A Forecast of Effective Energy Efficient Policies for the Building Sector in Shanghai through 2050

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Abstract: Currently in China, the energy consumption of buildings is increasing rapidly. In this study, we used a macro-model to forecast the energy consumption of buildings in Shanghai through 2050. Total energy consumption from 2000 to 2050 and the potential energy savings were projected for both the residential and commercial sectors. For urban residential buildings, we developed a forecast model for 2050 to estimate the potential energy savings of residential measures. Compared to the business-as-usual (BaU) scenario, implementation of residential measures achieved a 24% reduction in energy consumption. The reduction rate rose to 65% by combining the implementation of residential and electrical measures. For commercial buildings, we first used official statistical data to determine the energy intensities of air conditioning, lighting, computing, and other thermal uses for the base year 2000. Then, estimates of the labor force, GDP, and floor area were predicted through 2050 according to past growth patterns and the literature. Likewise, estimates for energy intensities through 2050 were projected. Energy-saving scenarios also were integrated into the commercial model. Compared to BaU scenario, implementation of commercial measures achieved an 80% reduction in energy consumption. The reduction rate increased to 99% by combining commercial and electrical measures.

Keywords: *Shanghai, Energy consumption, Buildings, Forecasting*

1. Introduction

At the UN Climate Conference in Copenhagen in 2009, the European Union formulated the goals that temperature increase by no more than 2 °C, that global emissions peak no later than 2020, and that by 2050 global emissions be reduced to a level that is at least 50% below the figure for 1990. These goals require action by both industrialized nations and developing countries (Gaines and Jager, 2009). In the Copenhagen Accord, the Chinese government announced mitigation action to reduce CO_2 emissions per unit of GDP by 2020 to 40-45% of the 2005 level. This target was reaffirmed at the 2010 UN Climate Conference in Cancun. However, the most efficient way to achieve this reduction goal remains an unsolved problem.

In recent years, the economy of China has developed rapidly, which encourages demand for higher living standards and energy consumption. In this paper, we focus specifically on urban buildings in Shanghai, which is one of the biggest cities in China and has the highest GDP among all Chinese cities. First, we investigated the environmental performance of both residential and commercial buildings in Shanghai. Then, to quantify their sustainability, we developed macro-models to forecast CO_2 emissions for both residential and commercial buildings. The forecasts include global warming countermeasures and are intended to support decision making for determining reasonable CO_2 emission reductions.

2. Methodology

2.1. Residential Projections

2.1.1. Summary of the macro-model

The macro-model used for the residential sector has been modified from the "Estimation Macro-model for Residential Energy Consumption" (Ikaga, 2004). The flow chart in Fig. 1

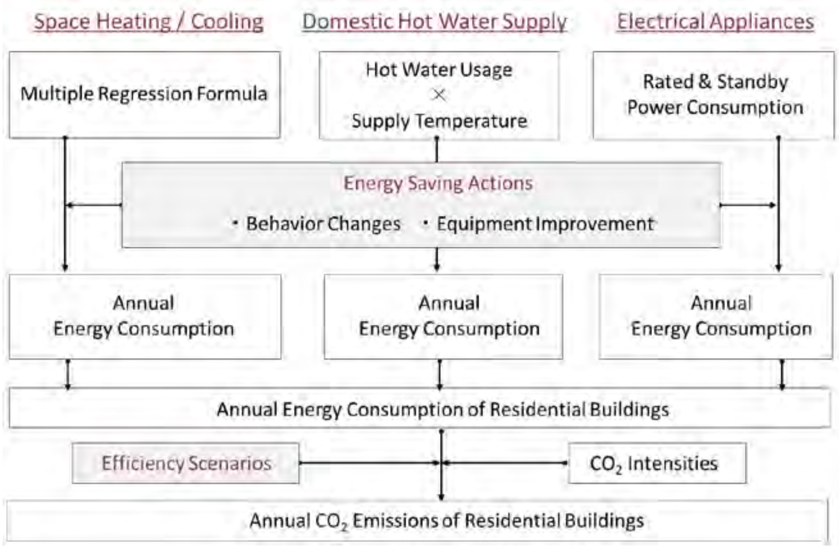

Fig. 1. Flow chart of the residential sector macro-model.

provides an overview of the model. It is a simulation model that estimates changes in energy consumption on the basis of family type, application, and energy source for each year. Estimation methods are described below.

Space heating/cooling: Annual load per household was calculated using a multiple regression equation for heating and cooling load. The annual total load of each city was computed multiplying the number of households of each household type by the energy use for the respective household type and taking the summation.

Domestic hot water supply: The total load of each city was calculated using the frequency of hot water use, the number of households and the average temperature of tap water for each month. Furthermore, energy consumption was calculated using the ratio of owned equipment and the average coefficient of performance (COP) by fuel type.

Other electrical appliances: Energy consumption was calculated as the product of the cumulative energy consumption per household per day and family type, the number of households, and the number of days in each month.

Total CO_2 emissions: By totaling the results of the three functions calculated above and multiplying by the CO_2 intensity of electricity for each energy source, we calculated the annual total CO_2 emissions.

2.1.2. Model parameters

The present model is based on a macro-model that was used to calculate the national residential CO_2 emissions in Japan. For the case of Shanghai, we switched the entire calculation database. The parameters that were set include the number and size of households, average gross floor area, and several pieces of household data. The parameters come either from official statistics or are based on the Chinese government development plan.

There were several parameters for which we could not find a source. To set these parameters we referred to data for the Japanese city of Fukuoka in place of Shanghai, as the two cities have similar latitudes and climates.

2.1.3. Scenarios

In this study, two scenarios are examined: one for residential measures and another for electrical measures. In the residential scenario, we recommend behavioral changes and equipment improvements as global warming countermeasures, having taken into account the social conditions and citizens' lifestyles in China. All the measures are listed in Table 1.

Table 1. Residential measures.

Scenario	Measure	Implementation rate (by 2050)
Behavioral changes	1. Regulation of room air temperature (Heating: STD -2 °C; Cooling: STD +1 °C) 2. Regulation of space heating and cooling operation time (STD×0.75) 3. Reduction of hot water supply temperature (STD +1 °C) 4. Reduction of hot water use 5. Using cold water during summer 6. Unplugging electrical equipment when not in use 7. Only washing clothes when there is a large load 8. Washing clothes using shorter cycles 9. Closing the lid of warm-water cleaning toilet seats 10. Adjusting the temperature setting of warm-water cleaning toilet seats	Implemented by 50% of all households
Equipment improvement	1. Old air conditioners replaced by energy-efficient models	Increase of COP: Heating from 3.0 to 8.0; Cooling from 4.0 to 8.0
	2. Enhancement of thermal insulation level	All houses meet new standard
	3. Water heaters replaced by heat pumps	Increase of COP: 3.0 → 6.0
	4. Use of water-saving shower heads	Implemented by 50% of all households
	5. Kerosene water heaters replaced by heat pump models	Electrification rate increases 2.5% every 5 years
	6. Replacement of incandescent bulbs with compact fluorescent lamps	Implemented by 50% of all households
	7. Accelerating the adoption of eco-appliances	Reduction of power consumption: 70% reduction of refrigerators, 75% reduction of TVs (compared to 2005)

As for electrical measures, the electric utilities made contributions to global warming mitigation. The CO_2 intensity of electricity in Shanghai was 1.027 kg-CO_2/kWh in 1990, which we use as the baseline figure (100%). The NDRC scenario was based on data from the National Development and Reform Commission (NDRC) of China. According to NDRC, the emissions rate will decrease to 80% of the baseline amount by 2030. The METI scenario was proposed by the Ministry of Economy, Trade and Industry (METI) of Japan. In the METI scenario, the reduction rate of the CO_2 intensity of electricity will be even larger, to 40% of the baseline amount by 2050.

2.2. Commercial Projections

2.2.1. Summary of the macro-model

Figure 2 shows the estimated flow chart of the macro-model applied to the commercial sector. Total energy consumption was divided into two parts: air conditioning and other electrical appliances. Air conditioning includes cooling and heating; other electrical appliances include lighting, computers, and other heating devices. The macro-model is a simulation model that estimates changes in energy consumption according to building type (retail space and hotels, office buildings, warehouses, education facilities, hospitals, and personal services facilities and others) and application (air conditioning, lighting, computing, and others) over a 5-year period.

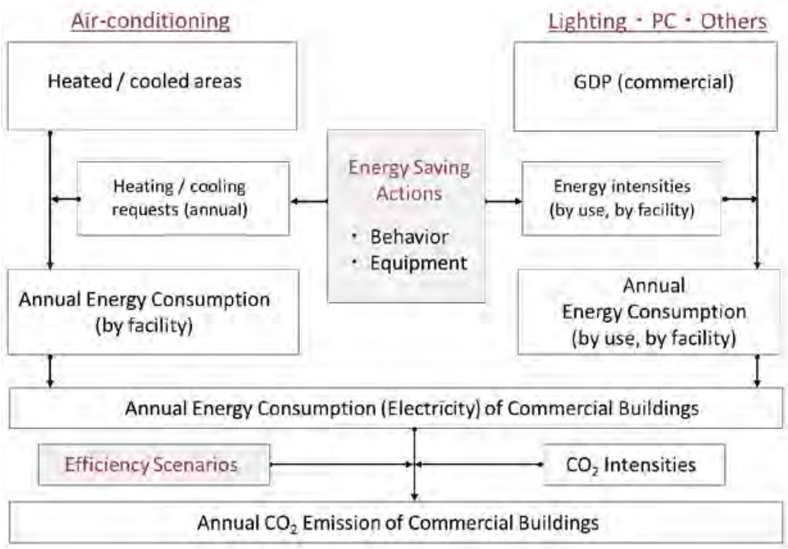

Fig. 2. Flow chart of the commercial sector model.

The commercial model is also a bottom-up engineering model that estimates energy consumption similarly to the residential model. Hence, we analyzed the connection between GDP and penetration rates of electrical appliances in the past 10 years to project penetration rates though 2050.

2.2.2. Model parameters

Because this is prediction research, every parameter was set through 2050. The data for 2000 and 2005 were primarily from the *Shanghai Yearbook*. Parameters for future years were based on relevant literature and the author's assumptions.

For the GDP projection, we referred to research results from the Department of Foreign Affairs and Trade (Wu, 1997) that suggested Chinese GDP will continue growing sharply and overtake the GDP of the United States by 2020. We then looked at the historical growth patterns of another Asian country, namely, Japan. Japan has also been through a period of high growth and development, starting with the "Golden Sixties" and ending with the "Lost Decade." After this period, growth became stable and the trend line became flat. China is now going through a period of high growth. On the basis of the two perspectives above, we assumed that this unusually high growth in China will last until 2030, at which time it will start slowing down. The GDP of Shanghai's service sector was projected through 2050 using this same trend line, as shown in Fig. 3 (left). Using a similar approach, we also projected the labor force and gross floor space for the next 40 years. For the labor force projection, we referred to the population projection by the Shanghai Municipal Population and Family Planning Commission (SMPC) and calculated labor force as a share of the overall population. For gross floor area, we analyzed the growth pattern over the past 10 years (Xing, 2010) and projected future gross floor area through 2050, as shown in Figure 3 (right).

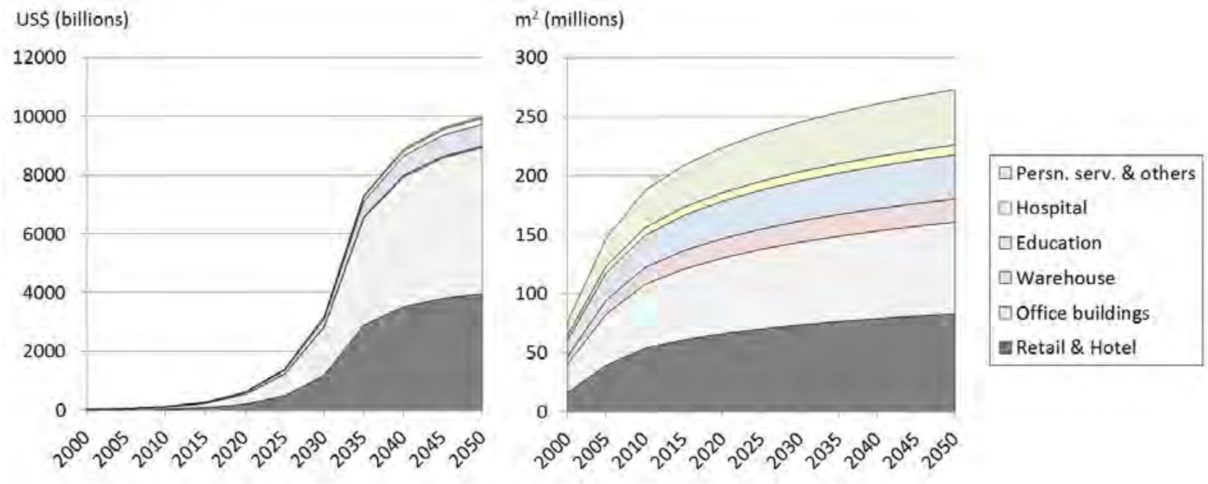

Fig. 3. Projected GDP (left) and floor space (right) through 2050.

Table 2. Commercial measures.

Electrical application	BaU	Energy saving scenarios	
		Behavioral changes	Equipment improvement
Air conditioning	Heating 18 °C, cooling 26 °C COP: 3.54	Heating 17 °C, cooling 27 °C Operational time × 0.75	COP: 3.54 → 8.0
Lighting	Lighting is used all day	Turn off the lights when away	Adoption of LED lighting
Computer	PC enters sleep mode after work	Shut down PC after work	Adoption of ECO-PC
Other heating devices	Waste of standby power	Unplugging electrical equipment when not in use	None

COP: Coefficient of Performance

2.2.3. Scenarios

Two projection scenarios for the commercial sector were also examined: one for commercial measures and another for electrical measures. As for the residential sector, we recommend behavioral changes and equipment improvements as global warming countermeasures for the commercial sector. Table 3 shows the operating power settings for electrical applications by building type under different energy use scenarios. In the Global Energy Assessment (GEA) electrical scenario, the CO_2 intensity of electricity will decrease to 10% of the baseline amount by 2050.

Table 3. Operational power settings by application and building type

	Air condition (COP)		Lighting (W/m^2)	
	BaU	Energy saving	BaU	Energy saving
	(DAIKIN, ZEAS 2000)	(METI)	(GB50189)	(Hitachi Lighting)
Retail and hotel			16,00	1,60
Office building			15,00	1,50
Warehouse			5,00	0,50
Education	3,54	6,00	15,00	1,50
Hospital			15,00	1,50
Personal services & others			12,00	1,20

	Computer (W/hour)				Other heating devices (W/hour)	
	BaU (NEC standard)		Energy saving (NEC eco model)		BaU (GB50189)	(LBNL)
	In use	Sleep	In use	Sleep	In use	Standby
Retail and hotel					15,00	
Office building					20,00	
Warehouse					5,00	
Education	300	30	240	24	20,00	0,98
Hospital					20,00	
Personal services & others					12,00	

METI: Ministry of Economy, Trade and Industry, Japan; GB50189: Design Standard for Energy Efficiency of Public Buildings, China Construction Division, July 2005; LBNL: Lawrence Berkeley National Laboratory

3. Results

We first compared the estimation results with government statistics to verify the reliability of the macro-model (Fig. 4). In the years 1990, 2000, and 2005, total annual energy consumption estimated by the macro-model was very close to the government's statistics, suggesting that this model is reliable.

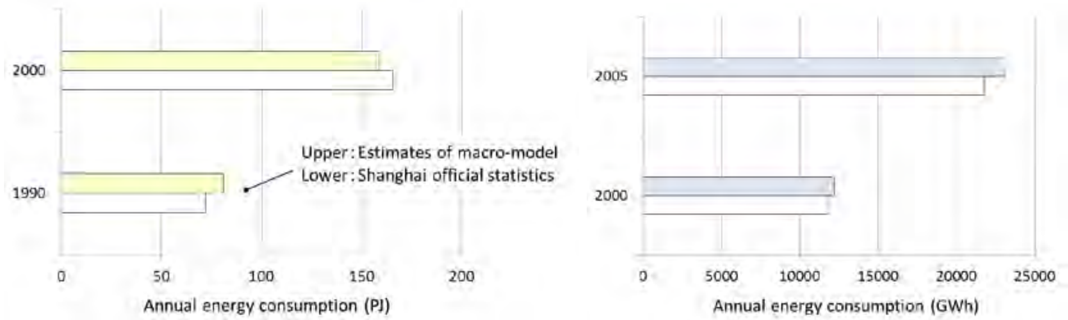

Fig. 4. Macro-model estimates and official statistics for the residential sector (left) and the commercial sector (right).

3.1. CO_2 Emission Reduction of Residential Buildings

The BaU scenario showed a 2.7 fold increase in CO_2 emissions above the 1990 level by 2050. Under the scenario where residential measures are adopted, behavioral changes caused a 6% reduction in CO_2 emissions by 2050 c ompared with BaU. Equipment improvements contributed an additional 18% reduction, which increased the total benefit of residential measures to 24% below the BaU scenario for 2050. When we combined residential measures with the NDRC scenario, the total emissions reductions reached 40%. Residential measures combined with the METI scenario reduced emissions by 65%. Figure 5 (top) shows the projected CO_2 emission reductions for the residential sector by electrical application.

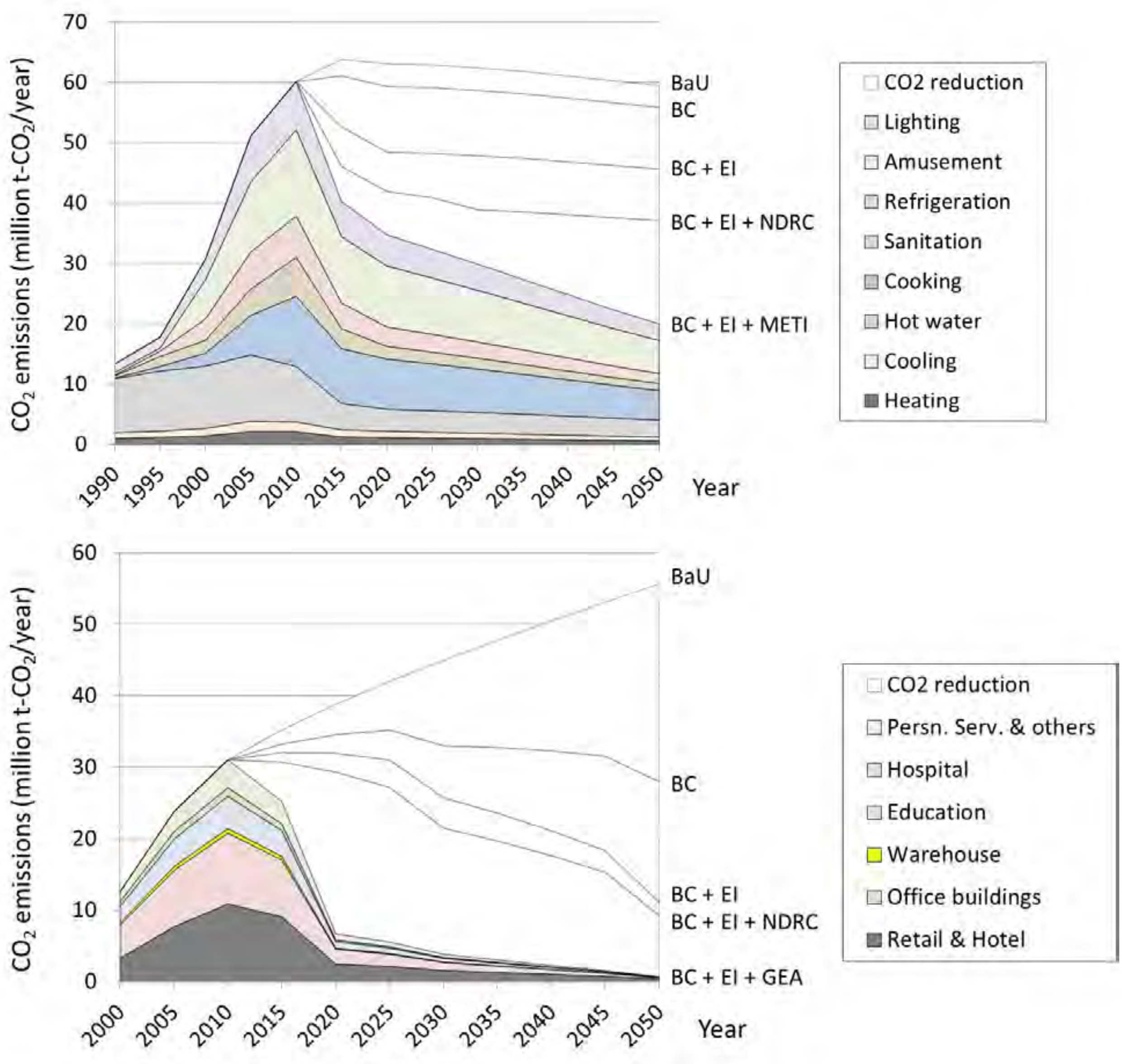

Fig. 5. Projected CO2 emissions for residential buildings (top) and commercial buildings (bottom). BC: Behavioral Changes; EI: Equipment Improvement; NDRC: National Development and Reform Commission of China; METI: Ministry of Economy, Trade and Industry of Japan; GEA: Global Energy Assessment, High case, CPA, WiP 0.5.1

3.2. CO_2 Emission Reduction of Commercial Buildings

Similar to the residential sector, the BaU scenario saw a 3.43 fold increase in CO_2 emissions by 2050 for the commercial sector above the 2000 level. The CO_2 emission estimates for commercial buildings were projected by building type and electrical application. Figure 5 (bottom) shows the results for commercial buildings by building type.

Under the scenario where commercial measures are implemented, behavioral changes caused a 50% reduction of CO_2 emissions compared with the BaU scenario by 2050. Equipment improvements contributed an additional 30% reduction, which increased the total benefit of residential measures to 80%. When we combined commercial measures with the NDRC scenario, total emissions reductions reached 83%. Commercial measures with the GEA scenario reduced emissions by 99%, which means near-zero contributions of CO_2 emissions from commercial buildings.

4. Discussion and Conclusions

In this study, we developed a model to predict the CO_2 emission reduction potentials by 2050 for diverse climates and policy scenarios. For energy savings in commercial buildings, we found that behavioral changes appear to be more efficient than equipment improvement. This finding will likely be appreciated in a developing country like China, since there is a limited budget for large-scale replacement of equipment.

In general, the projections in this research are theoretical. There is no evidence showing that all the suggested energy saving actions could be fully implemented as described in the scenarios projected. However, we hope the results of this research will help decision makers when they look for solutions to achieve CO_2 emission reduction goals in the future.

For the model parameters, we generally relied on the literature and official statistics. In future research, we will schedule local surveys and field measurements in Shanghai. These efforts are expected to improve the accuracy and reliability of the projection model.

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