Survey of Commercial Building Energy Use in Six Cities in South China

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ABSTRACT

Although attention has greatly increased in recent years on improving building energy efficiency in China, along with an assumption of large untapped savings based simply on its sheer volume and perceived absence of energy efficiency measures, there remains a great deal of uncertainty about actual building energy consumption in China, particularly in the rapidly evolving stock of public, i.e., commercial, buildings. Over the past four years, the Ministry of Housing and Urban/Rural Development (MOHURD) has developed a standard energy survey form for public buildings, and coordinated the efforts by five cities in southern China (Chengdu, Shenzhen, Fuzhou, Wuhan, and Chongqing) to survey up to several thousand public buildings in each city. In a separate effort, Shanghai has also done two surveys of over 100 buildings. Over this time, the author has been working with MOHURD and the six cities to put all this information together into a national data base of energy consumption of Chinese public buildings, similar in intent to the U.S. Commercial Building Energy Consumption Survey (CBECS). This data base now contains over 400 public buildings, but has the potential of being expanded to several thousand buildings as more data are released, or contributed to by other cities. This paper presents an initial overview of that data base, and the electrical Energy Use Intensities (EUIs) by building type and city.

Introduction

In China, buildings are classified as either civil or industrial. Industrial buildings include factories and other buildings used for manufacturing. Civil buildings are in turn classified as either residential or public. Residential buildings include residences, dormitories, apartments, residential portion of commercial buildings, childcare center, kindergartens, etc. Public buildings include the following six categories: (1) office buildings including office portion of government buildings, (2) commercial buildings including shopping and financial institutions, (3) recreational buildings including hotels and entertainment centers, (4) educational, scientific cultural, and health buildings including cultural, educational, scientific research, health, and athletic institutions, (5) communication buildings including post offices, communications, and broadcasting, and (6) transportation and shipping buildings, such as airports, train and bus stations, etc. (Lang 2010) Over the past decade, China's Ministry of Housing and Urban/Rural Development (MOHURD) has shown increasing concern about the energy usage of government offices and large public buildings such as shopping malls, Class A offices and high-end hotels. For government office buildings, the concern is due to scattered reports of their energy waste. For large public buildings, it has been reported that they have energy use intensities as much as 10-20 times that of residential buildings, so that even though they represent less than 4% of total building floor area, they consume roughly 20% of all building energy use.

To better understand the actual energy use characteristics of this rapidly growing building sector, MOHURD in 2006 sponsored a task force to develop a "Standard for Building Energy Consumption Surveys", and then in 2007 designated five cities in southern China, three in the Hot-Summer Cold-Winter Region – Chongqing, Chengdu, and Wuhan – and two in the Hot-

Summer Warm-Winter Region – Fuzhou and Shenzhen – as pilot cities to conduct surveys of government buildings and large public buildings, using the survey form from the 2006 Standard as a template.[1] The surveys were carried out by local building research centers or universities with support from the Energy Foundation's China Sustainable Energy Program (CSEP). The local institutions are the Chongqing Construction Technology Development Center (CCTDC), West China University in Chengdu (WCU), Wuhan Energy Conservation Office (WECO), Fuzhou New Technology Promotion Center (FNTPC), and Shenzhen Academy of Building Research (SABR).

At the same time, the author and his staff, also with support by the CSEP, worked with MOHURD's Information Center to provide coordination and technical assistance to the local efforts, and once the survey results became available, compare the survey results to each other, as well as to other available sources of data in China and abroad.

In parallel with the MOHURD-led effort, Shanghai's Energy Conservation Supervision Center (SECSC) commissioned a survey of 11 large public buildings in Shanghai (SECSC 2007), while Tongji University in Shanghai surveyed another 95 public buildings (Chen et al. 2006). Since these surveys were aimed at a better understanding of the energy usage and retrofit opportunities in high profile buildings, they collected more detailed information on the characteristics of the building envelope and HVAC equipment.

Status of Survey Data

The energy surveys were completed in 2008. The level of detail in the surveys is not all the same. While the Shenzhen Academy of Building Research was able to visit all 5,000 public buildings in Shenzhen, most of the other surveys chose instead to do a sampling and then conducted detailed energy audits of a small number of buildings to clarify the situation and identify energy saving potentials. Each city summarized their survey results into reports submitted to MOHURD and CSEP (CCTDC, WCU, WECO, FNTPC, SABR, all 2008).

After the survey data was obtained from the six cities, the author and his staff put them into a single database containing more than 400 buildings. Some of the cities released only a sampling of their data, due to confidentiality agreements with the building owners. As to be expected from six separate efforts, for most their first attempt at a large-scale building energy survey, the data are not uniform, especially in the details. For all buildings, the database has the building floor area, function, annual energy consumption, as well as some detailed HVAC information. Although it was recommended that all surveys collect monthly utility bills, these were not made public, so that the only monthly data available to the author and his staff were those in the reports or published by the SECSC for Shanghai.

When reporting fuel usage, the standard convention in China is to convert these to kWh equivalents, rather than the other way around as in the US. Since this implicitly neglects a source multiplier for electricity, the author recommended that the data be reported either in their original units or as coal equivalents, but that recommendation was not accepted. Consequently, all the numbers in this paper are given in kWhs, but it would be misleading (in the author's opinion) to

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[1] MOHURD has designated five climate regions for China, four from north to south being the Severe Cold, Cold, Hot-Summer Cold-Winter, and Hot-Summer Warm-Winter regions; and a small one in the southwest being the Temperate region in Yunnan province.

directly compare the heating and cooling energy consumptions shown without recognizing that they are site energies of natural gas for heating and electricity for cooling.

Climate Conditions in the Six Cities

The six cities are all located in southern China. Four of them (Shanghai, Wuhan, Chongqing, and Chengdu) are in the Hot-Summer Cold-Winter region, which has significant heating as well as cooling seasons. Of the four, Chengdu has a noticeably milder climate because of its higher elevation. The other two (Fuzhou and Shenzhen) are in the Hot-Summer Warm-Winter region, which has longer (but not hotter) cooling seasons. Table 1 shows the heating and cooling degree days of these cities and cities with comparable degree days in the US. Note that the climate in China tends to be more variable than in the US, i.e., locations with the same cooling degree days will have more heating degree days than comparable US locations.

Table 1 Weather Conditions in Six Cities

	Shanghai	Chengdu	Wuhan	Shenzhen	Fuzhou	Chongqing
Heating degree days (18^{o}C)	1648	1276	1549	289	605	1086
Equivalent US city	Memphis	Dallas/Fort Worth	Atlanta	Orlando	Jacksonville	Charleston SC
Cooling degree days (18^{o}C)	1075	887	1249	2074	1605	1288
Equivalent US city	Birmingham	Washington	Jackson MS	West Palm Beach	Austin	Charleston SC

Contents of Survey Data

The 2006 MOHURD survey standard used as a template in these surveys gives guidance on obtaining from the building owners or managers the utility bills, building use type and floor area, but not on the characteristics of the building envelope and mechanical system. Officials in each city designed their own survey forms, using their own judgment to decide on the level of detail in their surveys. For example, some surveys have detailed breakdown of building area by function, while others have only the total floor area. In some cases, detailed information was collected in the field, but not publicly released to protect the owners' privacy. Table 2 lists the publicly released information in the six surveys.

Table 2. Building Information Available from Each Survey

	Shanghai	Chengdu	Wuhan	Shenzhen	Fuzhou	Chongqing
Name	yes	yes	yes	no	yes	no
Area	yes	yes	yes	yes	yes	yes
year built	yes	no	no	no	yes	yes
end use	no	no	yes	no	no	no
monthly data	yes[1]	yes[2]	no	no	no	no
gas data	yes	yes[3]	yes	no	no	no[4]
electricity	yes	yes	yes	yes	yes	yes
building envelope	yes	no	no	no	no	no

1. ~70% of buildings have monthly gas and electricity data
2. Average monthly data for each type of building is available
3. ~10% buildings have annual gas consumption data
4. Total energy was provided, but no gas consumption alone

Although there are missing information and data gaps, it was still possible to compile a relatively large set of 402 public buildings in the database. Table 3 lists the sample size by city and twelve types of public buildings, with more than half being government or private office buildings. There are also from 20-58 samples of hotels, shopping malls, and university buildings, but the sample sizes for library, stadium, and airport terminal are too small to be statistically significant. The food stores in the table refer to grocery stores less than 5,000 m^2, not the large Wal-Mart type of supermarkets. There are also noticeable omissions of common building types, such as restaurants and medical outpatient clinics. Lastly, the three multi-function buildings refer to buildings that combine a hotel with offices, shops, and restaurants. There are now more and more of this type of buildings being built in China.

Table 3. Sample Size by City and Building Type

	Shanghai	**Chengdu**	**Wuhan**	**Shen zhen**	**Fuzhou**	**Chong qing**	**Total**
Government offices	4	19	12	13	41	27	116
Private offices	42	1	3	14	47		107
Hotels	5	14	4		30	5	58
Shopping mall **+** Offices	27			4	15		46
Shopping mall		8	4		7	16	35
College		15				5	20
Hospital		2			2	3	7
Food stores		4			2		6
Multi-function	2					1	3
Airport Terminal	1						1
Library					1		1
Stadium	1						1
Total	83	63	23	31	145	57	402

In terms of vintage, the surveyed buildings range from the 1930s to 2000s, including among its oldest the International Hotel in Shanghai, built in the 1930's and the tallest building in China before 1970. However, as to be expected, most of the surveyed buildings were built in the last twenty years after China's economic reform. Table 4 shows the surveyed buildings in each city by vintage and floor area. The majority of the buildings are larger than 20,000m^2. Those smaller than 5,000m^2 tend to be food stores and older government office buildings. For buildings built after 1980, 82% are larger than 20,000 m^2.

Energy Survey Results

Figure 1 shows the electricity EUIs of the following four major types of buildings in the six cities: government buildings, private offices, hotels, and shopping malls. The average EUIs of other building types, such as schools, museums, etc, have been omitted because their sample sizes are too small to be statistically significant. The findings on the energy usage of the four major building types are discussed below in sequential order.

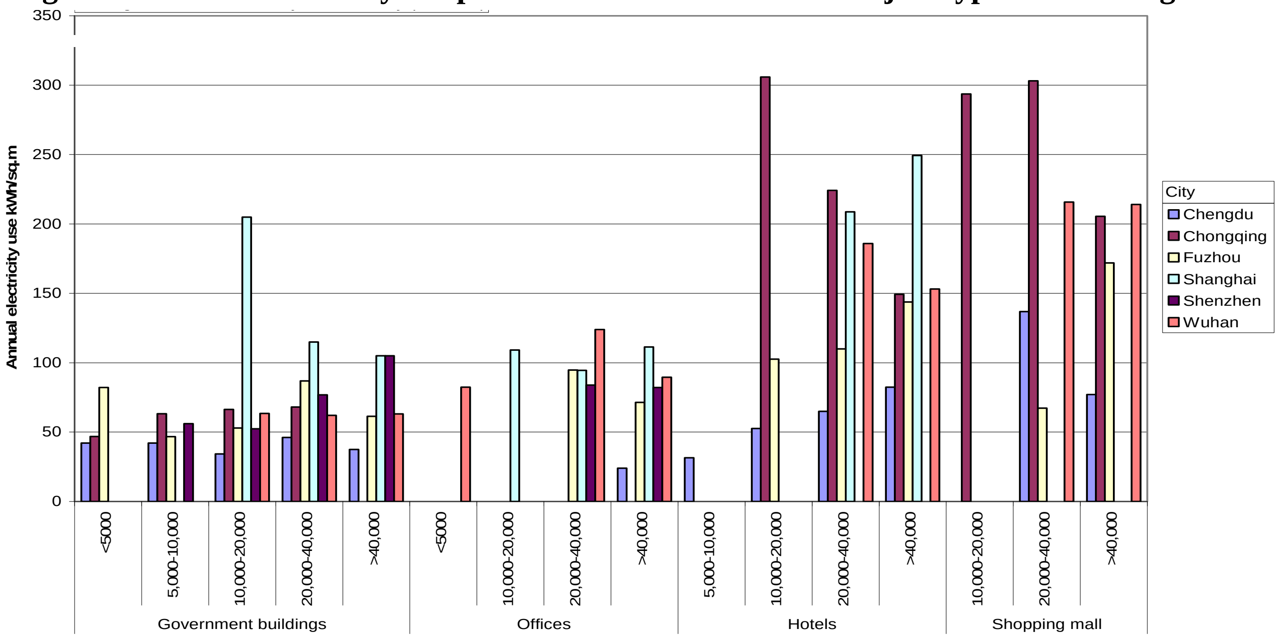
Government Office Building

One of MOHURD's main objectives for the surveys is to figure out the energy usage of governmental buildings, because of a growing concern that they are more wasteful than private

Table 4 Year Built and Floor Area of the Building Sample

Year built	Floor area	Shang hai	Cheng du	Wu han	Shen zhen	Fu zhou	Chong qing	Total
1930s	20,000 - 40,000	1						1
	> 40,000	1					5	6
1950s	< 5,000					2	2	4
	20,000 - 40,000	1						1
1960s and 1970s	< 5,000					12	2	14
	<10000					1		1
	10,000 - 20,000					3		3
	20,000 - 40,000					5		5
	> 40,000	2				1		3
1980s and 1990s	< 5,000					2		2
	<10000					4	2	6
	10,000 - 20,000	4				6	5	15
	20,000 - 40,000	13				40	4	57
	> 40,000	36				17	1	54
2000s	< 5,000					3	6	9
	<10000					5	5	10
	10,000 - 20,000	1				4	8	13
	20,000 - 40,000	6				23	15	44
	> 40,000	18				17	2	37
Unknown	< 5,000		4	1				5
	<10000		13		4			17
	10,000 - 20,000		13	4	8			25
	20,000 - 40,000		17	11	10			38
	> 40,000		16	7	9			32
Total		83	63	23	31	145	57	402

Figure 1. Annual Electricity use per m^2 Floor Area for Four Major Types of Buildings



buildings. Consequently, nearly all the government buildings, whether belonging to the central or local government, has been included in the surveys. Since the government buildings are nearly all offices, it is most meaningful to compare their EUIs to that of other, i.e., privately-owned, offices.

When the EUIs of government office buildings are compared to those for private offices, it shows that MOHURD's concern about excessive waste in government buildings is unwarranted. Table 5 shows the average, maximum, and minimum electricity EUIs of government versus private office buildings in five of the six cities. While government buildings had higher EUIs in Shanghai, Chengdu, and Wuhan, they had lower EUIs in Shenzhen and Fuzhou. Furthermore, the worst performing government buildings are not worse than the worst private offices (nor are the best performing better than the best of the private offices, either). There is also no compelling evidence that government buildings use more energy for cooling and lighting than do private offices.

Table 5 Comparison of Government and Private Offices

	Annual Electricity Use (kWh/m^2)	Shanghai	Chengdu	Wuhan	Shenzhen	Fuzhou
Govern-ment offices	Average	135.0	40.6	62.8	59.5	68.0
	Maximum	205.0	96.8	73.4	105.0	248.2
	Minimum	104.7	24.6	47.3	30.0	15.7
	Sample size	4	19	12	13	41
Private offices	Average	108.0	24.0	98.7	83.1	86.8
	Maximum	179.1	24.0	124.0	139.5	342.2
	Minimum	62.1	24.0	82.4	47.9	5.1
	Sample size	42	1	3	14	47

Private Offices

In all six cities, the EUIs for private offices are almost same as for government office buildings, from 50 to 100 kWh/m^2 for the former, as compared to 40 to 80 kWh/m^2 for the latter. There are, however, distinct regional differences. The office EUIs in Chengdu are significantly lower, and the government office EUIs are only a quarter that found in the other cities. Similar regional differences are seen for other building types as well, with electricity use in Chengdu for hotels and shopping malls likewise much lower than that in the other cities. Although one possible explanation is the cooler climate in Chengdu, another explanation is that buildings in Chengdu may not be providing the same levels of service as buildings in the other cities. It has been observed that lighting levels have been increasing, as well as the installation of central air conditioning, which often doubles or triples cooling energy consumption. As the richest city in China, Shanghai also has building EUIs that are the highest among the six cities. Even though Fuzhou has 50% more cooling degree days than does Shanghai, the building EUIs in the two cities are the same.

Hotel and Shopping Malls

The electricity EUIs of hotels and shopping malls are much higher than those for offices. Except for hotels in Chengdu, the average electricity use per year ranged from 200-300 kWh/m^2. In shopping malls, the lighting power density is typically higher than that in offices, which not only increases lighting electricity, but also cooling electricity due to the heat gain from the lights. The electricity EUI of hotels is higher compared to offices because of the food services and higher lighting power densities in the public areas. Electricity use in hotels is also very regionally specific. For example, hotels in Chongqing use much more electricity than do hotels in Chengdu.

The Impact of Size on Building EUIs

In Figure 1 and Table 6, the average electricity EUIs for the four major building types are disaggregated by floor area. Further study indicates there are also no observable trends in electricity EUIs with changes in floor area by building type in each of the individual city. There may be interrelations between building size, vintage, and EUI, but these were not investigated in this study.

Table 6. EUIs by Floor Area for Government Buildings, Offices, and Shopping Malls

<table>
<tr><th></th><th>Floor area (m^2)</th><th>Govt. offices</th><th>Private offices</th><th>Shopping malls</th></tr>
<tr><td rowspan="6">Average Annual Electricity Use (kWh/m^2)</td><td>< 5,000</td><td>70.08</td><td>82.40</td><td></td></tr>
<tr><td><10,000</td><td>54.07</td><td rowspan="2">109.11</td><td rowspan="2">293.67</td></tr>
<tr><td>10,000 - 20,000</td><td>63.82</td></tr>
<tr><td>20,000 - 40,000</td><td>75.83</td><td>93.72</td><td>223.48</td></tr>
<tr><td>> 40,000</td><td>76.53</td><td>95.36</td><td>197.20</td></tr>
<tr><td>All</td><td>66.35</td><td>95.03</td><td>228.04</td></tr>
<tr><td rowspan="6">Maximum Annual Electricity Use (kWh/m^2)</td><td>< 5,000</td><td>248.21</td><td>82.40</td><td></td></tr>
<tr><td><10,000</td><td>96.19</td><td rowspan="2">144.18</td><td rowspan="2">394.46</td></tr>
<tr><td>10,000 - 20,000</td><td>205.00</td></tr>
<tr><td>20,000 - 40,000</td><td>125.35</td><td>342.20</td><td>397.96</td></tr>
<tr><td>> 40,000</td><td>104.96</td><td>179.08</td><td>252.90</td></tr>
<tr><td>All</td><td>248.21</td><td>342.20</td><td>397.96</td></tr>
<tr><td rowspan="6">Minimum Annual Electricity Use (kWh/m^2)</td><td>< 5,000</td><td>15.71</td><td>82.40</td><td></td></tr>
<tr><td><10,000</td><td>21.40</td><td rowspan="2">86.07</td><td rowspan="2">212.61</td></tr>
<tr><td>10,000 - 20,000</td><td>19.22</td></tr>
<tr><td>20,000 - 40,000</td><td>5.13</td><td>6.08</td><td>8.93</td></tr>
<tr><td>> 40,000</td><td>40.91</td><td>5.11</td><td>130.62</td></tr>
<tr><td>All</td><td>5.13</td><td>5.11</td><td>8.93</td></tr>
<tr><td rowspan="6">Sample size</td><td>< 5,000</td><td>29</td><td>1</td><td></td></tr>
<tr><td><10,000</td><td>21</td><td rowspan="2">4</td><td rowspan="2">4</td></tr>
<tr><td>10,000 - 20,000</td><td>25</td></tr>
<tr><td>20,000 - 40,000</td><td>16</td><td>47</td><td>17</td></tr>
<tr><td>> 40,000</td><td>6</td><td>54</td><td>6</td></tr>
<tr><td>Subtotal</td><td>97</td><td>106</td><td>27</td></tr>
</table>

Variations in Electricity EUIs for Worst and Best Performing Buildings

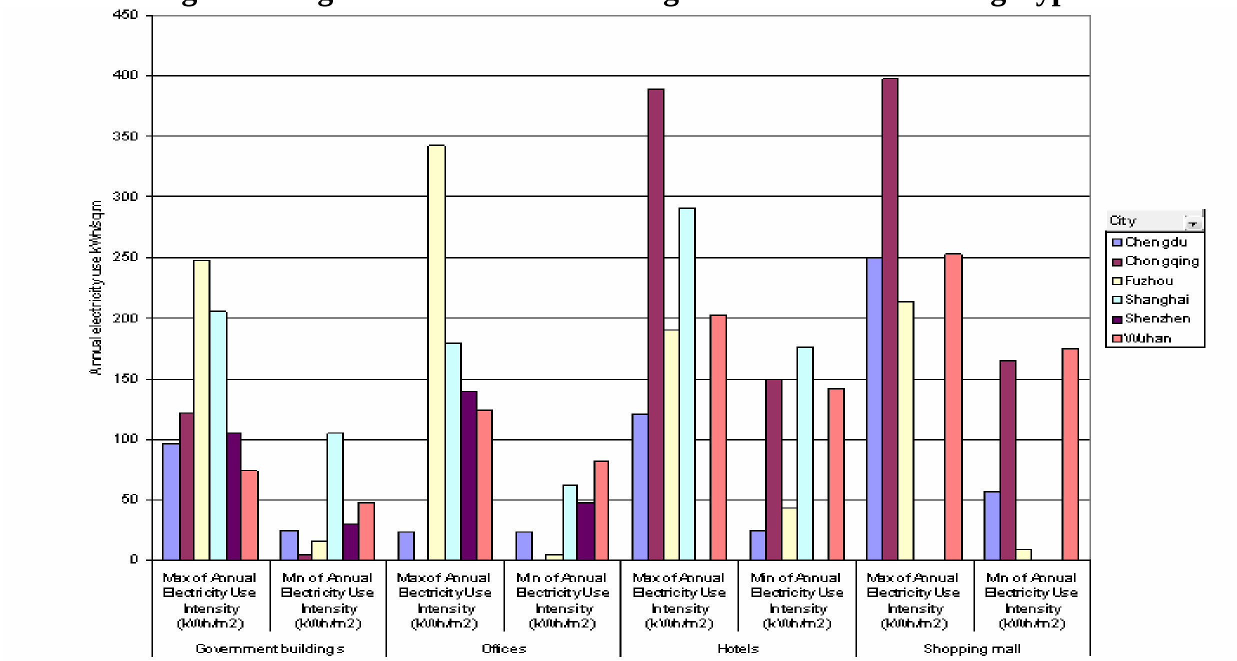
Figure 2 compares the worst and best performing buildings among the four major building types in the six cities. There are large variations in EUIs for all four building types in the six cities, a sign of large potentials for improving building energy efficiency.[2] The variations are much higher for office buildings than for shopping malls and hotels, with the highest EUIs ten times larger than the lowest EUIs. The surveys do not contain information on comfort levels or indoor air temperatures, thus making it is hard to judge whether the buildings with the lowest EUIs are indeed the best performing buildings. A general impression left with the author from site visits is that the buildings with the lowest EUIs are energy efficient, but also do not meet basic requirement for comfort and lighting levels. A typical building with low EUIs in south China is one built in the old Soviet style with no heating, and only window air conditioners for cooling.

The situation with large hotels and shopping malls are different. Since most of these buildings were built after 1990, they have similar service levels and strive to provide high levels of thermal comfort and lighting to attract clients. However, even for these two building types,

[2] The full report shows the variations in EUIs by building size in each city.

the highest EUIs are still about twice that of the lowest EUIs. Since all the large hotels and shopping malls in the survey are equipped with central air-conditioning, the differences in EUIs can only be attributed to the building design and operation

Figure 2. Highest and Lowest Building EUIs for Four Building Types



The Impact of Vintage on Building EUIs

Table 7 shows average EUIs by building vintage for three major building types - government buildings, offices, and hotels.[3] The sample sizes for the other building types are not large enough to be included in the analysis. The difference in average electricity EUIs between buildings of different vintages is small. For example, in Table 7, the average electricity EUIs for office and government buildings, as well as hotels, are only slightly higher for buildings built in 1980s as compared to before. The comparison of minimum EUIs also shows that there are buildings with low EUIs regardless of their vintage. This suggests that building operations is more important than their physical characteristics in determining their energy efficiency. The best buildings built in 2000s are not necessary better than those built in1950s. For example, in Shanghai, the 1930s hotel has about the same EUI as hotels built after 1990.

However, when the maximum EUIs by vintage are compared, a clear trend is apparent. Figure 3 is a plot of the maximum electricity EUIs for buildings of different vintages, which shows the EUIs of the worst buildings getting higher and higher over the years. The same trend applies to government buildings, offices, hotels and shopping malls in virtually all cities. For example, in Chongqing, the worst government building built in the 1950s uses about 75 kWh/m^2, while the same such building built in 2000s uses about 120 kWh/m^2 of electricity a year. In Shanghai, the most energy intensive building built in 1940s uses about 175 kWh/m^2, while the same such building built in 2000s uses about 275 kWh/m^2 of electricity per year.

[3] The full report shows the average EUIs by building type and vintage for each city.

Table 7. Electricity EUIs of Three Building Types by Vintage

	Year of built	Govt bldgs	Offices	Hotels
Average Annual Electricity Use (kWh/m^2)	1930			175.9
	1950	57.1		265.8
	1970s or before	72.7	70.7	135.5
	1980-1990s	70.7	96.4	120.1
	2000s	66.2	99.6	172.6
	Unknown	61.1	85.8	169.5
	All	66.3	95.0	146.3
Maximum Annual Electricity Use (kWh/m^2)	1930			175.9
	1950	78.2		265.8
	1970s or before	138.4	74.5	290.6
	1980-1990s	128.4	263.8	223.1
	2000s	248.2	342.2	388.8
	Unknown	105.0	139.5	203.1
	All	248.2	342.2	388.8
Minimum Annual Electricity Use (kWh/m^2)	1950	29.2		265.8
	1970s or before	15.7	66.9	42.9
	1980-1990s	21.4	6.1	70.1
	2000s	5.1	5.1	51.4
	Unknown	30.0	47.9	142.2
	All	5.1	5.1	42.9
Sample size	1930			1
	1950	4		1
	1970s or before	15	2	8
	1980-1990s	18	59	18
	2000s	35	28	12
	Unknown	25	17	4
	All	97	106	44

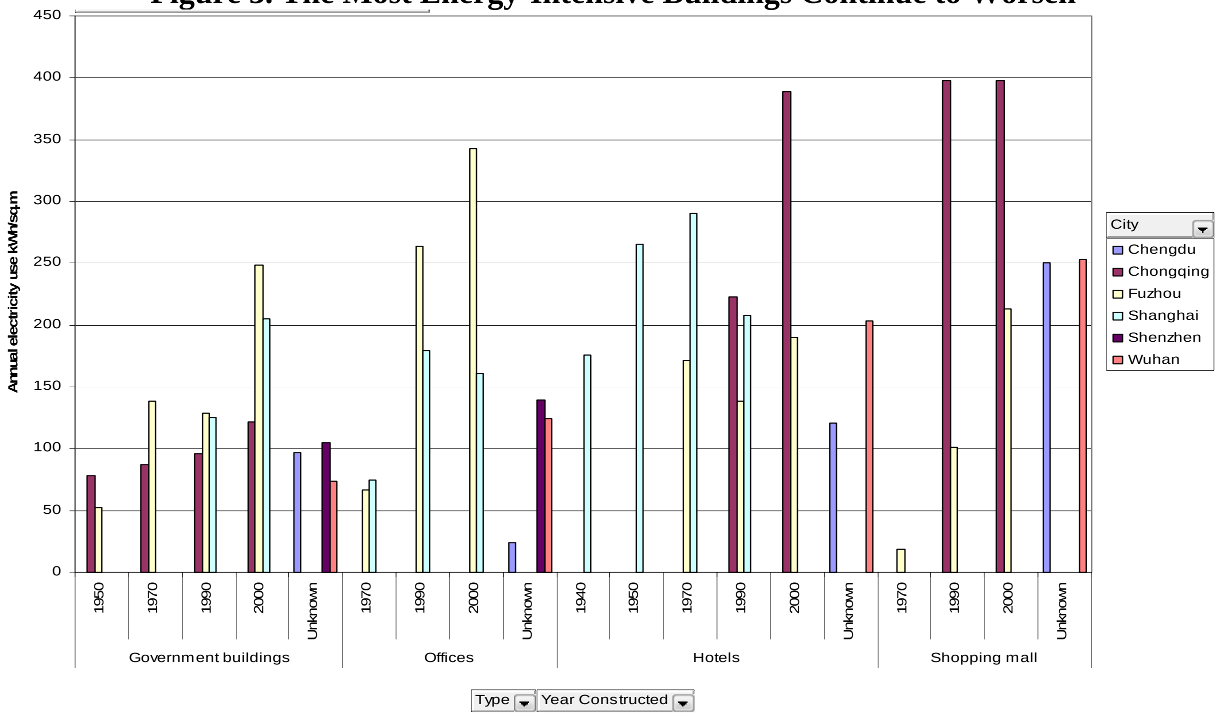
Comparison building EUIs between China, the US, and India

The EUIs derived from these surveys are compared to those available in the literature for the US and India. For the US, EUIs are obtained from the 2003 Commercial Buildings Energy Consumption Survey (CBECS) for buildings in the southern part of the U.S (EIA 2007). In India, the equivalent weather zone to the six Chinese cities is the “Subtropical humid area” in northeast India. In 2008, the Bureau of Energy Efficiency (BEE) under the Ministry of Power completed a survey of 40 buildings for different types of commercial buildings, including shopping malls, hotels, and hospitals, and calculated average EUIs by building type (Spatial Decisions 2008).

Figure 4 compares the EUIs of different building types in the three countries. Although the building types in the surveys are slightly different, in general, the EUIs of buildings in India are very close to those in China, and both are significantly lower than those of buildings in the US. The average EUI of all public buildings in China is about half that of the equivalent commercial buildings in the US.

The EUI of schools in China are the lowest of all reported building types in the three countries. This is not unexpected because in southern China, educational facilities normally have neither heating nor cooling. Compared with food sales in the US, the EUI of Chinese supermarkets is roughly one third as much. Compared with US health care facilities, the EUI of Chinese hospitals is roughly half, although still 50% more that that in Indian hospitals. Compared to US hotels, the EUI of Chinese hotels are about half, while that of Indian hotels are about the same. Compared to mercantile in the US, the EUIs of Chinese shopping malls are lower by 20% lower, as are that for shopping malls in India, although overall the difference are much less than for other building types. Compared to office buildings in the US, Chinese office buildings have EUIs lower by 60%, and also lower by 30% compared to offices in India.

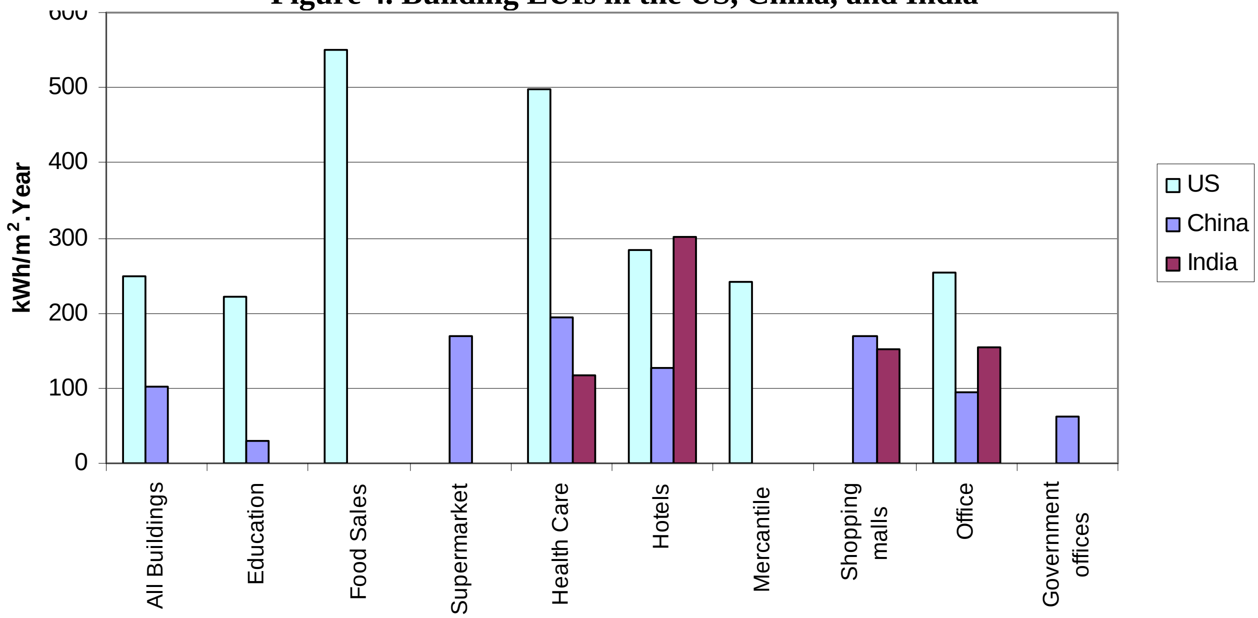
Figure 3. The Most Energy-Intensive Buildings Continue to Worsen



Conclusions

As an initial attempt to gather survey data on building energy use, this project has been a learning process for MOHURD as well as the participating cities. Although MOHURD had provided a survey template, there was still a great deal of variation in the surveys done in each city. The author was disappointed that his recommendations to gather more information on building characteristics and energy efficiency measures was largely ignored. Nevertheless, he is hopeful about the progress being made, and the interest shown in all the cities to expand the data base and develop benchmark buildings using the data that would clarify the energy use characteristics of public buildings in those cities.

Figure 4. Building EUIs in the US, China, and India



Initial analysis of the data has found that, on average, annual building electricity use is between 50100 kWh/m^2 for offices, 120-250 kWh/m^2 for shopping malls and hotels, and below40 kWh/m^2 for schools. The variation of EUIs among the six cities is related primarily to differences in their level of economic development, and only secondarily to differences in their climate.

Building EUIs have also been found to correlate neither to building size, nor vintage, although vintage does have an effect on the EUI distribution. While the average EUI of newer public buildings are the same as of older buildings, the most energy-intensive new buildings use much more energy than do such buildings of older vintage, the reason being that newer buildings have more energy-using equipment, and thus greater potential for energy waste. Many old Soviet style buildings have no heating, and only window air conditioners for cooling. Thus, poor energy performance or management results in poor comfort and lighting levels, but not energy waste. For new buildings, poor energy performance or management may not affect comfort levels, but produce much more energy waste.

Although the average EUIs of Chinese public buildings are rising, they are still only half compared to US buildings of equivalent usage in similar climates, but about the same as compared to Indian buildings of equivalent usage. This again may be a reflection of the countries' different levels of economic development.

As China continues to develop, building EUIs will likely continue to increase. However, with improved building energy design combined with energy efficient operations, this trend can be slowed and eventually reversed, although the challenge will be great.

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