



# Study on Energy Efficiency and Measurement of CO<sub>2</sub> Emissions on Buildings: A Case Study in Hebei, China

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**Abstract:** Research on energy efficiency and measurement of CO<sub>2</sub> emissions on buildings, is crucial for taking countermeasures against climate change and identifying low carbon pattern in buildings of Hebei. Energy efficiency directly influence CO<sub>2</sub> emissions. This paper presents two measurement methods of CO<sub>2</sub> emissions, including the measurement from top-down using energy balance sheet and the measurement from bottom-up regarding structure decomposition of energy consumption of various service demand. Meanwhile, this study decomposes the energy consumption of buildings into detailed categories of service demands to explain energy efficiency, such as cooling, household appliance, domestic hot water and cooking in urban and rural residence except for central heating. Results reveal that energy consumption and CO<sub>2</sub> emissions in urban, rural and public buildings maintain continuous growth reaching a highest year-increasing rate 18.07% in 2010. Specifically, public buildings show an extreme increasing rate with a total CO<sub>2</sub> emissions of 208.45 million tons. Besides, CO<sub>2</sub> emissions in cooling and cooking reach higher than other service demand. Eventually, policy implications are provided to mitigate the growth of CO<sub>2</sub> emissions and identify energy efficiency strategies in Hebei.

**Keywords:** CO<sub>2</sub> Emissions, Energy Efficiency, Buildings, Measurement

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## 1. Introduction

Since 2004, global CO<sub>2</sub> emissions burned by fossil fuels have accounted for 56.6% of greenhouse gas emissions. In addition, China's CO<sub>2</sub> emissions from fossil energy accounted for as high as 26.38% of the world's total and ranked the first with absolute predominance [1]. Copenhagen agreement in 2009 has urges China solemnly to pledge a significant cut in carbon intensity by at least 40% by 2020 from 2005 level. Since Copenhagen agreement, energy efficiency issue and greenhouse gases growth, has made China a focal point for criticism.

As a critical part, buildings released a lower CO<sub>2</sub> in the process of construction and a higher CO<sub>2</sub> due to the pull effect on majorities of other industries, accounting for 50% of the total CO<sub>2</sub> emissions. Therefore, the application of more accurate method to measure CO<sub>2</sub> emissions on buildings sector and then decompose impact components are crucial in promoting low-carbon buildings. Development and Reform Commission of China established a Low-carbon City policy and announced the selection of five provinces and eight cities to pilot low-carbon development work [2-6]. As an

economy-developed province in China, Hebei ranks the sixth with GDP reaching 2019.71 billion yuan in 2010. Moreover, as economic development is highly dependent on energy consumption, the latter has also increased to 25418 million tons on standard coal in 2009. In this context, research on the measurement of CO<sub>2</sub> emissions on buildings of Hebei in China has experienced a remarkable impetus.

This paper presents two measurement methods of CO<sub>2</sub> emissions, including the measurement from top-down by the energy balance sheet and the measurement from bottom-up regarding structure decomposition of energy consumption of various service demand on building sector. The paper is structured as follows. Section 2 presents an overview of the main methods related to the measurement from top-down and bottom-up. In section 3, the data source is reported. Section 4 draws the result and discussions followed by conclusions and implications in section 5.

## 2. Methodologies

This paper conforms to international general classification and decomposes buildings sector into residential buildings

and public buildings. Meanwhile, residential buildings can be divided into urban and rural residence buildings, seen as Figure 1.

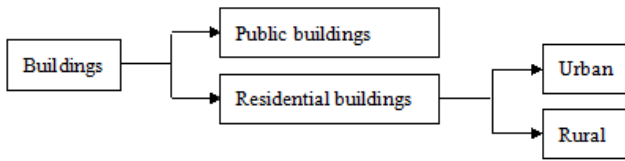


Figure 1. Buildings sector after redivision.

## 2.1. The Measurement From Top-Down

Energy balance sheet intuitively reveals balance between energy resources, conversion and final consumption judged by data. Accordingly, energy consumption in buildings involve in four factors, namely consumption in central heating, urban residence except for central heating, rural residence except for central heating, and public buildings except for central heating. In addition, energy consumption in central heating are overall derived from heating production sector thus been calculated in heating production sector. Table 1 shows the adjustment method of energy consumption in buildings of Hebei [7].

Table 1. The measurement from top-down in buildings of Hebei.

Sector	Sectors in energy balance sheet	Adjustment method
Urban Buildings	Final consumption in urban living	Various energy consumption except for all gas and 95% diesel oil
Rural Buildings	Final consumption in rural living	Various energy consumption except for all gas and 95% diesel oil
	Final consumption of wholesale, retail, hotels and catering industry in tertiary industry	Various energy consumption except for 95%gas and 35% diesel oil
Public buildings	Final consumption of other industry in tertiary industry	Various energy consumption except for 95%gas and 35% diesel oil
	Final consumption of transportation, storage, mail industry in tertiary industry	15% electricity consumption

## 2.2. The Measurement from Bottom-Up

The measurement from bottom-up, typically taking energy service demand and technology level into account, is to break down the structure of all sectors energy consumption [8]. Calculating steps and formulas are shown in Table 2.

(1) The combination of technologies for achieving specific energy service demand is calculated as follows:

$$P_i = \sum P_{t,i} \quad (1)$$

where  $P_i$  is the demand quantity for energy service demand  $i$ ;  $P_{t,i}$  presents the demand quantity for energy service demand  $i$  by technology  $t$ ;  $i$  is the type of energy-service demand, such as building lighting in urban, steel demand quantity etc;  $t$  denotes the type of technology, such as building lighting in cities including incandescent, energy-saving lights, LEDs.

(2) Total energy consumption for all sectors energy-service demand is calculated as follows:

$$E = \sum_i \sum_t \sum_n F_{n,t,i} \times P_{t,i} \quad (2)$$

where  $E$  denotes the total energy consumption for all sectors energy-service demand (ton standard coal);  $F_{n,t,i}$  presents the energy consumption of  $N$  during the process of meeting energy service demand.  $N$  is energy types, such as electricity, coal, natural gas etc.

(3) Emissions that satisfy the sector's energy-service demand are calculated as follows:

$$CE = \sum_i \sum_t \sum_n EF_{n,t,i} \times F_{n,t,i} \times P_{t,i} \quad (3)$$

where  $CE$  is the CO<sub>2</sub> emissions of this sector;  $EF_{n,t,i}$  denotes emission factor of  $n$  in the process of meeting energy-service demand with technology  $t$ .

Table 2. The measurement from bottom-up in buildings of Hebei.

Sector	Various categories	Adjustment method	Emission factor
Urban buildings	Cooling	$E_{cool,u} = \sum E_i = \sum H \times EQ_i \times T_i \times W_i$	0.9914 TCO <sub>2</sub> /MWh
	Household appliance	$E_{happ,u} = \sum E_i = \sum H \times EQ_i \times T_i \times W_i$	
	Domestic hot water	$E_{dome,u} = \sum P_u \times 1.3$	2.62 TCO <sub>2</sub> /MWh
	Cooking	$E_{cook,u} = \sum P_u \times 4.5$	
Rural buildings	Cooling	$E_{cool,u} = \sum E_i = \sum H \times EQ_i \times T_i \times W_i$	0.9914 TCO <sub>2</sub> /MWh
	Household appliance	$E_{happ,u} = \sum E_i = \sum H \times EQ_i \times T_i \times W_i$	
	Domestic hot water	$E_{dome,u} = \sum P_r \times 1.3$	2.62 TCO <sub>2</sub> /MWh
	Cooking	$E_{cook,u} = \sum P_r \times 4.5$	
Public buildings	Operational Area of Catering Services	$E_{cate,u} = \sum M_c \times 195$	0.9914 TCO <sub>2</sub> /MWh
	Operational Area of hotels	$E_{area,u} = \sum M_d \times 195$	
	Floor Space of Public Buildings	$E_{flo,u} = \sum M_j \times 95$	

Note:  $E$  is total energy consumption of various categories (ton standard coal);  $E_i$  is energy consumption of equipment  $i$  (ton standard coal);  $H$  is the total households;  $EQ_i$  is ownership of household appliance  $i$ ;  $T_i$  is the time using household appliance  $i$  (hours);  $W_i$  is the power of household appliance  $i$  (watts);  $I$  is equipment type, such as air-conditioning etc.  $P$  is the total person;  $M$  is the total area. Per capita domestic hot water demand coefficient is 1.3; Per capita cooking heating demand coefficient is 4.5 kgce/a. Big hotels and restaurants electricity consumption per unit area is 195(kWh/(m<sup>2</sup>·a)); large schools, public library electricity consumption per unit area is 95(kWh/(m<sup>2</sup>·a)).

### 3. Data Sources

The data for buildings is obtained from the Hebei Statistic Yearbook (2003–2012). Moreover, various coefficients of energy conversion and CO<sub>2</sub> emissions are collected from the general principles of the comprehensive energy consumption calculation GB/T 2589-2008. In accordance with related departments, this study is accessed to Hebei statistical review and energy balance sheet, and then picks the methodology from IPCC guidelines for inventories. Besides, energy consumption multiplies emission factor is taken as 2.62 reference to China city greenhouse-gases inventory guide and per capita heating demand coefficient is reference to China city greenhouse-gases inventory Guide [9]. All unit is in 10<sup>4</sup> tons.

### 4. Results and Discussions

#### 4.1. The measurement of CO<sub>2</sub> Emissions from Top-Down in Buildings

Investigating Table 3 and Table 4, energy consumption of buildings reach the highest year-increasing rate at 18.07% in 2010; CO<sub>2</sub> emissions of buildings approaches the highest annual growth rate at 18.08% in 2010. Both annual growth rate keep 6.75%.

**Table 3.** The energy consumption of buildings in 2003-2012.

	Urban	Rural	Public buildings
2003	525.666	585.988	195.905
2004	537.196	581.411	263.901
2005	544.338	598.850	459.806
2006	477.309	555.074	458.636
2007	462.097	556.941	509.988
2008	581.977	599.352	587.565
2009	613.533	586.167	602.870
2010	764.177	654.697	709.431
2011	787.182	664.551	773.103
2012	794.552	707.477	795.612

**Table 4.** The CO<sub>2</sub> emissions of buildings in 2003-2012.

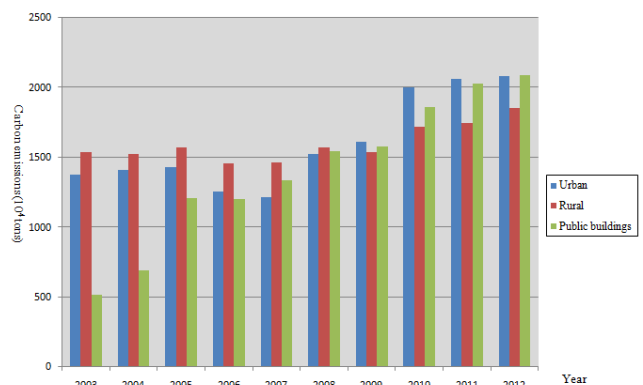
	Urban	Rural	Public buildings
2003	1377.244	1535.289	513.271
2004	1407.454	1523.297	691.421
2005	1426.165	1568.988	1204.693
2006	1250.550	1454.294	1201.625
2007	1210.694	1459.186	1336.169
2008	1524.781	1570.303	1539.421
2009	1607.456	1535.758	1579.519
2010	2002.143	1715.307	1858.709
2011	2062.416	1741.124	2025.529
2012	2081.727	1853.591	2084.505

Figure 2 shows a fluctuated trend of CO<sub>2</sub> emissions in urban residence except for central heating, namely an upward trend in 2003-2005, followed by a little decreasing in 2006-2007 and finally a remarkable increasing. However, CO<sub>2</sub> emissions in rural residence except for central heating, fluctuates around 15,800,000 tons; More specifically, owing to a improving

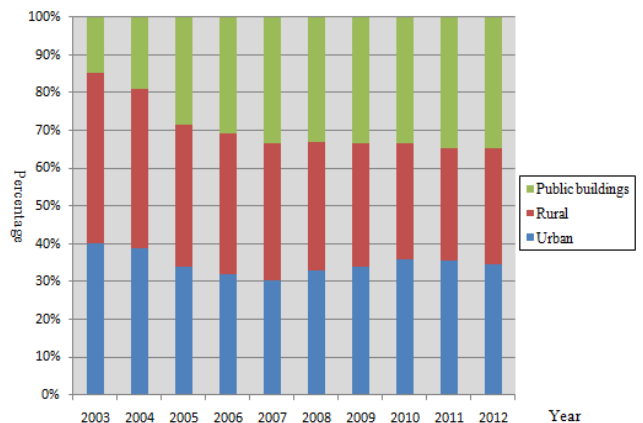
living standard and then more utilization of heating radiator or small boiler etc, CO<sub>2</sub> emissions shows a sharply increasing trend since 2010. CO<sub>2</sub> emissions in public buildings except for central heating keeps increasing mainly in recent years, except for a little decline in 2006-2007.

Figure 3 presents the percentages of CO<sub>2</sub> emissions from urban, rural and public buildings in 2003-2012. The percentage of in urban residence except for central heating, shows a cyclical changing trend, namely a little decrease in 2003-2007, followed by a little increase in 2008-2012. The percentage of in rural residence except for central heating mainly keeps decreasing, while the percentage of public buildings except for central heating shows an upward trend continuously. Therefore, the orientation of emission reduction has been urged toward public buildings except for central heating.

Figure 4 demonstrates CO<sub>2</sub> emissions variations from various industries of public buildings in 2003-2012. Figure 5 shows the detailed percentage variations. Figure 4-5 illustrates that CO<sub>2</sub> emissions of transportation, storage, mail industry wholesale, retail, hotels and catering industry and other industry in tertiary industry keeps stead increasing. Besides, CO<sub>2</sub> emissions of transportation, storage, mail industry wholesale, retail, hotels takes up the majority of total CO<sub>2</sub> emissions, accounting for 70%.



**Figure 2.** The bar chart of CO<sub>2</sub> emissions from urban, rural and public buildings in 2003-2012.



**Figure 3.** Percentages of CO<sub>2</sub> emissions from urban, rural and public buildings in 2003-2012.

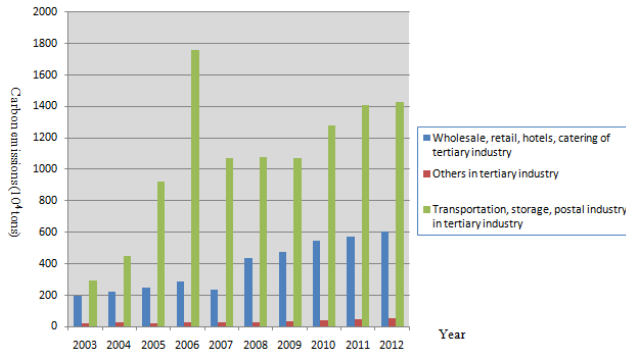


Figure 4. CO<sub>2</sub> emissions from various industries of public buildings in 2003-2012.

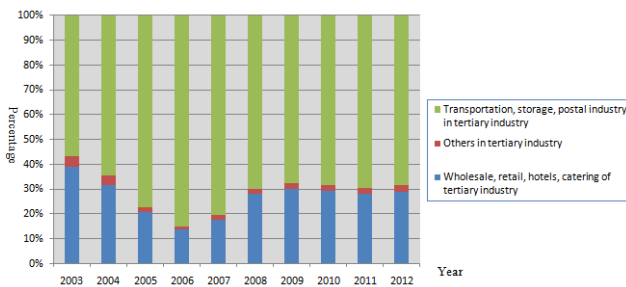


Figure 5. CO<sub>2</sub> emissions percentages from various industry of public buildings in 2003-2012.

buildings in 2003-2012.

## 4.2. The Measurement of CO<sub>2</sub> Emissions from Bottom-Up in Buildings

### 4.2.1. CO<sub>2</sub> Emissions of Urban Residence Except for Central Heating

Table 5-8 demonstrate CO<sub>2</sub> emissions of urban residence except for central heating respectively, including cooling, household appliance, domestic hot water and cooking. Results show that CO<sub>2</sub> emissions in urban cooling and household appliance electricity, keep decreasing over a decade. Both decline rate reach the highest at 22.14% and 23.33%. However, domestic hot water and cooking keep increasing at an annual growth rate at 6.42% and 6.12% respectively.

Table 5. Urban cooling energy consumption and CO<sub>2</sub> emissions in 2003-2012.

Year	Air-conditioning energy consumption (MWh)	CO <sub>2</sub> emissions (10 <sup>4</sup> tons)
2003	494394.900	49.014
2004	442064.700	43.826
2005	413951.966	41.039
2006	481367.374	47.723
2007	515421.709	51.099
2008	545687.863	54.099
2009	431984.383	42.827
2010	336300.914	33.341
2011	380700.000	37.743
2012	334568.000	33.169

Table 6. Urban household appliance electricity consumption and CO<sub>2</sub> emissions in 2003-2012.

Year	TV energy consumption (MWh)	Washing machine energy consumption (MWh)	Refrigerator energy consumption (MWh)	Total energy consumption of domestic appliance (MWh)	CO <sub>2</sub> emissions (10 <sup>4</sup> tons)
2003	136384.800	51144.300	315.896	187844.996	18.623
2004	126304.200	45928.800	300.701	172533.701	17.105
2005	123680.770	38889.796	297.885	162868.452	16.147
2006	119215.838	36032.178	286.667	155534.683	15.420
2007	116447.127	35634.093	277.714	152358.935	15.105
2008	105175.219	35457.301	294.105	140926.625	13.971
2009	105462.854	34487.642	289.070	140239.566	13.903
2010	81029.024	26265.047	220.149	107514.221	10.659
2011	95175.000	25380.000	258.833	120813.833	11.977
2012	83642.000	19302.000	238.664	103182.664	10.230

*Table 7. Urban domestic hot water energy consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	People (persons)	Per capital heating demand (kgce/a)	Domestic hot water energy consumption (tons of standard coal )	CO <sub>2</sub> emissions (tons)
2003	19950000	1.3	25935.000	67949.700
2004	23870000	1.3	31031.000	81301.220
2005	25820000	1.3	33566.000	87942.920
2006	26990000	1.3	35087.000	91927.940
2007	27950000	1.3	36335.000	95197.700
2008	29280000	1.3	38064.000	99727.680
2009	30770000	1.3	40001.000	104802.620
2010	32010000	1.3	41613.000	109026.060
2011	33020000	1.3	42926.000	112466.120
2012	33870000	1.3	44031.000	115361.220

*Table 8. Urban cooking energy consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	People (persons)	Per capital heating demand (kgce/a)	Cooking energy consumption (tons of standard coal )	CO <sub>2</sub> emissions (tons)
2003	19950000	4.5	89775	235210.5
2004	23870000	4.5	107415	281427.3
2005	25820000	4.5	116190	304417.8
2006	26990000	4.5	121455	318212.1
2007	27950000	4.5	125775	329530.5
2008	29280000	4.5	131760	345211.2
2009	30770000	4.5	138465	362778.3
2010	32010000	4.5	144045	377397.9
2011	33020000	4.5	148590	389305.8
2012	33870000	4.5	152415	399327.3

#### 4.2.2. CO<sub>2</sub> Emissions of Rural Residence Except for Central Heating

Table 9-12 demonstrate CO<sub>2</sub> emissions of rural residence except for central heating respectively, including cooling, household appliance, domestic hot water and cooking. Findings demonstrate that, these four parts show a decreasing trend in recent years, out of which, rural cooling has the largest annual decreasing rate at 1.04% and cooking decreases slowly at 1.59%.

*Table 9. Rural cooling energy consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	Air-conditioning energy consumption (MWh)	CO <sub>2</sub> emissions (10 <sup>4</sup> tons)
2003	1248624.000	123.789
2004	1114267.000	110.468
2005	1002977.537	99.435
2006	1086830.049	107.748
2007	1172286.292	116.220
2008	1282680.891	127.165
2009	1029939.359	102.108
2010	998347.325	98.976
2011	922140.000	91.421
2012	804544.000	79.762

*Table 10. Rural household appliance electricity consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	TV energy consumption (MWh)	Washing machine energy consumption(MWh)	Refrigerator energy consumption (MWh)	Total energy consumption of domestic appliance (MWh)	CO <sub>2</sub> emissions (10 <sup>4</sup> tons)
2003	344448.00	129168.00	797.81	474413.81	47.033
2004	318362.00	115768.00	757.95	434887.95	43.115
2005	299670.12	94227.34	721.76	394619.21	39.123
2006	269165.22	81353.36	647.24	351165.82	34.815
2007	264849.87	81046.95	631.64	346528.46	34.355
2008	247222.37	83345.09	691.32	331258.77	32.84
2009	251445.07	82225.61	689.20	334359.89	33.15
2010	240543.83	77970.77	653.54	319168.13	31.64
2011	230535.00	61476.00	626.95	292637.95	29.01
2012	201136.00	46416.00	573.92	248125.92	24.60

*Table 11. Rural domestic hot water energy consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	People (persons)	Per capital heating demand (kgce/a)	Domestic hot water energy consumption (tons of standard coal )	CO <sub>2</sub> emissions (tons)
2003	46010000	1.3	59813.000	156710.060
2004	43670000	1.3	56771.000	148740.020
2005	42690000	1.3	55497.000	145402.140
2006	41990000	1.3	54587.000	143017.940
2007	41480000	1.3	53924.000	141280.880
2008	40610000	1.3	52793.000	138317.660
2009	39570000	1.3	51441.000	134775.420
2010	39930000	1.3	51909.000	136001.580
2011	39390000	1.3	51207.000	134162.340
2012	39760000	1.3	51688.000	135422.560

*Table 12. Rural cooking energy consumption and CO<sub>2</sub> emissions in 2003-2012.*

Year	People (persons)	Per capital heating demand (kgce/a)	Cooking energy consumption (tons of standard coal )	CO <sub>2</sub> emissions (tons)
2003	46010000	4.5	207045.000	542457.900
2004	43670000	4.5	196515.000	514869.300
2005	42690000	4.5	192105.000	503315.100
2006	41990000	4.5	188955.000	495062.100
2007	41480000	4.5	186660.000	489049.200
2008	40610000	4.5	182745.000	478791.900
2009	39570000	4.5	178065.000	466530.300
2010	39930000	4.5	179685.000	470774.700
2011	39390000	4.5	177255.000	464408.100
2012	39760000	4.5	178920.000	468770.400

#### 4.2.3. CO<sub>2</sub> Emissions of Public Buildings Except for Central Heating

Table 13 shows the construction areas of various public buildings. In addition, Table 14 illustrates energy consumption of various public buildings. As for this sector, CO<sub>2</sub> emissions keep an upward trend.

*Table 13. Construction areas of various public buildings.*

	Operational Area of Catering Services (sq. m)	Operational Area of hotels (sq.m)	Floor Space of Public Buildings (sq.m)
2003	278000	371000	249000
2004	299000	418000	251100
2005	310000	489000	259600
2006	311000	627000	260300
2007	411000	718000	265600
2008	543000	974000	267000
2009	654000	1222000	256500
2010	774000	974000	249000
2011	1062000	1374000	304000
2012	1209000	1614000	323000

Note: reference to Hebei Statistic Yearbook.

*Table 14. Energy Consumption of various public buildings.*

	Operational Area of Catering Services (MWh)	Operational Area of hotels (MWh)	Floor Space of Public Buildings (MWh)
2003	54210	72345	48555.0
2004	58305	81510	48964.5
2005	60450	95355	50622.0
2006	60645	122265	50758.5
2007	80145	140010	51792.0
2008	105885	189930	52065.0
2009	127530	238290	50017.5
2010	150930	189930	48555.0
2011	207090	267930	59280.0
2012	235755	314730	62985.0

## 5. Conclusion and Implications

Derived from energy efficiency and measurement from top-down, the increasing rate of CO<sub>2</sub> emissions in public buildings ranks the first, while total CO<sub>2</sub> emissions in urban and rural residence keeps a huge base value in the decade. Based on the measurement from bottom-up, CO<sub>2</sub> emissions in the service demand of cooling and cooking involved in technique combination, shows a huge growth potential.

Firstly, utilization of low-carbon material and low-carbon buildings technology should be promoted, including exterior energy-saving technology, energy-saving windows and doors, energy-saving roof, development of new energy as well as heating, refrigeration and lighting technology. Secondly, national policy support and supervision should be paid huge attention. Development of low-carbon buildings needs various energy-saving materials and technology as well as relevant policy support. China's energy conservation in buildings is backward, which is not merely technical problems, but also governmental supervision, industrial operation and public mind. Thirdly, low-carbon buildings concept popularizing education and professional education is significant. Meanwhile, courses are also necessary to teach low-carbon buildings technology in related majors such as architecture, civil engineering, energy, management.

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## References

- [1] Bo Peng. Green construction lifecycle energy consumption and carbon dioxide emission case study [D]. Tsinghua University, 2012.
- [2] BP. Statistical Review of World Energy. <http://www.bp.com/statisticalreview>
- [3] He, K. et al., Oil consumption and CO<sub>2</sub> emissions in China's road transport: current status, future trends and policy implications. *Energy Policy*, 2005, 33, 1499–1507.
- [4] International Transport Forum, 2011. Top10 CO<sub>2</sub>-emitting non-ITFeconomies China. Available online at: <<http://www.internationaltransportforum.org/jtrc/environment/CO2/China.pdf>> [accessed July 10<sup>th</sup> 2011].
- [5] Lu, I. J., Lin, S. J. and Lewis, C., Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. *Energy Policy*, 2007, 35, 3226–35.
- [6] National Development and Reform Commission (NDRC). (2010). The notice of piloting low-carbon provinces and low-carbon cities. <http://www.sdpc.gov.cn/>
- [7] Taixin Zhang, Yueyun Zhou, Peng Lu. The concept of low-carbon city construction and the measurement model of carbon dioxide emission in China [J]. *Hunan industrial journal*, 2011, 25(001): 77-80.
- [8] Xiaolin Cao, Ting Qu, Study on green construction lifecycle cost measurement model [J]. *Construction economics*, 2011, 6: 92-95.
- [9] Zhang, M. et al., Energy and energy efficiencies in the Chinese transportation sector, 1980–2009. *Energy*, 2011, 36, 770–76.