Energy consumption in the building sector in China. (A) Direct energy consumption, (B) percentage to total energy consumption in China. Data from Qiu (2007) and Sun and Li (2005). Updated data derived from National Bureau of Statistics (2008) using the methodology of Qiu (2007).

Table 2
Data relating to buildings in Beijing and Shanghai (National Bureau of Statistics, 2007; Shanghai Statistical Bureau, 2007 and Shanghai Statistical Bureau, 2007).

	Beijing (2006)	Shanghai (2006)
Total building area	543 million m^2	703 million m^2
Total non-residential building area	232 million m^2	294 million m^2
% of area classed as non -residential	43%	42%
Consumption of energy in non -residential buildings as a percentage of whole sector.	72%	~70%
Consumption of energy in residential buildings as a percentage of whole sector.	28%	~30%
Ratio of energy consumption in non residential buildings to residential buildings	3.41	3.22

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2. Energy consumption and CO_2 emissions in non-residential buildings in China

In the last few decades, many large modern skyscraper buildings have been built in the large cities in China. Frequently these incorporate extensive curtain glass walls, have nearly constant internal temperatures, 24-h artificial lighting and extensive lift systems. In the current era when environmental issues are becoming more prominent the classification of such buildings as "modern" can be challenged. Even today, stunning external or internal architecture is seen as "modern" but with pressures on natural resources and concern over global warming, such icons of the first decade of the 21st century may soon be seen as old fashioned and "modern" buildings will be seen as those which are environmentally friendly, use less energy and minimise carbon emissions. There have been notable so-called "low-energy" buildings completed in the last few years many such as the so-called low-energy building at Tsinghua University in Beijing (Jiang, 2003). This building appears to be more of an architectural statement and of questionable low-energy credentials as significant overheating issues appear to be the norm in summer requiring additional cooling. In the UK, many low-energy buildings have also been shown to have little benefit over traditional buildings, although there are some notable exceptions such as the low-energy buildings at the University of East Anglia (Tovey and Turner, 2006).

2.1. Energy use and carbon emissions in large commercial buildings

In 2006, the total area of large commercial buildings was around 24 million m^2 in Beijing, i.e. about 5% of the total building stock. Despite this relatively small proportion of the electricity consumption in these buildings was over 4 TWh representing 12% of the total electricity consumption in the whole building stock in Beijing (Fig. 3) (derived from data in Beijing Statistical Bureau, 2007). This information is displayed in Fig. 3 and indicates that the electricity consumption in large commercial buildings per unit area was about 5 times that in residential buildings and over 1.5 times that in other non-residential buildings in 2006. Qiu (2007) also noted that the energy consumption was 70–300 kWh/m^2 per annum in large commercial buildings in Chinese cities.

As part of the research reported in this paper, nine large commercial buildings (five in Beijing and four in Shanghai) were selected for analysis of the energy performance during 2006 (Fig. 4). The average electricity consumption in these buildings was 173 kWh/m^2 per annum and 132 kWh/m^2 per annum in Beijing and Shanghai, respectively. These consumption figures were nearly 6 times the consumption rate in residential buildings in Beijing (at around 30 kWh/m^2 per annum, Beijing Statistical Bureau, 2007) and 4 times the rate in residential buildings in Shanghai (at around 32 kWh/m^2 per annum, Shanghai Statistical Bureau, 2007).

Within the nine buildings the electricity consumption per square metre varies by a factor of 350%. In some of these buildings, electricity is the sole fuel providing for both heating and cooling, but as there is natural gas in both cities and centralised hot water provision in certain districts, some buildings will not need electricity for space heating in winter and will thus have proportionally lower electricity requirements. If the consumption of centralised hot water, natural gas, liquid petroleum gas (LPG) and coal gas for heating and cooking is also considered the average total energy use in large commercial buildings in both Beijing and Shanghai will be higher.

The carbon emission factor for electricity generation varies significantly depending on the fuel mix used in the generating plant and also the thermal efficiency of those plants. In Norway the emission factor is as low as 2 gm/kWh, in France around 70 gm/kWh and in the UK around 540 gm/kWh. These data were derived by the authors from raw data extracted from the International Energy Agency (IEA, 2008), the methodology of which will be reported in the forthcoming thesis (Jiang, 2009). In China data obtained from the National Development and Reform Commission of China (2008) show a variation in emission factor across the country and average close to 1000 gm/kWh (Table 3). These figures reflect the very high hydro-electricity component in Norway, the high nuclear component in France, a typical average mix in the UK, and a predominantly coal-fired generation in China. Within China the emission factor does vary as some regions have a relatively high hydro-electric component.

A consequence of this variation in emission factors is that in summer the air-conditioning requirements for a building in

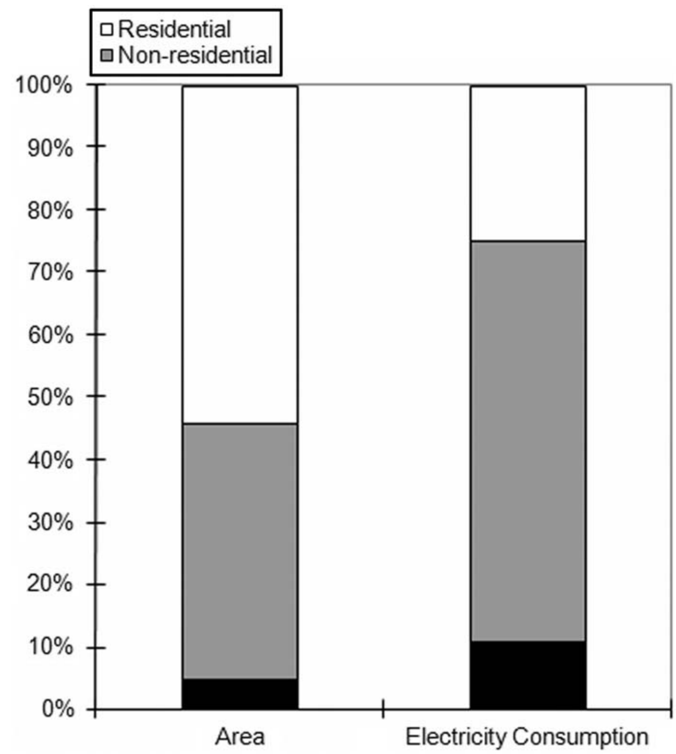

Fig. 3. Electricity use in non-residential and large commercial buildings in Beijing in 2006 (derived from Jiang et al., 2007; Beijing Statistical Bureau, 2007).

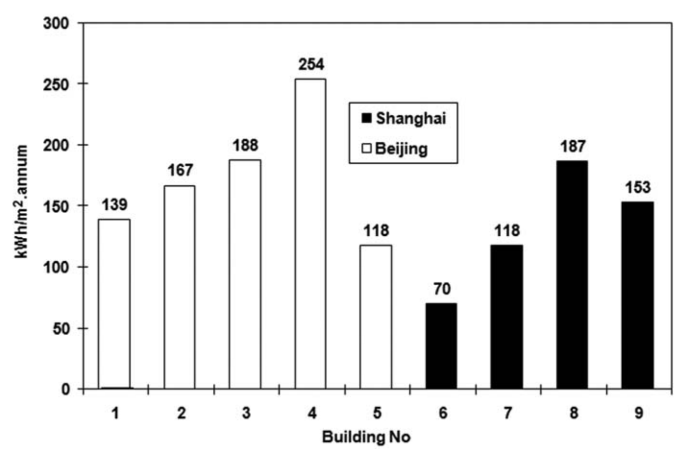

Fig. 4. Electricity consumption in sample buildings in 2006 (Jiang, 2009).

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Table 3
Carbon dioxide factors for electricity generation in different regions in China in 2008 (National Development and Reform Commission of China, 2008).

Electricity grid	Emission factor ($kgCO_2e/kWh$)
North China Grid (for Beijing)	1.030
East China Grid (for Shanghai)	0.905
Middle China Grid	0.997
Northeast China Grid	1.025
Northwest China Grid	0.877
South China Grid	0.879
Hainan Province Grid	0.829

Beijing will emit 13.8% more CO_2 than an identical building in Shanghai when the external temperature is the same. Allowing for these differing emission factors the electricity consumption leads to an average CO_2 emission in large commercial buildings of 178 kg CO_2/m^2 per annum in Beijing's sample buildings and 138 kg CO_2/m^2 per annum in Shanghai's sample buildings. When other energy sources (such as natural gas, LPG, coal gas and centralised hot water) used for heating in large commercial buildings are included the total average energy consumption in such buildings rises from an average of 155 kWh/m^2/annum for electricity alone to around 200 kWh/m^2/annum. At the same time, the average CO_2 emission levels will be higher than the figures quoted above, but as a precise split of heating from all these supplementary sources is generally not available and it is not possible at this stage to give a definitive figure.

2.2. Current standards relating to carbon sustainable development in large commercial buildings

Since 1986, China's Ministry of Construction has issued six design standards relating to energy conservation and in July 2005, the Public Buildings Energy-efficient Design Standards GB50189-2005 came into force (Chinese Construction Ministry, 2005). The current standards require that all new and refurbished public and commercial buildings should reach a 50% reduction in energy use compared to the benchmark of energy use in similar buildings built in the 1980s. The Chinese Construction Ministry has more recently been renamed as the Ministry of Housing and Urban and Rural Development (MOHURD). Although new legislation relating to energy use in buildings was enacted on 1st October, 2008 (MOHURD, 2008) this is in very general terms. The specific requirements relevant to large commercial buildings which are the subject of this paper are still covered in GB50189-2005. However, regional governments may modify these to take account of local conditions. Thus, the Beijing and Shanghai regional governments issued their own energy saving design standards in 2005 (Beijing Construction Bureau, 2005; Shanghai Government, 2005). The energy saving objectives are set at a tougher level than the national standard requiring a 65% reduction in Beijing. In Shanghai the standard largely follows accepted the 50% reduction of the national standard. As a result of these standards, many energy-efficient measures have been adopted in the large commercial buildings in both cities such as improving the insulation of walls and roofs, using low-energy lighting system and green appliances, etc. Indeed some modern hotels in both cities now have double glazing, something which was quite rare just a few years ago. Despite this and annual temperature variations above those in the UK, there are still new buildings which have been built in the last year or two which do not have double glazing (such as buildings on the new Fudan campus). This is despite the fact that the insulation value of single glazing would appear not to meet the required 2005 standards. While sensible policies may now be in place there would appear to be a lack of adequate building control to ensure that the required standards are met in practice. It is to be hoped that Articles XIII–XVII of MOHURD (2008) which relate to supervision and control will help in this matter.

According to the Youth Daily Newspaper of 8th November, 2008 (Shanghai Youth Daily, 2008), gas prices which were 2.10 RMB per cubic meter or 0.19 RMB per kWh (£0.21/m^3 or £0.19/kWh) were shortly to go up by 20% to 2.50 RMB/m^3 or £0.23/kWh (£0.25/m^3 or £0.023/kWh). This compares with an average prices in mid-2008 in the UK for medium to large non-domestic premises of £0.0215/kWh in the UK (DECC, 2008). Electricity prices are also increasing. In 2008, in Beijing and Shanghai, the average price for commercial buildings was 0.76 RMB/kWh (£0.076/kWh) and 0.67 RMB/kWh (£0.067/kWh), respectively, (Beijing Municipal Commission of Development and Reform, 2009; Shanghai Municipal Commission of Development and Reform, 2008). These prices are very comparable with an average figure of £0.073/kWh in the UK (DECC, 2008). Different regions in China have different energy prices and the energy price tends to be fixed by the local governments and not based on the market forces. The ever increasing energy price has provided a driver towards energy conservation in the large commercial building sector. Stakeholders, energy managers and occupants who own, manage and occupy the buildings are becoming more influenced directly by the energy price rises, providing an incentive to reduce energy use and consequently reduce the impact of energy price rises and at the same time reduce carbon emissions.

There can be no doubt that the Chinese Government's policies could accelerate the energy saving activities in large commercial buildings. For example, The Comprehensive Energy Reduction Programme under The "Eleventh Five-Year Plan" (State Council of the People's Republic of China, 2007) was issued in 2007, with its core objective to reduce the per capita energy consumption density per GDP unit by 20% by 2010. However, these targets may well be missed if there is inadequate control of building construction and effective management of energy use once the buildings are occupied. More recently the Chinese National Climate Change Programme (CNCCP) was issued in June 2007 (National Development and Reform Commission of China, 2007). This outlines the objectives, basic principles, key areas of actions, as well as policies and measures to address and mitigate climate change for the period up to 2010.

2.3. Barriers to low carbon sustainability in large commercial buildings in Beijing and Shanghai

With the current energy use in large commercial buildings being much higher than in other buildings and also having a much higher annual growth rate of 26.5% compared to 12.5% in other buildings (Qiu, 2007; National Bureau of Statistics, 2007), this makes the implementation of relevant policies incorporating enhanced regulations and standards even more imperative. However, even with this objective, the majority of such buildings fall outside the scope of the new regulations for the following reasons:

- According to reports from Tsinghua University (Jiang et al., 2007) and the National Bureau of Statistics (2007), approximately 80% of large commercial buildings in Beijing and Shanghai were built before 2005 and do not reach the current national or local energy saving standards and energy use in these buildings is thus proportionally higher than new and refurbished buildings.
- A lack of adequate building control to ensure that the regulatory standards are actually met in new buildings.

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- Limited use of effective monitoring and adaptive energy management strategies.
- A lack of awareness of access to energy saving and environmental protection measures as witnessed in the sample buildings in both cities. In the study conducted as part of this research, it was found that 70% of stakeholders, energy managers and occupants in those buildings have little or no knowledge of potential energy saving measures that could be achieved through either effective energy management or changes towards environmentally friendly behaviour (Jiang, 2009).
- A lack of drivers to promote low carbon sustainability, particularly in the form of financial drivers. The relatively low historic cost of energy compared with other business operational costs means that stakeholders have few incentives to promote energy conservation, although the recent rise in gas tariffs in Shanghai may help here.
- A lack of energy saving objectives at either the corporate or individual level. Of those surveyed 80% had not set up an overall energy saving goal details of which are reported in Jiang (2009).
- A perception that there are limited or no available resources in staffing or financial terms to implement energy saving activities, etc. Such a perception appears to arise from a lack of knowledge of how little some of the energy management approaches may cost and the true financial benefits of implementation.

All the above barriers increase the difficulty of implementing the energy saving and carbon-reduction activities. At the same time, the very high annual construction rate of new buildings in this sector coupled with ever increasing use of appliances in buildings makes the current energy consumption and consequential carbon emissions increasingly more serious. This rise in energy consumption is a consequence of the encouragement of the Chinese Government towards increased urbanisation of the Chinese population as part of the strategy of increasing the wealth of the population as a whole. This rise will be a particularly significant challenge to the long-term sustainable development of cities such as Beijing and Shanghai and in particular the building sector.

3. A low carbon sustainability strategy for large commercial buildings in Beijing and Shanghai

In order to achieve a reduction in both energy consumption and CO_2 emissions a comprehensive and integrated low carbon sustainability strategy is required. This approach method should not only focus on technological aspects, but also address the vital role that effective management and behavioural change play in energy conservation, something which is usually neglected in China's building sector.

While there will always be legislative and regulatory issues initiated by governments, these are generally outside the realm of direct influence of corporate bodies or the individual. Outside these areas, there are five separate strategies which need to be considered in any effective low carbon sustainability strategy of buildings (see Fig. 5). Some of these require limited expense and are obvious strategies to adopt first:

1. promoting awareness among staff and occupants of large commercial buildings,
2. effective energy management which can identify at an early stage whether energy consumption is varying from expected norms,

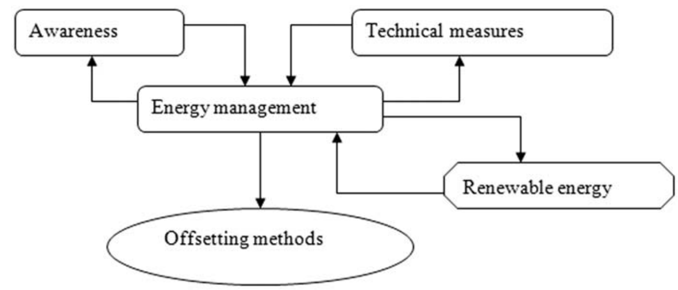

Fig. 5. Interaction of five separate strategies to the low carbon sustainability in the large commercial building sector in Beijing and Shanghai.

3. implementing technical changes to improve insulation or enhance control of energy use,
4. installation of renewable energy systems and
5. exploring use of offsetting measures to compensate any residual carbon emissions remaining after all the previous four strategies have been implemented.

From a financial point of view, items 1 and 2 above are likely to be the most cost-effective. Offsetting emissions as under item 5 may or may not be more cost effective than items 3 or 4 depending on the prevailing price of carbon. However, for effective strategies, offsetting should be considered as the last option as questions can be raised on whether or not the offsetting funds relate to projects which meet the strict additionality criteria laid down by schemes such as the Clean Development Mechanism.

Critical within, and central to, this overall strategy is the importance of energy management which interacts with all other strategies. The five component parts of an integrated strategy as listed above are further discussed separately below.

3.1. Effective energy management

As shown in Fig. 5, effective energy management is critical in any overall strategy to reduce energy consumption. Through rational analysis of consumption data energy management can be used to monitor the performance of buildings following awareness campaigns and the installation of technical conservation measures or renewable energy generation. In turn, the results of analysis can then inform the improvements to be made in awareness campaigns and identify new technical strategies which should be implemented. Thus, at the University of East Anglia in the UK the energy demand in newly built low-energy buildings was reduced by a further 50% by adopting effective adaptive energy management strategies over the first 2 years of occupation using techniques of data analysis summarised furthur (Tovey and Turner, 2006).

With 80% of large commercial buildings in large cities in China built before the implementation of the current standards in 2005 (Jiang et al., 2007; National Bureau of Statistics, 2007), these buildings represent an important area to target climate change reduction strategies. Many effective management strategies involve relatively little additional cost or resources and thus are a less risky investment for investors and the companies themselves.

An effective energy management system should contain several key aspects, both technical and non-technical and address issues of governance and ownership. In particular, it should be supported at all levels within an organisation from the senior managers through the technical energy managers themselves to a core "Energy Champions" team and finally be accepted at the lowest levels of staff within the organisation. Such management systems should provide clear and comprehensive guidance on how to achieve a better energy performance across all operations in the building sector and staff involved. In many cases, systems can be established which require very limited resources and thus are very cost effective. At the other extreme, full building energy management systems may be implemented with sub-metering to enhance control of consumption although the latter may initially require a commitment of resources to develop. However, if monetary savings achieved by the more basic measures are "ring fenced", these savings can be used to finance more expensive measures in the future and in this way continual improvement at no additional cost can be achieved.

The role of energy performance data and information is crucial to all aspects of energy management and baseline data must be collected and analysed early in any energy management campaign. Key data requirements are:

- The regular recording of actual energy consumption through a robust system of energy meter readings. It is not sufficient to rely on bills from utility companies as often the date and time of the meter read are not recorded, and not infrequently there are estimated readings.
- All energy consumption data must be normalised to a standard period. Frequently, readings are not taken on precisely the same day or time each week or month, and the raw data should be normalised to the standard period.
- If there is good control, the heating and cooling energy consumption should be proportional to the external temperature and the relevant normalised consumption should be plotted against the corresponding number of degree–days (or mean external temperature) over the period.
- The data should show a linear relationship between consumption and degree–days (or mean external temperature) which in the heating season should indicate a declining consumption as the external temperature rises. If good control of the heating is in place, then the scatter of the data around the trend line should be relatively small, but a high degree of scatter is symptomatic of poor control.
- Once a baseline trend line has been established this can be used as the basis to track future energy consumption. If the consumption rises significantly above the trend line, this could be indicative of a malfunction of the heating or cooling equipment. Indeed, one of the authors reported a situation in an office block where an equipment malfunction had gone unnoticed for 9 months and had resulted in the unnecessary emission of nearly 100 tonnes of carbon dioxide and at the same time an increased energy cost of around £12,000 when the cost to repair the faulty equipment was probably around £1000 (Tovey et al., 2006).

An example of how electricity consumption data may be effectively plotted is shown as three examples in Fig. 6. The data in each example fall into two parts: those points referring to winter time consumption are represented by the line A–B while those points referring to summertime consumption, when cooling requirements are important, plot with a trend line B–C. The line B–C shows the expected trend as cooling requirements are linearly related to external temperature. In the case of Beijing (Fig. 6a and b), the buildings have heating provided by district heating and there is little difference in consumption from 1 month to the next during the winter period. The electricity consumption during these winter months thus defines the electricity use for lighting and appliances and will not be affected by the thermal performance of the buildings. In the Shanghai building (Fig. 6c), heating is provided electrically using the same air-conditioning heat pump systems as are used for cooling. In this example, the effect of external temperature on electricity demand is seen in both winter and summer.

The scatter of the data around the trend line during the cooling period (Fig. 6a) is moderately small (coefficient of correlation = 0.79) indicating that the management of heating is generally good. On the other hand, the data in Fig. 6b indicate that the management is poor (coefficient of correlation = 0.54). Fig. 6c indicates that the energy management is good in both cooling and heating modes (coefficients of correlation = 0.93 and 0.89, respectively).

The nearly constant electricity consumption at 118 MWh per month during the winter (Fig. 6a) is an indication that electrical use from lighting and appliances, etc. is likely to remain approximately constant throughout the whole year. Over the 5.5 months when cooling is required, the total electricity consumption is 845 MWh of which only 196 MWh (or 23%) is associated with cooling. In this building, it is apparent that measures to reduce energy consumption by using more efficient lighting and appliances will have a greater impact than measures to improve the thermal performance of the building.

In case of the building shown in Fig. 6b, the baseline consumption for appliances and lighting is around 1295 MWh per month, and during the months in which cooling is required, only 26% of the total electricity consumption is attributable to cooling reflecting a similar situation to the building shown represented by Fig. 6a.

Any changes in the energy efficiency of appliances or lighting used in either building should be manifest by the horizontal line A–B moving downwards. A measure of the efficiency improvements can be obtained by comparing the consumption defined by the horizontal line corresponding to the situation before the implementation with that afterwards. Such improvements in appliance efficiency will not change the general slope of the line B–C. On the other hand, improvements to the air-conditioning equipment or the insulation of the building will cause the gradient of the line B–C to decline without affecting the horizontal line A–B.

The Shanghai building has a baseline electricity consumption of approximately 395 MWh per month. Deducting this value from the actual consumption in each month provides an estimate of the electricity needed to control the thermal environment. Unlike the examples from Beijing, 46% of the annual electricity consumption in this building is associated with the provision of adequate heating and cooling. Measures to improve the thermal performance of this building will thus be more effective than the examples from Beijing.

The above approach for analysis of energy consumption data provides a robust baseline set of energy consumption data which can then be used to determine the most effective strategy for the future. More importantly, such analyses can help to track any changes whether they are simply awareness campaigns or the implementation of technical or management measures. They will also form the basis towards answering the following questions within an organisation:

- "What do we want to achieve through the management system?"
- "How are we going to achieve improved energy performance?"
- "Who will be responsible for ensuring strategies are implemented?"
- "What resources in terms of personnel and finance are required to implement the proposed management system?"
- "What additional training is required for staff?"

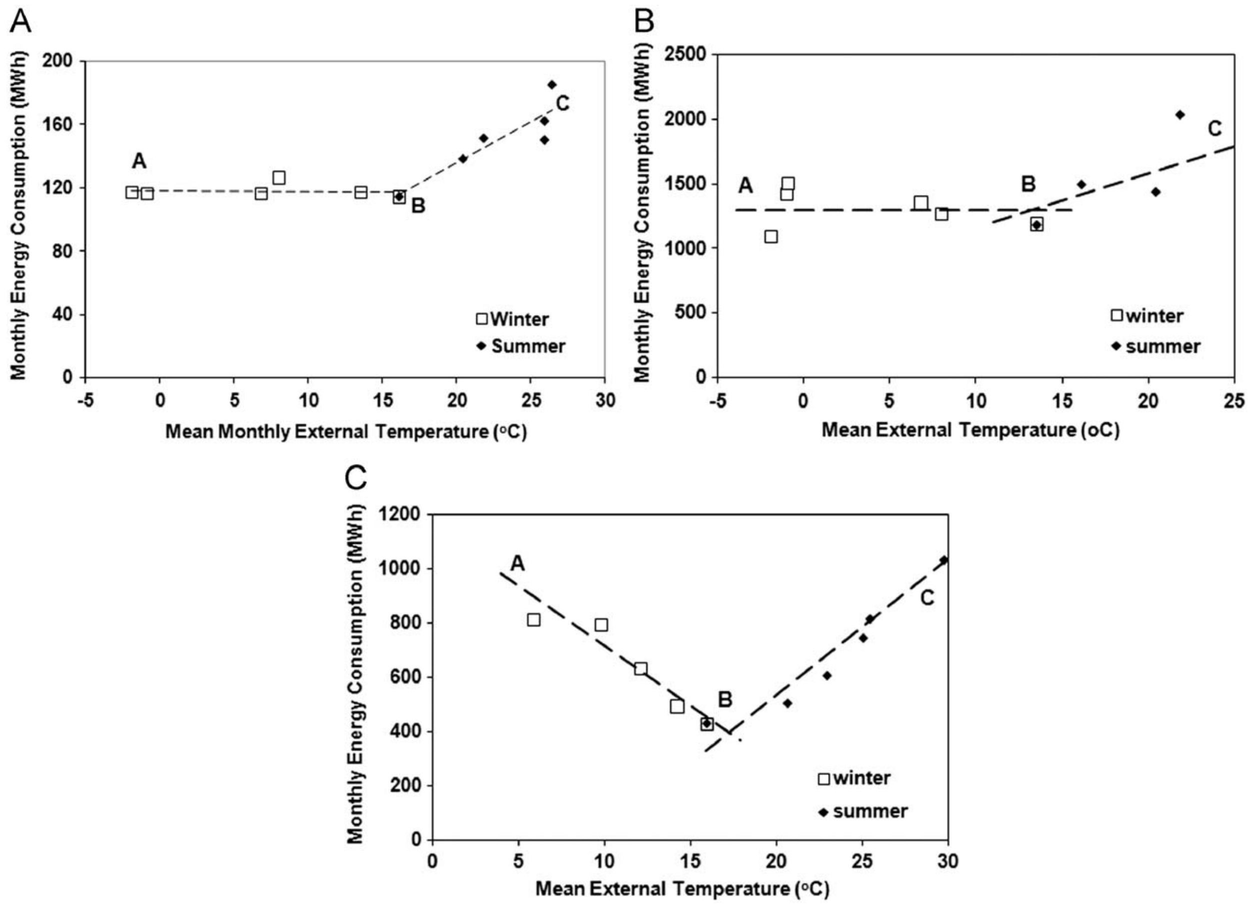

Fig. 6. Typical plots of electricity consumption against external temperature for large commercial buildings. (A) Beijing showing good management of cooling, (B) Beijing showing poor management of cooling and (C) Shanghai with electricity used for both heating and cooling (Jiang, 2009).

- "What savings are likely to be achieved?"
- "What enhanced reputation and other non-financial benefits might the company achieve through the proposed measures?"

Finally, the analysis strategy outlined also provides a means whereby the effectiveness of energy management within a building can be assessed. Where the scatter of data point on the plot of consumption against mean external temperature (or degree–days) is small, this is indicative of good energy management. A clear and well-described action plan should be made for the actual execution of any energy management system and this should address all the above questions. Many consulting companies in big cities in China now specialise in energy management in building stock and attempt to provide customers with professional advice. However, some of the basic monitoring strategies outlined above are frequently lacking and more effective guidance should be provided by government to promote energy management development in large commercial buildings.

3.2. Technical measures for energy conservation

Though some technical measures such an improved insulation has been incorporated into new large buildings to achieve energy conservation in Beijing and Shanghai, there are other technologies which have found limited application. Such technologies include combined heat and power (CHP) which when combined with adsorption chilling can provide a very cost-effective solution to integrated energy provision in existing buildings, and heat pumps which are more suitable for places in southern China where both heating and cooling are required. Other technical energy conservation measures are more appropriate when considering new buildings such as natural ventilation and natural lighting (Omer, 2008), although naturally ventilated buildings may often not be as effective at reducing energy requirements as those provided with effective mechanical ventilation. Thus, considerations of ventilation heat or cool recovery rarely seem to be used in China, nor are the issues relating to the benefits of thermal mass fully exploited even though both can provide effective solutions towards energy reduction. Indeed it was by more effective use of thermal mass and ventilation heat recovery that, following analysis of initial energy data in several recently constructed low-energy buildings, that the University of East Anglia in the UK was able to reduce energy consumption by an average of 50% over the first 2 years of operation (Tovey and Turner, 2006). For example, the total heating and hot water energy requirements for one building were reduced to just 35% of the level required in the equivalent naturally ventilated buildings (Turner, 2007).

3.3. Renewable energy technologies

Renewable energy systems such as solar thermal schemes which have been used widely in southern China, wind turbines, biomass and solar photovoltaic (PV) systems, are technologies which are becoming more popular in buildings in China, but mostly these seem to be incorporated only in new buildings, whereas there remain opportunities for retro fitting both technologies in many existing buildings. Where new constructions are considered, there are further energy savings and carbon-reduction possibilities when PV is installed. Traditionally, any PV electricity generated is converted from DC to AC and this incurs a loss of approximately 9%, (Tovey and Turner, 2008). Furthermore, many office appliances such as computers then convert the AC electricity to DC via individual power packs resulting in significant further losses sometimes as much as 50%. Equally, other appliances and also LED lighting can work effectively on DC electricity. Using such appliances by the inclusion of DC distribution networks within buildings would minimise unnecessary power conversions and improve the financial case for renewable energy schemes and also reduce or eliminate the heat gain from the waste in conversion. Such waste heat reduction can then reduce the cooling requirements in summer providing additional savings.

3.4. Awareness raising and behaviour change

In many cases, awareness raising will lead to particularly cost-effective methods to achieve the objective of carbon reduction. Tovey and Turner (2006) reported on an awareness campaign implemented at the University of East Anglia, and showed that a saving of up to 25% in electricity consumption is possible through encouraging occupants of an office building to switch off unnecessary lights and appliances when leaving a room. This was achieved through use of "Energy Champions" to encourage the occupants to cooperate in the campaign.

Even though the efficiency of energy use in China has improved significantly in recent decades, the overall energy consumption continues to increase at a rate of 8.98% (National Bureau of Statistics, 2007). The 2005 directive on Energy Efficiency Design Standards (GB50189-2005) encouraged the use of advanced energy-efficient measures in the buildings sector. However, data derived from the National Bureau of Statistics (2008) indicates that electricity consumption per unit area in large commercial buildings has risen by 32% since 2002 (Fig. 7). It is thus apparent that technical measures alone are not sufficient and effective awareness campaigns should be adopted to combat this adverse trend.

A holistic approach is needed to the behavioural attitudes towards energy consumption. Thus within the UK, it is not uncommon to find that electricity consumption per employee in office accommodation exceeds the annual total electricity consumption of that person and his or her family by a significant margin even though the time spent in the office is significantly less than that spent at home (Tovey et al., 2006). In the UK, some firms are now encouraging their work force to raise their awareness about energy consumption issues in the work place but at the same time are promoting awareness so that employees are encouraged to also reduce consumption in their homes.

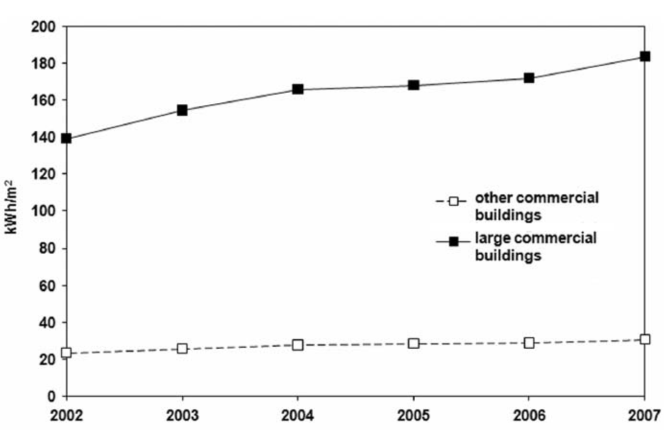

Fig. 7. Specific electricity consumption per unit area for large commercial buildings. Data derived using methodology of Qiu (2007) and updated with recent data from National Bureau of Statistics (2008).

Heating and cooling requirements account for around 50% of the total energy consumption in many large commercial buildings in Beijing and Shanghai and even when technical controls are in place occupants are often unaware of the best strategy that should be adopted for optimum energy consumption within the requirements of thermal comfort. It is in this area that managers within large buildings can help. Thus, government legislation or corporate policies can help here for instance adjusting the internal temperature within any building by just 1 °C can result in significant savings in annual energy consumption. Table 4 shows the mean temperatures in Shanghai and Beijing throughout the year of 2006.

During the heating season, internal thermostat temperatures are typically set at 20 °C. However, because of incidental gains from body heat, appliance use and solar gain, it is only when the temperature falls below the base temperature (sometimes also known as the balance or neutral temperature) used in degree–day calculations that heating is actually required. The base temperature is commonly set at 15.5 °C (e.g. Carbon Trust, 2007). It should be noted that the base temperature will vary from building to building and will depend largely on physical aspects and the specific proportion of incidental gains in each individual building. From the data in Table 4, it is possible to obtain an approximate estimate of the heating degree–days over the 4 winter months of December–March when heating will be required in both Shanghai and Beijing. Using the 15.5 °C base temperature the degree-days are 877 and 1742 for Shanghai and Beijing, respectively. These figures indicate that over these 4 months an identical building will require approximately twice as much energy for heating in Beijing as it would do in Shanghai.

If steps were taken to reduce the internal thermostat setting by 1 °C during the 4 winter months, then the heating degree–days to a base of 15.5 °C would reduce to 756 and 1621 in Shanghai and Beijing, respectively, and would represent a saving in energy consumption of 14% over the 4 months in Shanghai and 7% in Beijing. It should be emphasised again that the base temperature for a particular building may be noticeably different from that

Table 4
Mean Temperaturestemperatures in Shanghai and Beijing (Shanghai Statistical Bureau, 2007, Beijing Statistical Bureau, 2007).

Month	Mean temperatures (°C)		Degree-–days (15.5 °C base)		Degree-–days (18 °C base)	
	Shanghai	Beijing	Shanghai	Beijing	Shanghai	Beijing
Jan.uary	6.5	−1.9	279	539.4	356.5	616.9
Feb.ruary	6.1	−0.9	263.2	459.2	333.2	529.2
Mar.ch	11.6	8.0	120.9	232.5	198.4	310
Apr.il	17.0	13.5		60	30	135
May.	21.3	20.4				
Jun.e	25.9	25.9				
Jul.y	29.8	25.9				
Aug.ust	30.4	26.4				
Sep.tember	24.2	21.8				
Oct.ober	22.3	16.1				58.9
Nov.ember	15.9	6.8		261	63	336
Dec.ember	8.6	−1.0	213.9	511.5	291.4	589
Degree–days for January–March and December which are heating months in both Beijing and Shanghai			877	1742.6	1179.5	2045.1
Difference in heating requirements as a proportion of Beijing			50%		57%	

Degree-–day data were estimated using base temperatures of 15.5 °C and 18 °C.

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used in tables i.e. 15.5 °C, but the potential savings indicated above demonstrate the level of savings that on average might be achieved with rational policies in place.

During the summer months cooling is required in both cities, however, the situation is a little more complex than in the heating season as incidental gains are still present and assuming these remain at the same level throughout the year, the mean external temperature of 21.3 °C in May in Shanghai would effectively produce a typical internal temperature of about 25.8 °C and would thus require some cooling if the thermostat is set at 25 °C. Adopting a similar analysis to that for heating indicates that an identical building in Beijing will require only 58% of the cooling energy of one in Shanghai over the summer months. If as part of a conservation strategy the internal thermostat setting in summer was raised to 26 °C this would represent a 19% saving in energy in Shanghai and a 22% saving in Beijing.

Conventional business attire has male members of the population wearing business suites. Thermal comfort analysis indicates that discarding a jacket reduces the insulation level and this can give the same level of comfort at a temperature approximately 2 °C warmer than previously. Such a change in Beijing and Shanghai could result in savings in air-conditioning requirements of 30% or more. Indeed in 2005, the Japanese Government introduced the "Cool Biz" Campaign in public sector buildings where the internal thermostat setting is now set noticeably higher at 28 °C than previously, and short-sleeved shirts are becoming the norm for office workers in this sector even in a traditional culture such as in Japan (Government of Japan, 2005).

Besides raising awareness and encouraging behaviour change for cutting energy use, other simple and effective approaches need to be accelerated in China's large commercial buildings as well. In the nine commercial buildings studied in this research all the energy managers were responsible for the operation of the whole complex and it was the sub-occupants who paid the energy bills and thus the energy mangers had no incentive to give simple advice as to how energy might be reduced. Simple advice such as the issue listed below could be particularly effective:

- Closing windows and doors when the heating and cooling systems work and opening them only for the minimum time.
- Using heating and air-conditioning only when people are in buildings or during the initial pre-warm/cool period only rather the being on 24 h a day as at present.
- Switching off lights and other appliances when people leave buildings rather than leaving them on stand-by.
- Replacing lights within the sub-units by low-energy lamps and using appropriate energy-efficient appliances.

None of the businesses occupying the sub-units in the complexes had energy managers themselves and merely paid the bills when required. There is thus a need to coordinate the activities of the energy manager with the occupants of the sub-units throughout the complex for the financial benefit of all occupants and also for a benefit towards carbon reductions.

All these above strategies can lead to significant savings. However, any predicted savings from technical intervention or awareness raising will only be achieved if all other conditions remain the same both before and after any changes. Not infrequently occupants of buildings will change their behaviour adversely following technical changes and careful awareness raising is needed if the full potential of any investment is to be realised. In a recent study, Bourgeois (2009) examined the savings in energy consumption following insulation improvements in homes in the UK. He found that the actual savings were only between 30% and 56% of those predicted from technical assessments of the insulation improvements. This so-called "comfort taking" arose because the occupants allowed internal temperatures within the houses to rise thereby reducing the full impact of any theoretical saving. Anecdotal evidence obtained by one of the authors acquired during studies of some commercial buildings also indicated that actual savings were less than those expected (Tovey et al., 2006).

3.5. *Offsetting*

Offsetting carbon emissions has a place to play in combating global warming but should always be done after all the measures described above have been completed. Offsetting can be achieved by paying into a fund which will invest in projects such as tree planting, renewable energy projects, etc. There is a role for such offsetting, but only when all other measures fail to give the required reduction in carbon emissions. Offsetting should never be used as an alternative to one of the above four strategies. There are issues associated with offsetting such as to whether additionality is actually achieved—i.e. would the offsetting project have gone ahead without additional funds paid into offset funds. This is a controversial topic and beyond the scope of the present paper.

Some areas where offsetting may have a role in reducing the carbon emissions from buildings relates to the initial compensation of carbon emissions associated with the construction of the building itself. Thus, heavy weight buildings may have a larger embodied energy than a light weight one, but as shown by Turner (2007), effective management of a heavy weight building designed to low-energy standards can lead to significant carbon reductions over the life time of a building. However, if the accounting period is short (~5 years) then it may be difficult to demonstrate the true benefits of an energy saving and carbon-reduction strategy without recourse to a small amount of offsetting. A poorly managed building can cause the carbon emissions to be as much as 200% higher than expected and effective management should be tackled first rather than exploring ways to reduce carbon emissions by offsetting.

4. Conclusions

With the rapid rate of economic growth energy use in the building sector in China is increasing rapidly and currently amounts to 6700 TWh or nearly one third of all energy consumed. The consequential GHG emissions are large and it is crucial that this sector plays an important role with regards to energy conservation with the aim of achieving sustainable development.

The electricity use at 153 kWh/m^2 per annum in nine sample large commercial buildings is around 5 times that in the residential building sector in Beijing and Shanghai. At the same time the associate carbon emissions are around 158 kg/m^2 per annum in the two cities.

An energy management strategy involving five separate aspects has been outlined including:

1. awareness raising,
2. improvements in energy management,
3. implementation of technical measures for energy conservation,
4. deployment of renewable energy, and
5. offsetting methods.

In the past, some of these such as awareness raising and effective energy management have received much less attention than they deserved even though they can be, particularly, cost effective. Offsetting as a strategy for carbon reduction should only be considered as the last resort after all other measures have been completed.

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