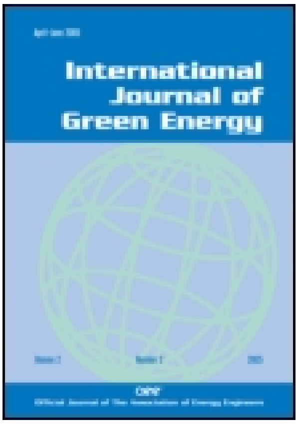

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IMPROVING THE ENERGY PERFORMANCE OF LARGE COMMERCIAL BUILDINGS IN CHINA USING EFFECTIVE ENERGY MANAGEMENT

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In many Chinese cities, such as Beijing and Shanghai, the energy use in large commercial buildings is significantly higher than that in the other building sectors. Monthly electricity consumption data from six large commercial buildings in Shanghai and Beijing in 2006 and 2007 were analyzed by exploring the energy consumption with temperature variations throughout the year. Intrinsic heating and cooling electricity requirements and baseline functional electricity consumptions were identified. Different patterns of energy consumption in buildings emerged and it was possible to separate the intrinsic energy requirements for heating and cooling from other energy uses. In most buildings, it was found that the dominant energy use was for requirements other than heating and cooling and this information provides an important insight into those areas where the most cost effective energy conservation strategies should be targeted. Thus, in many cases improving the thermal performance of the building by technical means will have less impact than reducing the requirements of functional energy use within the building. Such reductions may be achieved either by the deployment of more efficient appliances or through the use of effective energy management.

Keywords: ***Electricity consumption; Energy conservation; Energy management; Buildings; China***

INTRODUCTION

In 2009, the primary energy consumption in China amounted to 3,066.5 million tons of standard coal equivalent (or 24,961 TWh) (National Bureau of Statistics, 2010). Since 2000, the energy consumption has been rising at 13.5% per annum in China while at the same time, the annual GDP growth has averaged approximately 10% (National Bureau of Statistics, 2010) indicating a continued improvement in the energy intensity—that is, the energy requirements per unit of output, However, as China has now become one of the largest energy consumers and greenhouse gas (GHG) emitters in the world (The Netherlands Environmental Assessment Agency, 2007) it has recognized as important the need to ensure that steps are taken to continually improve energy performance.

China's building sector consumes 25% of the total energy in the country (Jiang and Tovey, 2009; National Bureau of Statistics, 2010) and with an estimated total building

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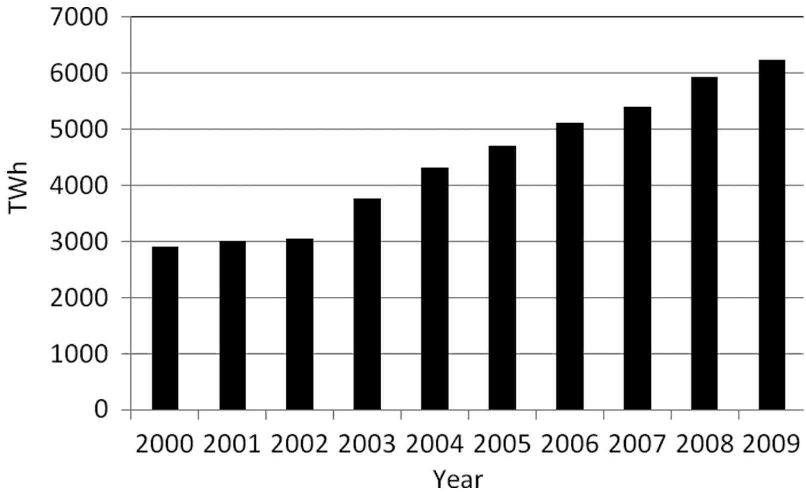

Figure 1 Energy consumption in the building sector in China.

area of over 50 billion m^2 the annual energy use was around 6,240 TWh in 2009 (Qiu, 2007; National Bureau of Statistics, 2010) (Figure 1). 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 including the material manufacture and transport of those materials to site. The total energy consumption in the building sector has increased by 121% since 2000 (Figure 1), and this trend is predicted to continue till at least by 2020 (Wei et al., 2007; Zhou and Lin, 2008). With a high growth in building construction recent years, the building sector thus plays an important role in China's long-term sustainable development strategy (Zhao, Liu, and Zhao, 2004).

There are two main categories of buildings in China: rural buildings and urban buildings. Urban buildings cover 40% of total area of all buildings but account for almost 90% of the total energy use in buildings in China (Qiu, 2007). Urban buildings include both residential and non-residential buildings, but it is in the latter category that the energy use is significantly higher, and particularly in those buildings classed as large commercial buildings (i.e., over 20,000 sqm is area), Such large buildings include hotels, office buildings, and shopping malls. Qiu (2007) noted that the energy consumption in such buildings was in the range 70∼300 kWh/m^2/annum. To achieve overall energy conservation and carbon reduction within the building sector, priority must thus be given to this type of building.

Beijing and Shanghai are the two largest cities in China, both of them not only have the largest number of buildings but also the highest growth rate in this sector. According the Shanghai Statistical Year Book (Shanghai Statistical Bureau, 2008), the total area of building stock in Shanghai in 2007 was 749 million m^2 of which the non-residential building area accounted for 294 million m^2 or 37% of the total area. However, this sector consumed abound 70% of total energy in whole building stock in Shanghai Corresponding data from Beijing Statistical Year Book (Beijing Statistical Bureau, 2007) indicates a total building area of around 543 million m^2 in 2006, of which the non-residential area comprised 232 million m^2 or 43% and accounted for 72% of total energy consumption of all buildings in Beijing. Using the non-residential building sector in Beijing as an example,

Table 1 The Six Sample Buildings in Shanghai and Beijing

Building number	Type	Number of floors	Floor area (m^2)
Shanghai			
1	Multi-function	31	120,000
2	Hotel	21	24,600
3	Hotel	28	56,700
Beijing			
4	Office	35	83,400
5	Shopping mall	8	63,000
6	Hotel	23	70,000

the total area of large commercial buildings in 2006 was around 24 million m^2 (Beijing Statistical Bureau, 2007; Qiu, 2007), that is, about 5% of the total building stock in that city. Despite this relatively small proportion, the electricity consumption in these buildings was over 4 TWh representing 12% of the total electricity consumption in the whole building stock. In both cities, this non-residential sector has a separate sub-sector of large commercial buildings which are the main focus in this paper.

Six large commercial buildings (three in Shanghai and three in Beijing) were selected to analyze their energy performance during 2006 and 2007. Electricity is the main source of energy in these selected buildings accounting for over 80% of energy consumption (Jiang and Tovey, 2010), and thus the analysis in this paper focuses on the electricity performance. Basic data relating to the six buildings are given in Table 1.

METHODS TO ASSESS THE ENERGY PERFORMANCE IN THE BUILDING SECTOR

For effective energy management in buildings, it is important to separate the intrinsic and functional energy uses within buildings. The intrinsic energy consumption relates to that energy which is consumed to maintain an adequate thermal environment as opposed to that energy associated with the actual operation of the building (i.e., functional energy use). The intrinsic energy use for buildings with the same insulation standards should be largely the same irrespective of the functions taking place in the building. Functional energy use will reflect consumption related to the actual function within a building—for example, use of computers, escalators, lifts, drinks machines, etc. in such buildings.

The intrinsic energy to provide an adequate thermal environment will always, in a properly designed system, correlate with the external temperature. On the other hand, functional energy use will normally be independent of external physical factors, although in some cases, it may be possible to identify small changes in energy consumption from changes in the number of hours of daylight at different times of the year. However, in many commercial buildings where natural daylight levels are low, the lighting levels will often be nearly constant throughout the year.

In any effective energy management strategy to reduce energy consumption and consequentially the associated carbon emissions, it is important to target those areas which are most effective in bringing about the desired reductions (Kilkis, 2004). In some cases, the functional energy use may be a small component of the total energy consumption and in such cases, methods to reduce the intrinsic energy consumption through better insulation or the installation of more efficient heating/cooling systems will be important. On the other hand, if the dominant energy use arises from functional energy use, then more effective reductions can be achieved by targeting these areas rather than the intrinsic thermal performance of the building.

There are two main quantitative methods available for analyzing the energy performance against external temperature variations in the building sector, they are the Degree-Day Method and the Mean Temperature Method which are closely related to each other and are summarized below.

Degree-Days Method

This is a simple and effective tool for assessing weather related energy consumption in buildings. According to the Carbon Trust (Carbon Trust, 2005), the degree-day method was originally adopted in agricultural research for assessing the variation of outdoor air temperature and then the principle was transferred to the building energy study. The method is used to estimate a weighted mean effective temperature difference between the inside and outside of buildings over a specified time period. This relevant internal temperature is variously referred to as the base, neutral, or balance temperature. A key issue in the application of this degree-day method is the definition of the base temperature which is related to the energy balance of the building and includes an understanding of incidental heat gains from solar energy, body heat, appliance use, etc. It can be used to assess overall heating and cooling requirements of a building through a specification of heating Degree-Days or cooling Degree-Days respectively.

Analysis of energy consumption in buildings using the Degree-Day Method is used in many countries for estimating overall annual energy consumption. There are some limitations in the Degree-Day approach in its basic form in respect of the choice of the base temperature. Thus, for such a system to be valid, Degree-Day data on a regional/sub-regional basis must be readily available. So, in the UK, the country is divided in 18 different climate zones (Carbon Trust, 2005). In China, there are only five such regions covering extensive areas (Chinese Construction Ministry, 2005), and even then the required information in the form of Degree-Days is not generally available and this is perhaps the main reason why this method has been seldom used in China in the past. Consequently, the main focus of this paper will be directed to analysis of energy performance using the following method.

Mean Temperature Method

The mean temperature method provides a relatively simple and effective tool for analyzing the energy consumption. It has the advantage in that assumptions over exactly what base temperature should be used are no longer an issue. On the other hand, more work is needed to convert the results from the basic analysis into an actual energy consumption over a given period. Given the issues raised above, it is the method which is potentially more suitable for use in China at the present time.

In this paper, the electricity consumption in six large commercial buildings in Beijing and Shanghai are analyzed using this Mean Temperature approach. These six samples have several similar characteristics:

1. They are all large commercial buildings with floor areas over 20,000 m^2 which incorporate central air-conditioning systems, and are all located within the central areas in Beijing and Shanghai. They include one office building, three hotels, one shopping mall, and one multi-function building as shown in Table 1;
2. Electricity is a main energy source for all the sample buildings, although in Beijing, space heating in winter is provided by the district heating system;
3. The energy performance in all the buildings is managed by local property management companies.

Data relating to energy consumption were obtained in two ways: (1) from energy bills/invoices, and (2) from manual reading of meters. The data obtained thus provided monthly electricity consumption over a period of 12 months.

In order to make effective comparison of the electricity use for heating and cooling and also to identify the base load functional electricity use in the sample buildings, each case study was categorized into one of two types:

i. *Type 1*: These buildings have electricity as the only energy source which is used for space heating and cooling using electrically driven heat pumps, and also for functional energy use and are typical of large commercial buildings in Shanghai. When energy consumption is plotted against the mean external, temperature two different trends are seen as shown schematically in Figure 2. Trend line A–B relates to the heating season energy requirements demonstrates an increasing energy requirement as the temperature falls. The gradient of the trend line is related to the heat loss coefficient (in W°/C) and is a measure of the intrinsic energy requirements to maintain and adequate thermal environment.

   Energy consumption for space cooling in summer is represented by the cooling line B–D where the consumption increases as the temperature increases while the line E–B–F represents the functional energy use within the building and in many cases will be independent of external temperature.

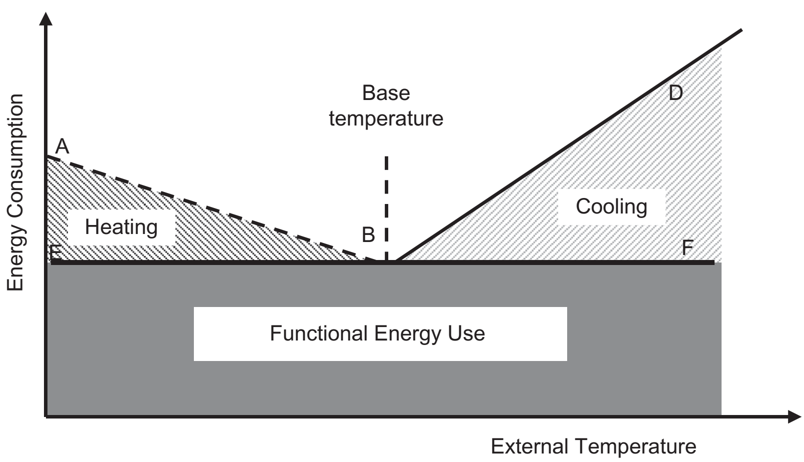

Figure 2 Schematic illustration of electricity performance in a Type 1 Building where electricity is used for heating.

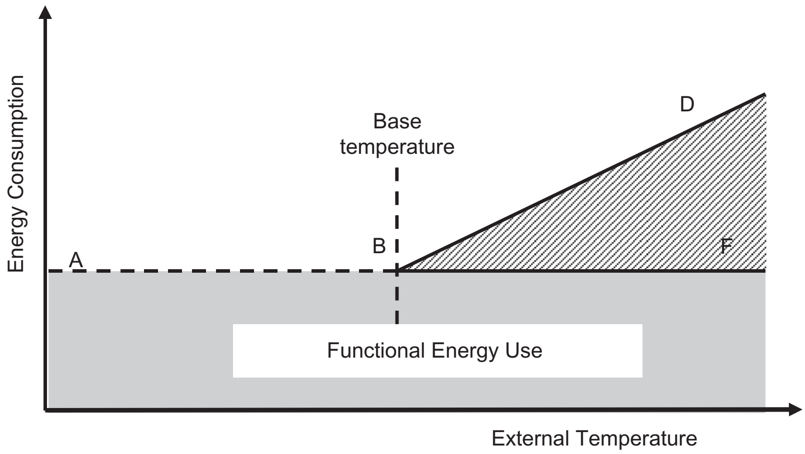

Figure 3 Schematic illustration of electricity performance in a Type 2 Building. The line A–B is nearly horizontal representing the base load functional electricity use.

ii. *Type 2*: In this building type, space heating in winter is provided by the district heating main and is typical of many buildings in Beijing. A typical plot of the electricity consumption data for this type of building is presented as Figure 3. In general there is no routine monitoring of heat energy supplied to individual buildings from the district heating main as there is a fixed tariff for heat energy supplied based on floor area and irrespective of actual energy used. In this type of building, as expected, the electricity consumption during winter as demonstrated by the line A–B is approximately constant, and no estimate of the heat loss coefficient for this building is possible. The trend line B–D relates to the cooling season and demonstrates increasing energy requirements as the temperature increases. Once again the gradient this line is related to the heat gain coefficient. The line A–B–F represents the functional energy use in the building.

CASE STUDIES

Sample Buildings in Shanghai

Shanghai is representative of one of the five typical climate zones within China—"hot summer and cold winter" (Chinese Construction Ministry, 2005). The monthly temperature data for Shanghai (Shanghai Statistical Bureau, 2007, 2008) are shown in Table 2.

The monthly electricity consumption data for the three large non-residential buildings in Shanghai are presented in Table 3. All heating and cooling in these buildings was provided electrically.

The first building (No 1) is the largest building on a local university campus which is located close to the central area of Shanghai. It is a multi-functional building which contains offices, classrooms, libraries, meeting rooms, etc, and has a total floor area of 120,000 m^2 with 31 floors above ground and 2 underground floors. The daily maintenance work to keep the building running normally is fulfilled by a property management company managed by the university.

Table 2 Monthly Data Related to the Temperature in Shanghai in 2006 and 2007 (Shanghai Statistical Bureau, 2007, 2008)

Month	Temperature (°C) in 2006			Temperature (°C) in 2007		
	Max	Min	Mean	Max	Min	Mean
Jan.	17.7	−3.5	6.5	12.7	−0.7	5.9
Feb.	22.2	−1.9	6.1	23.4	−1.1	9.8
Mar.	23.7	1.2	11.6	28.4	0.8	12.1
Apr.	31.4	6.8	17.0	28.9	7.2	15.9
May.	32.2	13.7	21.3	32.6	14.7	22.9
Jun.	37.3	16.7	25.9	36.4	19.2	25.0
Jul.	37.9	22.3	29.8	39.6	24.0	30.4
Aug.	38.6	25.5	30.4	39.5	24.0	29.7
Sep.	33.5	17.6	24.2	32.6	20.2	25.4
Oct.	28.9	16.0	22.3	31.1	12.6	20.6
Nov.	26.7	7.4	15.9	22.0	6.8	14.2
Dec.	18.5	−0.7	8.6	16.9	2.1	9.8

The trend of electricity use in 2007 is shown in Figure 4 and demonstrates performance of a Type 1 building. Electricity use in February was much lower than would normally be expected and coincided with the extended Chinese New Year Holiday and was thus not used in subsequent analysis. As expected there are two separate trend lines (A–B) and (C–D) representing the heating and cooling seasons respectively.

The heating requirement (H_i) in month ***i*** may be specified as

$$H_i = 1114 - 41.7T_i \tag{1}$$

where T_i is the mean temperature in month i.

The corresponding relationship in the cooling season (C_i) is given by:

$$C_i = 63.5T_i - 824 \tag{2}$$

Table 3 Electricity use in Three Large Buildings in Shanghai (kWh)

Month	Building 1 (2007)	Building 2 (2006)	Building 3 (2006)
Jan	811,160	195,000	726,000
Feb	416,400	171,000	540,000
Mar	632,800	198,000	732,000
Apr	427,800	166,500	762,000
May	604,760	225,000	840,000
Jun	743,080	306,000	1,032,000
July	1,135,040	370,500	1,218,000
Aug	1,031,760	339,000	1,176,000
Sep	814,040	346,500	1,104,000
Oct	502,320	222,000	882,000
Nov	492,240	178,500	834,000
Dec	792,480	186,000	780,000
Total	8,403,880	2,904,000	10,626,000
Floor area	120,000 m^2	24,600	56,700
Average annual consumption	70 kWh/m^2	118 kWh/m^2	187 kWh/m^2

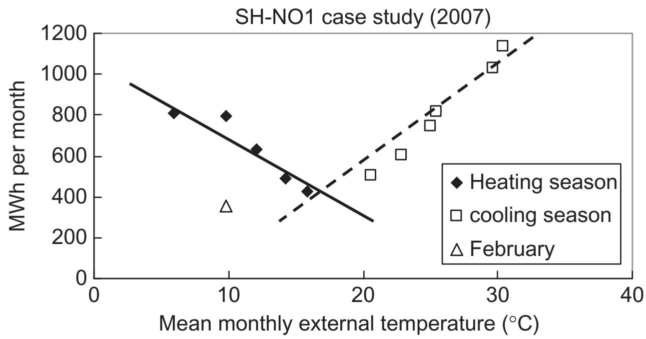

Figure 4 Building 1: Variation of monthly electricity use with monthly mean temperature for a non-residential University Campus building in Shanghai in 2007.

Solving these two simultaneous equations allows the points of intersection (i.e., the point at which no heating or cooling is required) to be determined. This point of intersection occurs at a temperature of 18.4°C and an energy consumption representing the functional energy use of 346 MWh/month.

Several observations may be made about the data presented in Figure 4.

- The scatter of data points around the trend lines is very low with high coefficients of correlation of $r^2 = 0.893$ and 0.988 respectively. This demonstrates that the management of the thermal environment in this building is good.
- The gradient of the heating trend line (G_{heat}) is 41.7 kW/°C while that of the cooling line (G_{cool}) is 63.5 kW/°C. Heating and cooling the building is provided by heat pumps with coefficients of performance of around 2.5 in the heating and cooling modes respectively. Multiplying these gradients by 2.5 shows that the estimated heat loss coefficient is 124.9 kW/°C which is very close indeed to the estimated heat gain coefficient of 127.0 kW/°C giving an average of 126 kW/°C. This figure is important as it provides a baseline against which improvements in insulation or ventilation rates may be made.
- In this building, the base or neutral temperature is 18.4°C while the functional energy consumption may be estimated as 346 MWh/month or 34.6 kWh/m^2/annum.
- Deducting the functional energy use (i.e., 346 MWh) from the actual consumption in each month provides an estimate of the electricity needed to control the thermal comfort. This analysis indicates that 4,181 MWh/annum are required to provide an adequate thermal environment of which 1,426 MWh/annum is for heating and 2,755 MWh for cooling. With a total consumption in 2007 of 8,404 MWh, 49.8% of the annual electricity consumption in this building is associated with the provision of adequate heating and cooling. The overall unit area annual consumption is 70.0 kWh/m^2/annum, of which the overall intrinsic unit area annual consumption is 34.9 kWh/m^2/annum.

Buildings 2 and 3 are located in central Shanghai each with more than 20 floors,. They have total floor areas of 24,600 and 56,700 m^2 respectively. Adopting the same analysis method used in Building 1, the results of energy performance are summarized in Table 4 for these two buildings.

As with Building 1, the data covering the Chinese New Year Holiday were excluded in the estimation of the heat loss coefficients. In both cases, the coefficient of correlation as measured by the r^2 value was much lower than in the case of building 1. This indicates that

Table 4 Results of Analysis of Energy Consumption for Buildings 2 and 3

Item	Building 2	Building 3
Annual electricity consumption (kWh)	2,904,000	10,626,000
Floor Area (m^2)	24,600	56,700
Unit area annual consumption (kWh/m^2)	118	187
Base (neutral) temperature (°C)	16.5	15.4
Baseline monthly functional energy consumption (kWh)	174,676	756,978
Annual intrinsic energy requirement for heating and cooling (kWh)	807,892	1,815,194
Annual functional energy use (kWh)	2,096,108	8,810,806
Intrinsic energy use as a percentage of total energy use	27.8%	17.1%
Unit area intrinsic annual energy consumption (kWh/m^2)	32.8	32.0
r^2 value of heating data	0.613	Almost constant energy requirement
r^2 value of cooling data	0.680	0.816

the control and management of space heating is noticeably less effective than in the university campus building. However, the equivalent base temperatures are somewhat lower at 16.5°C and 15.4°C respectively.

In both buildings, it is clear that the intrinsic energy requirements for space heating and cooling constitute a relatively small proportion of the total energy demand at 27.8% and 17.1% for buildings 2 and 3 respectively.

Sample Buildings in Beijing

The three large buildings in Beijing are located in downtown Beijing. Beijing is within the cold climate zone (Chinese Construction Ministry, 2005) with the heating period running from early November to the following March. In all three buildings, the heating resource is provided by the local heating power companies through the district heating hot water networks. The electricity consumption data are thus expected to follow a Type 2 building trend. Relevant temperature data (Beijing Statistical Bureau, 2007) and electricity consumption data are presented in Table 5.

Figure 5 shows the plot of electricity consumption against mean external temperature for building 4 with the data for the Chinese New Year excluded and demonstrates a near constant consumption of around 840 MWh/month during the heating season. This constant electricity consumption reflects the provision of heating from the district heating mains.

The gradient of the cooling line is 23.5 kW/°C while the annual electricity consumption is 11,564 MWh with 6,712 MWh consumed over the summer months when cooling is required. Of this latter figure only 1,667 MWh (or 24.8%) is associated with cooling with 75% associated with functional energy use. This implies that the total functional energy use over the year is around 9,900 MWh. Specific heating information is not available for this building for the reasons given above, but according to the “2007 Annual Report on China Building Energy Efficiency (Qiu, 2007),” the average of energy requirements for heating in the heating season in Beijing’s commercial buildings is around 40–60 kWh/m^2/annum. If building 4 is typical at the mid-point of this range (i.e., 50 kWh/m^2/annum) then the annual heating requirement would be about 4,170 MWh/annum giving a total intrinsic energy consumption for heating and cooling in this building from both electricity and district heating of around 5,800 MWh and an overall energy consumption of approximately

Table 5 Temperature Data in Beijing (Beijing Statistical Bureau, 2007) and Energy Consumption Data for 2006

Month	Temperature (°C)			Building electricity consumption (kWh)		
	Max	Min	Mean	No. 4	No. 5	No. 6
Jan.	2.5	−7.0	−2.2	648,000	1,155,600	360,000
Feb.	4.3	−7.2	−1.2	872,000	1,064,400	524,000
Mar.	14.4	0.3	8.1	828,000	1,099,800	628,000
Apr.	19.4	6.9	13.5	884,000	1,300,000	616,000
May.	25.8	14.3	20.6	1,000,000	1,469,200	668,000
Jun.	31.7	19.4	25.8	1,268,000	1,563,400	932,000
Jul.	29.8	21.6	25.6	1,304,000	1,663,600	852,000
Aug.	30.7	21.7	26.1	1,060,000	1,622,200	896,000
Sep.	28.0	15.0	21.5	1,084,000	1,479,800	920,000
Oct.	21.5	10.7	15.9	996,000	1,305,600	636,000
Nov.	11.7	1.1	6.5	820,000	1,125,600	616,000
Dec.	3.6	−6.3	−1.6	800,000	1,150,800	616,000
			Total	11,564,000	16,000,000	8,264,000
			Floor area (m^2)	83,400	63,000	70,000
			Average (kWh/m^2/annum)	139	254	118

15,500 MWh. Thus, even allowing for the uncertainty in the heating requirements the total intrinsic energy requirement to provide thermal comfort only is only about 35% of the total requirement. Thus, as the intrinsic heating/cooling energy requirement is only a low proportion of overall consumption, greater returns in energy saving and carbon reduction can be achieved by reducing the functional energy consumption as opposed to improving the thermal performance of this building. Such functional energy improvements could be achieved through the use of more efficient appliances and lighting and through behavior change of the occupants.

However, on the cooling front, there is considerable scatter of the data point with a coefficient of correlation significantly lower (at 0.51) than the buildings in Shanghai indicative of relatively poor energy management in the building.

Corresponding data for buildings 5 and 6 are shown in Table 6. As with building 4, the summertime cooling requirements are only around one quarter of the total summertime

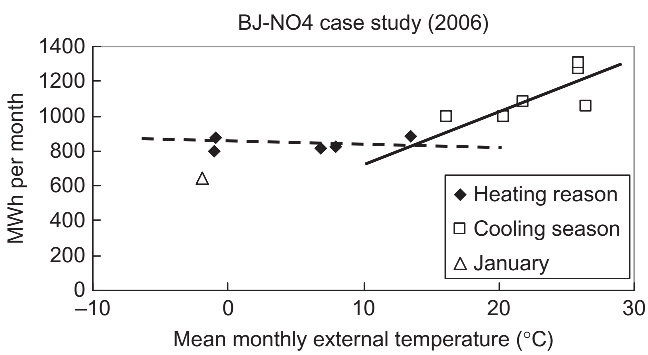

Figure 5 Electricity consumption data for Building 4 in Beijing.

Table 6 Results of Analysis of Electricity Consumption for Buildings 4, 5, and 6 in 2006

Item	Building		
	No. 4	No. 5	No. 6
Total annual electricity consumption (MWh)	11,564	16,000	8264
Total floor area (m^2)	83,400	63,000	70,000
Unit area consumption kWh/m^2/annum	139	254	118
Summertime cooling electricity requirements (MWh)	1667	2215	1304
Cooling requirements as % of total summertime energy	24.8%	24.3%	26.6%
Gradient of cooling line	23.5 kW/°C	30.3 kW/°C	26.4 kW/°C
r^2	0.51	0.93	0.68
Energy use for heating (MWh)	4170	3150	3500
All intrinsic cooling and heating requirements as % of total energy consumption	33%	28%	40%

electricity requirements at 24.3% and 26.6% for buildings 5 and 6 respectively. The gradients of the cooling lines are also similar at 30.3 and 26.4 kW/°C respectively. However, where there is a significant difference is in the amount of scatter around the cooling lines demonstrating that management in building 5 is significantly better than that in buildings 4 and 6. If the energy requirements in the heating season are also included, then in buildings 2 and 3 functional energy use amounts to 72% and 59% respectively.

Of all the large buildings studied only the university campus building had a significant energy demand from heating and cooling. In all other buildings, functional energy use dominated consumption, and tackling this latter energy use to reduce consumption though a combination of the installation of more efficient appliances and better awareness training will have the potential to create greater energy and carbon savings than tackling issues solely relating to the intrinsic heating requirements even though the latter are also important.

In most Chinese cities, the energy performance in large commercial buildings is managed by the local property management companies. Jiang (2009) noted that in less than 20% of large commercial buildings had an adequate energy management system for a long-term energy conservation strategy been set up. Indeed he found that over 70% of energy managers from property management companies have not even attempted to undertake a basic analysis of energy consumption yet alone the more detailed appraisal of energy use described above. There are thus many missed opportunities with regards to energy saving and carbon reduction which could lead to a low carbon sustainable future in the sector. Some of the potential opportunities that could be employed are discussed below.

IMPROVING ENERGY MANAGEMENT IN LARGE COMMERCIAL BUILDINGS

Sections "Sample Buildings in Shanghai" and "Sample Buildings in Beijing" have demonstrated how the mean temperature method may be used to analyze energy performance in large commercial buildings and in particular provide a method to separate intrinsic energy requirements for heating and cooling from functional energy use.

The functional energy use may arise from several causes, and if adequate submetering is present it may be possible to sub-divide the functional energy block in Figure 2 into the following:

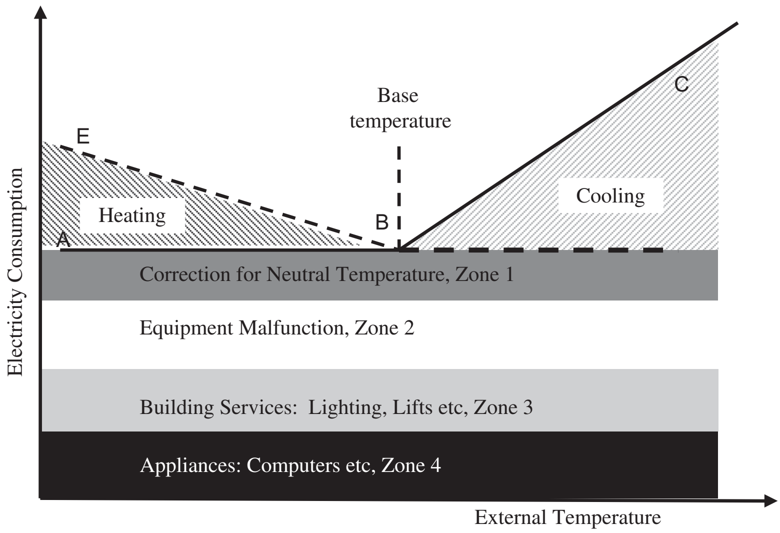

Figure 6 Separation of functional energy use into component parts.

1. A correction for a high thermostat setting leading to additional energy consumption as indicated by zone 1 in Figure 6,
2. Additional energy consumption arising from equipment malfunction (zone 2),
3. Energy use for communal area services such as lighting, lifts, etc. (zone 3), and
4. Energy use for appliances such as computer, refrigerators, etc. (zone 4).

Zone 1 energy use is associated with corrections to the base temperature associated with high/low thermostat settings and incidental gains from appliances and lighting use, body heat, solar gain, etc. In Figure 6, this zone has a positive thickness and represents the case when the free temperature rise is less than the difference between the thermostat and base temperatures. If the free temperature rise equals this difference as it will do in for the average building, then zone 1 will have zero thickness.

Any malfunction of building services equipment including electrically driven heating/cooling equipment will lead to excessive electricity consumption (zone 2), An example of this is shown in Figure 7 where poor energy management in an office building in the UK resulted in the unnecessary emission of 100 tons of carbon dioxide over a nine month period (Tovey et al., 2006). Over the first 18 months electricity consumption averaged at just over 30,000 kWh/month shown by the solid line. After July in the second year, low energy lighting was installed taking several months to complete and during this time the consumption fell progressively to a lower level which was maintained for around 6 months. However, subsequently, the electricity consumption rose significantly above the original level and remained there for several months unnoticed. The cause was eventually identified as a malfunction in the heating and cooling controls causing both to be on much of the time. Good energy management should have identified the problem before the fault occurring and would have saved significantly in energy use and emissions and also in unnecessary expenditure on energy. If there is no malfunction of equipment, then zone 2 would have zero thickness in Figure 6.

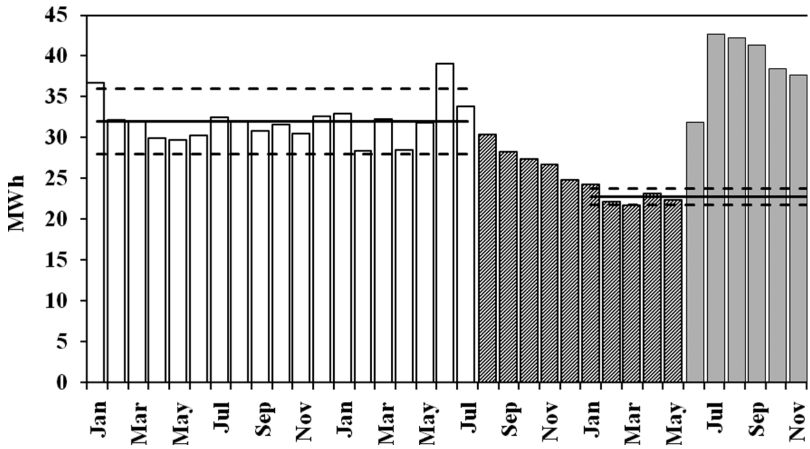

Figure 7 Electricity consumption in a UK office building.

The amount of electricity associated with zones 3 and 4 in Figure 6 may be reduced by the installation of more energy efficient building services or appliances (Bertoldi and Atanasiu, 2011). On the other hand, an increase in the use of computers and other appliances would conversely see an increase in thickness of zone 4.

It is important to emphasize that while technical measures to reduce energy consumption are important—such as the installation of low energy lighting and utilization of energy saving technologies such as the ground source heat hump for heating to reduce demand covered by zones 3 and 1 in Figure 6, even greater savings can be achieved through better management not only through the early identification of a malfunction, but also in the appropriate setting of thermostats and in the promotion of awareness campaigns to ensure that lights and appliances are not left on unnecessarily.

Effective energy management should focus on the use of diagrams such as Figures 6 and 7 in order to save energy to reduce carbon emissions, and also save money. In the former figure, the proportions of energy required for heating, cooling, and functional energy use can be identified and indicate those areas where the most effective savings can be made. Thus, if the cooling and heating areas are significantly smaller than the area representing functional energy use, it is the latter which should be targeted so as to give greater financial returns rather addressing the thermal performance of a building. If on the other hand the heating/cooling areas dominate energy consumption then improvements to insulation of the fabric or the upgrading to more efficient heating/cooling appliances will pay greater dividends.

Whatever energy saving strategy is adopted, the initial analysis of energy consumption data on the lines discussed will provide a rational baseline against which future energy performance can be measured.

CONCLUSIONS

Energy consumption in the building sector in China has risen significantly in recent years and addressing this consumption in the large commercial building sector must therefore be considered as a priority if China is to achieve low carbon sustainable development.

The analysis of energy consumption in relation to the mean external temperature provides a method to separating the intrinsic energy requirements for providing thermal comfort within a building from the functional energy use within the building. The functional energy uses include central building services such as communal lights, lifts etc. and in addition appliance use such a computers and refrigerators. In case studies in this paper, it has been shown that functional energy use almost always dominates total energy use, always being over 50% of the total energy use and sometimes as high as 80%.

Improvements in insulation standards and the performance of heating and cooling appliances will result in energy reduction, but in many large commercial buildings it would be more effective both financially and in terms of energy and carbon reduction to explore ways to reduce the functional energy use. To adopt the effective energy management, for instance, cutting the functional energy consumption if it dominates the whole energy use through energy efficiency measures, occupants' awareness raising, and behavioral changes, could be a cost-effective approach.

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