【論文】

Current Status and Future Scenarios of Commercial Building Energy Consumption in China

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中国の商業建築におけるエネルギー消費の現状と将来予測

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Abstract

While China's 11th Five Year Plan called for a reduction of energy intensity, whether and how the energy consumption trend could be changed in a short time has been hotly debated. This research intends to evaluate the impact of a variety of scenarios of GDP growth, energy elasticity and energy efficiency improvement on energy consumption in commercial buildings in China using a detailed China End-use Energy Model.

China's official energy statistics have limited information on energy demand by end use; further, China uses a different classification system for energy reporting, so official sectoral energy breakdown has long been questioned. It is a particularly pertinent issue for building energy consumption, for example, in China's statistics it only accounts for about 13% of the total, while it is about 30% in other countries. Therefore, it is crucial to evaluate and understand the reality, rather than simply accepting it, as many of the energy analysts have done. The authors have applied reasoned judgments, based on experience of working on Chinese efficiency standards and energy related programs, to present a realistic interpretation of the current energy data. The bottom-up approach allows detailed consideration of end use intensity, equipment efficiency, etc—as a way to apply judgments, thus facilitating assessment of impacts of specific policy and technology changes on building energy use.

The results suggest that 1) commercial energy consumption in China's current statistics is underestimated by about 44% and the fuel mix is misleading; 2) energy efficiency improvements will not be sufficient to offset the strong increase in end-use penetration and intensity in commercial buildings, and energy (particularly electricity) intensity in commercial buildings will increase; 3) different GDP growth and elasticity scenarios could lead to a wide range of floor area growth, and therefore, significant impact energy consumption in commercial buildings.

Keywords: China, commercial building, energy intensity, energy efficiency, scenario, elasticity

1. Introduction

China's 11th Five-Year Plan (FYP) sets an ambitious target for energy efficiency improvement: energy intensity of the country's gross domestic product (GDP) should be reduced by 20% from 2005 to 2010 (NDRC, 2006). Whether and how energy consumption might be changed have been hotly debated, considering the fact that energy consumption has grown more rapidly than GDP in the last five years; however, if the recent trend continues, not only will it jeopardize China's development goals, but also create significantly greater adverse environmental impacts and introduce a huge "unexpected" disturbance to the global energy and climate system.

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Experience in developed countries shows that energy intensity reduction in the industrial sector can be achieved through energy efficient technologies and structural change. Energy efficiency improvements in commercial buildings however are likely to be offset by growing demand for higher levels of energy services as living standards rise, including more space heating and cooling, brighter lights, more hot water, and more office equipment. These responses to the demand for higher functional standards make it difficult to reduce energy intensity in the building sector in China. However, higher equipment efficiency and stronger policies can together act to slow down the growth of energy consumption in buildings.

This research intends to evaluate the impact of a variety of scenarios in GDP growth, floor space elasticity, and energy efficiency improvement on energy consumption in commercial buildings in China using a detailed China End-use Energy Model (Lin et al, 2006). At the same time, this analysis offers a realistic interpretation of the current energy data for the building sector.

2. Methodology

Integrated assessment models have been used to project both baseline and alternative scenarios. Two general approaches have been used for the integrated assessment of energy demand and supply – the so-called "bottom-up" and "top-down" approaches. We used LEAP (Long-range Energy Alternatives Planning System) to build our China commercial end-use model, based on a bottom-up approach that allowed a detailed consideration of end-use intensity, equipment efficiency, and technology shares—as a way to apply reasoned judgments to sectoral energy statistics, and to form a base to facilitate the development of energy scenarios and assess impact of policy and technology choices on building energy use.

A baseline scenario that incorporates targets stated in China's official plans and business-as-usual technology improvement was developed first, and a contrasting green growth scenario was created to examine the impact of stricter policies. Upon these two scenarios, different GDP growth and elasticity scenarios have been created to evaluate the impact of a variety of scenarios in GDP growth, energy elasticity and energy efficiency improvement on energy consumption in commercial buildings.

Commercial energy use is dominantly driven by floor area growth. GDP is not used as a direct driver but rather than a force that drives the floor area growth. It is also shaped by a variety of factors, including building types, penetration of end-uses such as space heating and cooling, end-use energy intensity, the choice of technologies, and energy efficiency of each technology. Omitting repetitive subscripts for the energy intensity terms, these can be represented as:

Equation 1.

$$E_{RB}=\sum_{k}^{OPTION}\sum_{n}^{OPTION}\sum_{q}^{OPTION}\left[A_{CB,n}\times P_{q,n}\times\left(\sum_{k} Intensity_{q,n}\times Share_{k,q}/Efficiency_{k,q}\right)\right]$$

where, in addition to the variables listed above:

k	=	energy type (technology type)
q	=	type of end-use,
n	=	building type
ACB,n	=	total commercial floor area in commercial building type n in m2
Pq,n	=	penetration rate of end-use q in building type n
Intensityq,n	=	intensity of end-use q in building type n
Sharek,q	=	type of technology k for end-use type q, and
Efficiencyk,q	=	efficiency of technology k for end-use type q

3. Commercial Building Energy Consumption in China

The service sector consists of a wide range of activities whose common feature is the provision of services rather than the production of goods. It is often called the "commercial" sector, though some of the activities are not really commercial in character (e.g., education, provision of social services) (Schipper and Meyers, 1992). The types of buildings included in this sector include retail, hotel, office, education, hospital, government building and other type of buildings such as restaurants and warehouses. Except for some miscellaneous uses (e.g. sanitation and public lighting services), all of the energy use in this sector takes place in buildings of one kind or another.

Reliable and accurate data are critical to good analysis and calibration of energy consumption. China's official energy statistics does provide information on supply side. The energy data reports production of all energy sources in all regions, and consumption by fuels and sectors. However, it only has limited information on energy demand by end use. Further, China uses a different classification system for energy reporting, so the sectoral energy breakdown has long been questioned. It is particularly an issue for building energy consumption. Many analysts and even government agencies use this figure to place judgment on current China's energy status and make projections for China's energy future which could thus be misleading or wrong.

In addition, lack of information on end use demand could also lead to inadequate ability to capture the potential for efficiency improvement and the impacts of efficiency policies and programs. It is crucial to evaluate and understand the reality rather than simply using it as many of the energy analysts have done.

An existing study (Sinton, 2001) has pointed to problems with the statistics published by National Bureau of Statistics (NBS). It stated that: changes in definitions and coverage have raised questions about the reliability of trends observed over time; problems like misreporting or non-reporting, and the difficulties in adapting the systems of data collection to rapidly changing social and economic structures, have led to doubts about the accuracy of some indicators, especially economic output; some sectoral and categorical definitions do not accord with accepted practices in many other countries, and contradictions between some statistics have appeared. In 2000, the statistic shows 69% of the energy being used in the industrial sector, 12% in the residential sector, and 7% for the commercial sector (Services plus Other) and transportation sector respectively. By comparison, the commercial sector represents 13% of total final energy use in IEA countries (IEA, 2004). The discrepancy may be attributable to the fact that many energy uses in buildings associated with industrial enterprises have been reported as industry energy use. Similarly, many transportation oil uses were treated as energy use within the industrial, agriculture, and building sectors.

We have applied reasoned judgments based on long term experience in working on Chinese efficiency standards and energy related programs to present a realistic interpretation of the current energy data. Also by using our bottom-up end-use model, we adjusted the sectoral energy use. As discussed above, end-use fuel consumption in China is recorded by the sector in which the consumption occurred, not by the purpose for which it was used. What this means is that gasoline consumption, for example, is divided among the major users (agriculture, industry, commerce, transport, residential), even though gasoline provided transportation services in these sectors. For example, gasoline is assumed that all but a small volume of gasoline is used for transportation purpose, and all volumes from other sectors have thus been allocated to the transportation sector and subtracted from the other sectors; as for diesel, based on a study done in the 1990s (Sinton 1996), we have reallocated 20% of agricultural diesel use, 10% of industrial, 12% of commercial, and 10% of residential diesel use to the transport sector and subtracted accordingly from the other sectors. For coal and other fuel use, we calculated the fuel consumption in the commercial sector based on drivers such as activity, intensity and energy efficiency that will be elaborated in the following sections.

As a result, we estimate that the industry sector uses 61% of the total energy rather than 69% as in the statistics; simultaneously commercial sector energy use is up to 9%, with 16% for the residential sector, and 10% for the transportation sector in 2000 (Fig.1).That implies the commercial energy consumption should be 127.8 Mtce instead of 88.9 Mtce in the statistics, a 44% increase. Another research using data from Ministry of Construction (RNECSPC, 2005) also shows that building energy consumption accounts for 26.9% of the total primary energy consumption in 2000.

Furthermore, Wang (2005) indicated the building and agriculture together account for 27.6% of the total final energy. Correspondingly, while the statistics indicate that 57.7% of the energy used in the commercial sector is oil and oil products and only 5% is coal, we estimate that about 58% of the energy used in the commercial sector is coal, 20% is heat[1], and only 5% is oil.

4. Ordinary Effort Scenario

4.1 Assumptions of the Drivers

The Ordinary Effort (OE) case incorporates the collective scope of technology choices, efficiency improvements, policy targets, fuel switching, equipment

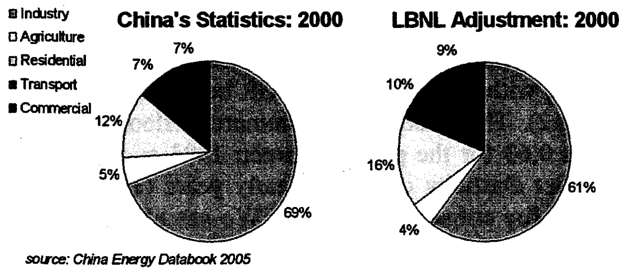

Fig.1 The Commercial Primary Energy Consumption by Sector

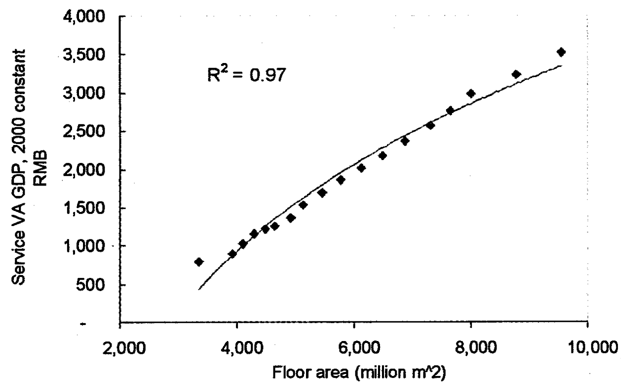

Fig.2 Commercial Floor Area and Value-added GDP, 1985-2002

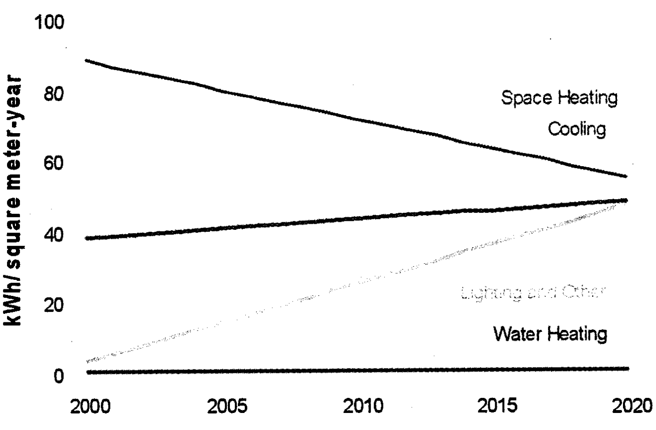

Fig.3 Enduse Energy Intensities in Office Building

[1] This is in final energy term, the primary source of the heat is mostly coal.

ownership and other elements of the development plan that China has proposed to shape its energy growth path to 2020. Underlying this scenario is the assumption

China's GDP will grow at a 7.9% CAGR (Compound Annual Growth Rate) through 2010 over its 2005 base and 6.6% CAGR from 2010 to 2020 (MGI, 2006).

4.1.1 Floor area

In Floor area is the key driver of commercial sector energy demand growth. Historical trends in developed countries show a strong correlation between the floor area and service GDP across time (IEA, 2004). In China, commercial floor area has increased at a relative steady level, with growth of 6% CAGR between 1985 and 2000 (Fig.2). The elasticity of commercial floor area to GDP was 0.63 for the period between 1985 and 2000, with a higher elasticity of 0.75 in early years (1985-1989) and 0.58 for subsequent years. We set elasticity in the Ordinary Effort scenario at 0.75 to 2010 to match official 2010 floorspace targets (Zhou, 2003), and 0.58 for years after 2010. That implies the commercial floor area will grow from 8.0 billion m2 in 2000 to 14.7 billion m2 in 2010, and 21.2 billion m2 in 2020.

This strong growth of commercial floor area corresponds to the rise of the service sector in China. Recent research by the McKinsey Global Institute (MGI, 2006) shows that, by 2025, China will become the world's third-largest consumer market, approaching Japan in real-dollar terms. Using a detailed approach by income class, the study shows that by 2025 there will be eight million "global" households in China with average spending of over 290,000 renminbi[2] per year, and 19 million affluent households with average spending of 109,000 renminbi per year. The pattern of spending will also change dramatically, with the share of discretionary spending, which includes services, increasing from 55 to 74 percent of total urban spending by 2025.

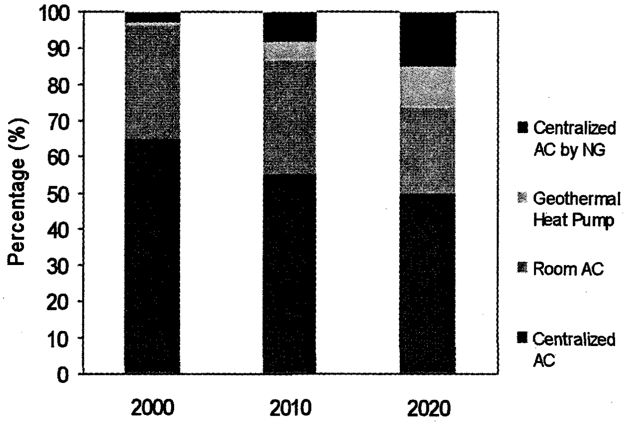

Fig.4 Space Cooling Technology Shift in Office Building

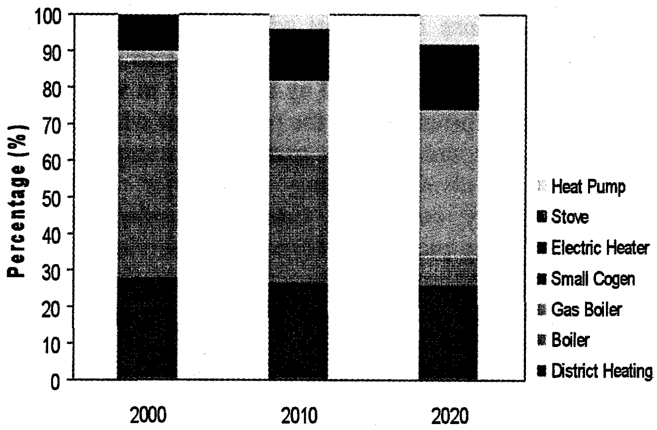

Fig.5 Space Heating Technology Shift in Office Building

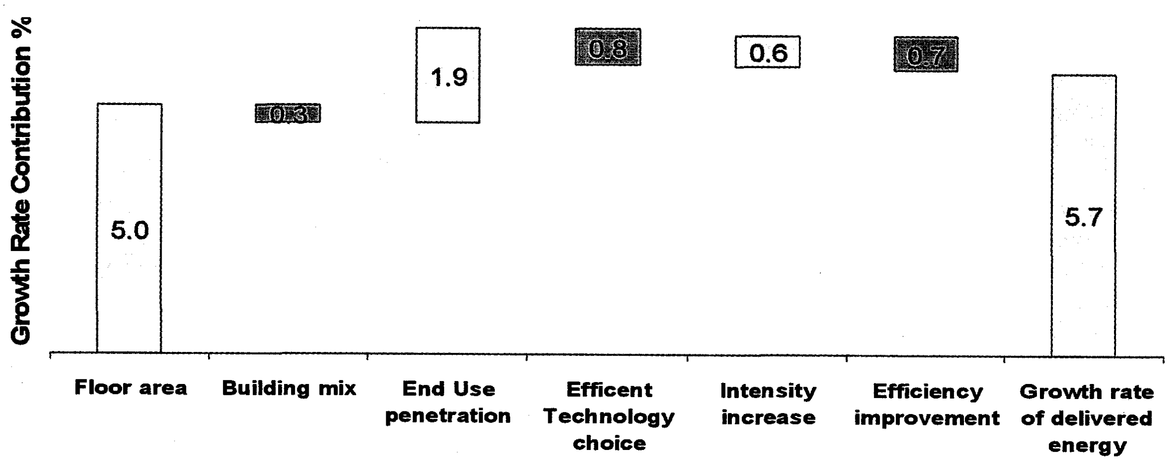

Fig.6 Growth Rate Contributed by Each Driver (%)

[2] 1 renminbi(RMB) = 0.13 US dollars

4.1.2 Penetration of building energy end-uses

To meet Chinese consumers' growing demand for comfort and convenience, penetration of all major building energy end-uses will increase significantly to 2020. For space heating, it will increase from 35 percent in 2000 to 55 percent as the country's "heating zone", historically limited to northern China, continues to expand into many southern regions. In Shanghai, 38% of the households use electric heater for space heating in 1999 (Brockett, 2003). The District Heating alone in 2004 has supplied about 25% of the total area, while some northern cities have reached 90%. Similarly, only a fraction of commercial buildings are currently air-conditioned, with very low penetration in older buildings and in hospitals and schools. We expect the penetration rate to reach 55 percent for most building types by 2020 based on qualitative objectives stated in research by China's Energy Research Institute (Zhou, 2003)

4.1.3 Intensity of building energy end-uses

Similarly, intensity will also increase to deliver higher levels of comfort (Fig.3). Space cooling and lighting intensity in Chinese buildings are still low compared to developed countries. Energy use varies when the quality of energy service is changed in a building, while the efficiency of equipment in the building has not changed. In addition, along with the economic development and change of the needs, energy intensity of a building will increase to maintain a suitable working and living environment (conditioned space). In commercial buildings, more office equipment will result in more energy use per floor area. We assume that energy intensity will grow rapidly, for example with brighter lighting of retail space or thermostats set at lower temperatures in the summer. The use of office equipment will also grow significantly, resulting in higher energy use per floor area in office buildings. The energy consumption of China's air conditioner users has increased dramatically, currently accounting for about 15 percent of national power consumption. In summer, electricity consumed by air conditioning accounts for 40 percent of the total electricity demand. Space heating stands out as the exception, since building shell improvements allow consumers to reach higher levels of comfort with the same energy consumption. Currently, heat loss through exterior walls is about 3-5 times as high in Chinese buildings as in similar buildings in Canada or Japan. Loss through windows is over twice as high. Additional major losses are caused by imbalances and inability to control heat use in central heating systems, commonly forcing consumers to open windows as the only means to regulate overheating. We project significant improvements on both these fronts.

As a result of both higher end-use penetration and intensity, overall energy intensity will increase in the commercial sector. Chen (2006) indicated that the average energy intensity in Shanghai increased by 31% from 148 kWh/m2-year in 1998 to 194 kWh/ m2-year in 2005. Our modeling results show average Chinese energy intensity increasing from 91 kWh/ m2-year in 2000 to 105 kWh/ m2-year in 2020. By comparison, it increased by 12% over the 1985-2004 period in the U.S. (EERE, 2006).

4.1.4 Energy efficiency

China's government plan calls for efficiency improvement through a tightening of standards, incentives and subsidies, as well as moderate measures to accelerate the adoption of higher-efficiency technologies (RNECSPC, 2005). We model energy efficiency as the combination of the efficiency and market shares of different types of technologies. Our analysis reveals a 35 percent demand-abatement potential compared with a business-as-usual scenario, mainly driven by sizable efficiency opportunities for space- and water-heating end-uses. Space heating shows a 90 percent efficiency-improvement potential, which, in turn, produces a 47 percent demand-abatement potential. This high figure is based on a double "catch-up" assumption—i.e. that both the efficiency and market shares of the different space-heating technologies used in the Chinese commercial sector will converge to their current level in Japan by 2020. As an illustration, an average efficiency of heat pumps (in heating mode) will double from 1.8 to 3.6 and their market share rise from less than 1 percent to more than 10 percent. In parallel, the use of conventional coal boilers will decrease significantly. For lighting, state-of-the art technology includes electronic ballasts and compact fluorescent lamps (CFLs). Fig. 4 and Fig.5 show an example of how space cooling and space heating technologies are projected to change respectively in office buildings under this scenario.

4.2 Future Energy Demand

The Ordinary Effort (OE) scenario offers a systematic and complete interpretation of the social and economic goals proposed in China's national plan. It shows energy demand growing at 5.7% per annum to 2020, as the result of strong floor area growth (5.0%), and increased end-use penetration and intensity (2.5%), only partially offset by significant energy efficiency improvement (-1.5%) and building mix (-0.3%)(Fig.6). This high growth rate means that this sector will contribute a large share of energy demand growth to 2020, both in China and globally: 14% and 5% respectively, based on recent research by the McKinsey Global Institute on energy demand and productivity (MGI, 2006) .

The sector's fuel mix will also change dramatically, with the share of coal dropping from 49 percent to 12 percent between 2003 and 2020, while the share of electric power will more than triple to 47 percent, and natural gas will grow from 2 percent to 19 percent,

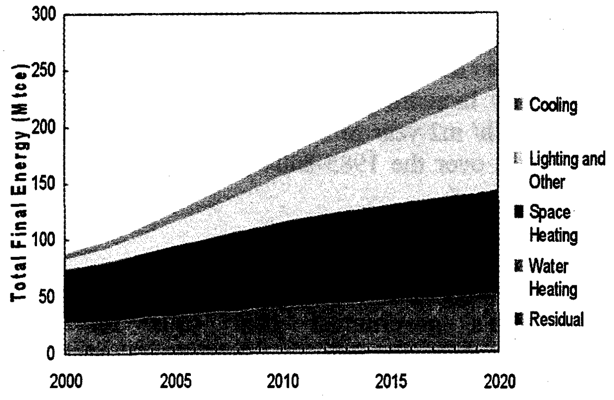

Fig.7 Final Energy Consumption by End Use (OE scenario)

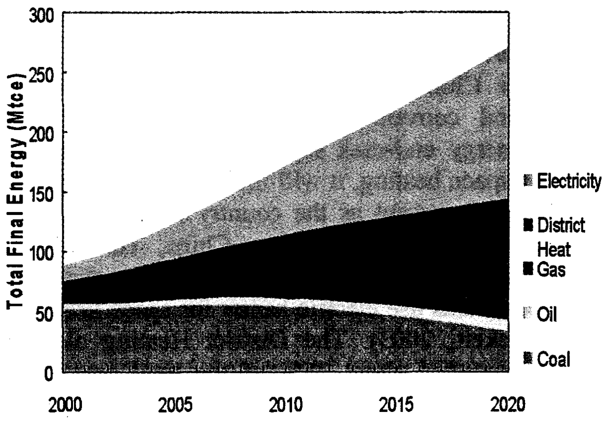

Fig.8 Final Energy Consumption by Fuel (OE scenario)

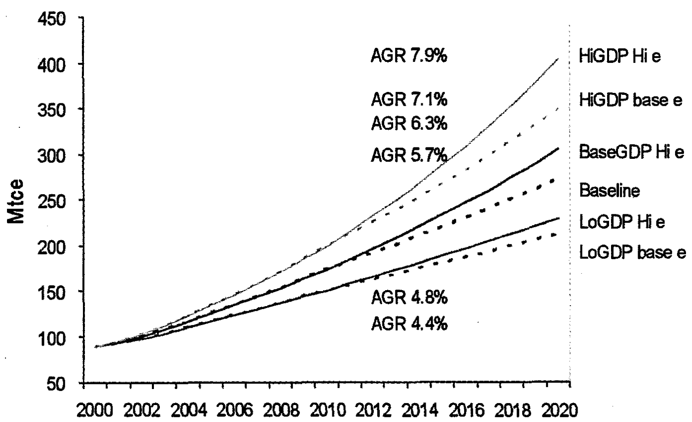

Fig.9 Energy Consumption in GDP Elasticity Scenarios

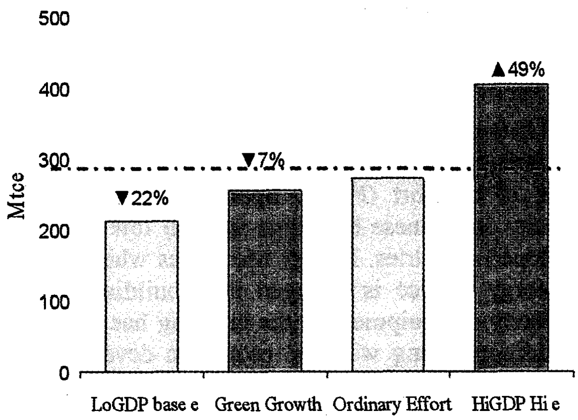

Fig.10 Energy Consumption Reduction Rate in 4 Scenarios

Table 1 Weighted average efficiency improvement by end uses

	Office	Retail	Hospital	School	Hotel	Other	Weighted Commercial Sector Efficiency improvements based on 2005 shares	based on 2020 shares	Share of total, 2005	Share of total, 2020
Space heating	99%	102%	89%	75%	86%	99%	93%	94%	49%	34%
Cooling	12%	10%	11%	12%	10%	12%	11%	11%	9%	15%
Lighting and Other application	6%	7%	6%	7%	7%	6%	6%	6%	17%	34%
Water Heating	41%	41%	41%	32%	41%	39%	40%	40%	26%	18%
Share of sector in total, 2005	25%	19%	7%	10%	26%	14%				
Share of sector in total, 2020	23%	28%	8%	9%	17%	15%				
Weighted average efficiency improvement 2003-2020									57%	
Weighted average efficiency improvement 2003-2020										43%

a change both in the mix of building end-uses, with power-intensive end-uses such as air conditioning, lighting, and office equipment doubling their share to 50 percent, as well as changes in technology choices (Fig.7 and Fig. 8).

5. Other Scenarios

Both the pace of GDP-driven floor area growth and policy-driven energy-efficiency improvements create uncertainty around our Ordinary Effort scenario. A series of scenarios ere developed to evaluate the impact of GDP growth and energy efficiency improvement on energy consumption in China's commercial buildings.

Our GDP scenarios assume variations versus our base case (Ordinary Effort Scenario) of ±2 percent growth annually. We also assume that the elasticity between GDP and floor area growth could remain at 0.75 after 2010, instead of decreasing to 0.58. As a result, we show a wide swing in demand between our "extreme" scenarios: in a low-GDP base elasticity scenario, demand would only grow at 4.3% per annum, while in a high-GDP high elasticity scenario, demand would grow at 8.9% per annum (Fig.9 and Fig.10). The high-GDP scenario could possibly jeopardize China's goal of reducing the energy intensity of GDP by 20% by 2010, which implies a growth rate of 2.8% per annum. However, the efficiency potential in the commercial building sector could contribute towards the goal, while additional substantial structural changes are also necessary.

Building on the Ordinary Effort scenario, the Green growth scenario incorporates additional energy efficiency improvements which lead China to capture its full efficiency potential. The analysis encompasses measures such as increasing the share of efficient technologies and efficiency improvement. This requires policy changes that encourage the shift to less energy intensive products. China has developed an extensive set of building energy codes and minimum efficiency standards for appliances. However, government agencies need to significantly increase the resources for enforcement actions in order to realize the full impact of the building cods and appliance standards. As a result, a change in the pace of energy-efficiency improvements would reduce annual demand growth moderately from 5.7% to 5.4%, bringing total energy consumption in 2020 down by 6.6%. Table 1 shows the average efficiency improvement by end uses for each type of building. The reduction is moderate because of the already strong efficiency gains in the Ordinary Effort scenario.

6. Conclusions

This paper's intended to evaluate the impact of a variety of scenarios of GDP growth, energy elasticity and energy efficiency improvement on energy consumption in China's commercial buildings using a bottom-up energy model. It has also evaluated the current energy statistics and made adjustments on sectoral energy consumption.

The results suggest that 1) commercial energy consumption in China's current statistics is underestimated by about 44% and the fuel mix is misleading; 2) energy efficiency improvements will not be sufficient to offset the strong increase in end-use penetration and intensity, particularly of electricity applications, in commercial buildings; however, higher equipment efficiency and stronger policies can together act to slow down the growth of energy consumption in buildings; 3) different GDP growth and elasticity scenarios could lead to a wide range of floor area growth and therefore, to a degree dependent on rates of penetration of various energy technologies, could significantly impact energy consumption in commercial buildings.

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